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ANALYSIS OF FOUR-STROKE CYCLE INTERNAL COMBUSTION V-ENGINE IN MATHCAD ENVIRONMENT

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Abstract: *This paper presents the method and the results of numerical analysis of the virtual model of four-stroke cycle internal combustion V-engine on the worksheet of the Computer Package Mathcad, provided that a crankshaft has constant (load mode) angular velocity and its pistons are loaded by pressures according to the indicator diagram for four-stroke cycle engines. The kinematic and dynamic analysis of V-engine is based on the publication by Lepikson (1998) [1]. Present article also contains a short review of papers that use the Computer Package Mathcad for the analysis of mechanisms and in teaching engineering subjects. The method presented in this paper can be used primarily in teaching process of engineering subject "Mechanics of Machinery" and by engineers of internal combustion engines.*
Key words: Mechanics of Machinery, V-engine, Mathcad, kinematics, dynamics.

1. INTRODUCTION

Advances in computer technology have opened new possibilities to solve engineering problems that require accurate composition of equations and using calculation methods, which are unique for every problem. Virtual reality–based methods allow verifying obtained solutions and simulating the motion of mechanical systems on computer screen that speeds up getting correct solutions, thereby reducing time and costs of product development.
There are several computer package environments (Matlab, Mathematica, Mathcad etc.) that can be used in teaching engineering subjects, to create virtual models for mechanical systems and to simulate their motion. The Computer Package Mathcad has been used to study the load distribution on the blade of a helicopter rotor [2], to compose the virtual model for planar linkage [3], to create a virtual model for a disk–ridging tool and simulation its motion [4], to simulate the motion of fertilizers particles on the spreading disk of a disk spreader [5], to generate the virtual models of four-bars [6], to compose a virtual model for stone protector and simulation its motion [7], to visualize the solutions of problems in engineering mechanics [8] to compose an interactive e-course of engineering analytical mechanics [9], to solve the examples for theoretical mechanics [10].
Common configurations of internal combustion engine are V-, RV-, W- and in-line [11]. This paper presents the method and the results of numerical analysis of the virtual model of four-stroke cycle internal combustion V-engine on the worksheet of Computer Package Mathcad. Special video clip is composed to simulate and verify the motion of the virtual model of V-engine [12].
The method and the results presented in this paper can be used first of all in teaching process of engineering subject "Mechanics of Machinery" and also by engineers in the design of internal combustion engines.

2. THE KINEMATICS SCHEME OF V-ENGINE

The kinematic scheme of V-engine is shown in Fig. 1.

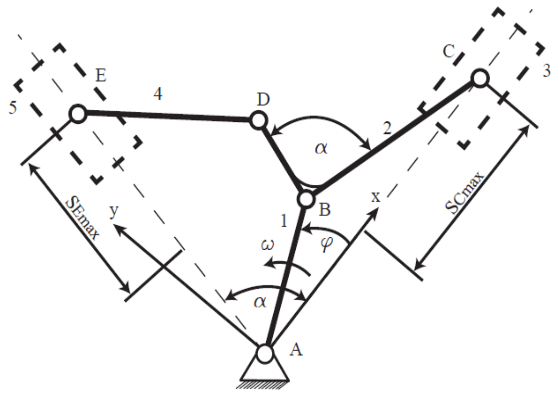

Fig. 1 The kinematic scheme of V-engine

Crankshaft 1 shown in Fig. 1 is supposed to rotate counter clockwise with angular velocity ω. This crankshaft is joined by pivot B to the main connecting rod 2 which moves main piston 3 along track AC in the main cylinder. This connecting rod is also joined by pivot D to the secondary connecting rod 4 that is joined by pivot E to the secondary piston 5 and moves it along the track AE in the secondary cylinder. Constructive angle α between tracks AC, AE and the arms BD, BC of main connecting rod 2 is permanent.

The following V-engine parameters were used in the calculations: lengths of the links $l_{AB}=0.090m$, $l_{BC}=0.322m$, $l_{BD}=0.085m$ $l_{DE}=0.240m$; constructive angle $\alpha=60^o$; inside diameters for cylinders $d_s=0.15m$; crankshaft rotation speed $n_m=1000rpm$; masses of links: $m_1=13.7kg$, $m_2=6.25kg$, $m_3=3.6kg$, $m_4=2kg$ and $m_5=3.6kg$. Moments of inertia of links 2 and 4:

$$I_2 = m_2 \cdot 0.174 \cdot {l_{BC}}^2 kgm^2,$$
$$I_4 = m_4 \cdot 0.083 \cdot {l_{DE}}^2 kgm^2.$$

Maximum pressure inside the cylinders: $p_{max}=4MPa$.

3. DETERMINATION OF THE POSITIONS OF LINKS

Let us suppose that the origin of the coordinate system Axy is in pivot A (Fig. 1). The x-axis coincides with track AC. The rotation angle of crank AB is φ. Co-ordinates of pivots B and C are

$$x_B = l_{AB} \cdot \cos\varphi \quad y_B = l_{AB} \cdot \sin\varphi, \qquad (1)$$

$$x_C = x_B + \sqrt{{l_{BC}}^2 - y_B^2}, \quad y_C = 0. \qquad (2)$$

Co-ordinates of pivot D can be determined from the following system of equations of restrictions

$$(x_D - x_B)\cdot(x_C - x_B) - (y_D - x_B)\cdot y_B = l_{BC}\cdot l_{BD}\cdot\cos\alpha \quad (x_D - x_B)^2 + (y_D - x_B)^2 = {l_{BD}}^2. \qquad (3)$$

The first equation in (3) means that during the motion the angle α between arms BD and BC is permanent. The second equation in (3) means that during the motion the distance between pivots B and D is permanent. Co-ordinates of pivot E can be determined from the following system of equations of restrictions

$$y_D = x_E \cdot \tan\alpha \quad (x_E - x_D)^2 + (y_E - y_D)^2 = {l_{DE}}^2. \qquad (4)$$

The first equation in (4) means that during the motion pivot E is permanently on track AE. The second equation in (4) means that during the motion the distance between the pivots D and E is permanent. Equations (1), (2) and systems of equations (3), (4) were solved in relation to the values of rotation angle φ of crank AB by using the solve block “Given-Find” of Mathcad. The virtual model in Fig. 2 was composed on Mathcad worksheet by using the results of computations of pivots co-ordinates.

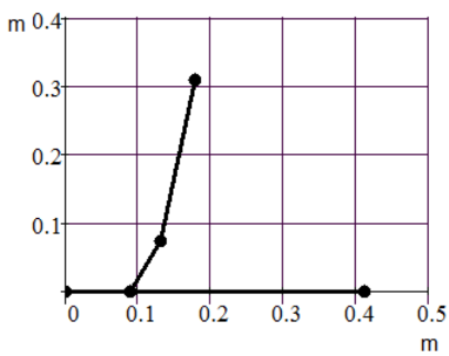

Fig. 2. The virtual model of V-engine

Before composing the video clip with simulation of motion of the composed virtual model in Fig. 2, rotation transformation was used to turn it to the position (Fig. 3) of the kinematic scheme in Fig. 1.

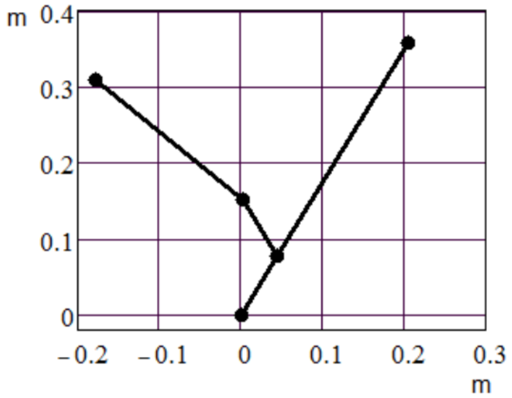

Fig. 3. Virtual model of V-engine, in the position of the scheme in Fig. 1

On the basis of Fig. 3 a video clip [12] simulating the motion of virtual model of V-engine was composed on Mathcad worksheet.

Maximum values of displacements (S) of pivots C (piston 3) and E (piston 5) can be determined by equations

$$S_C = \max_\varphi x_C - x_C,$$

$$S_E = \max_\varphi \sqrt{{x_E}^2 + {y_E}^2} - \sqrt{{x_E}^2 + {y_E}^2}.$$

The results of computations are visualized in Fig. 4.

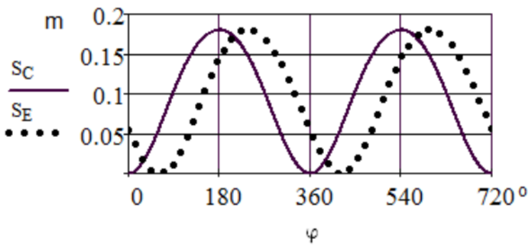

Fig. 4. Maximum values of displacements of the pivots C (main piston 3) and E (secondary piston 5) depending on the values of rotation angle φ of crank AB (Fig. 1)

Experimentally acquired p-V indicator diagram was used to create a diagram where volume (V) values are converted in displacement values in Fig. 5.

Fig. 4 was used to compose four strokes (intake, compression, power, exhaust) in V-engine by the pistons 3 and 5, when the pressures applied to the pistons change according to the indicator diagram in Fig. 5.

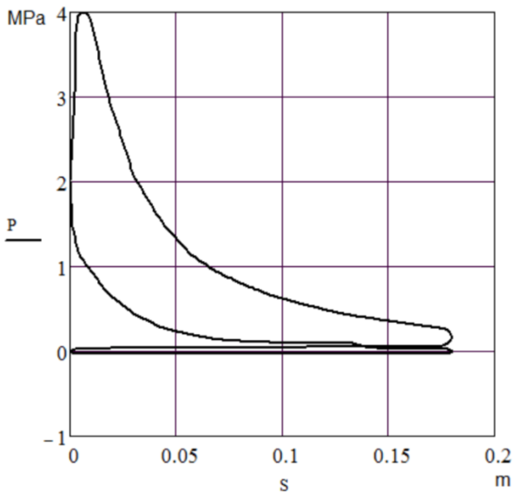

Fig. 5. The indicator diagram for the four-stroke cycle internal combustion engine, where p is the pressure applied to a piston and S is piston displacement

4. DETERMINATION OF THE VELOCITIES OF PIVOTS

The velocity projections of pivot B on the x- and y-axis can be obtained by differentiation of formulas (1)

$$v_{Bx} = -y_B \cdot \omega, \qquad v_{By} = x_B \cdot \omega,$$

where

$$x_B = l_{AB} \cdot \cos\varphi,\ y_B = l_{AB} \cdot \sin\varphi,\ \omega = \frac{d\varphi}{dt}.$$

The velocity projection of pivot C (main piston 3, Fig. 6) on x-axis can be found out from formula

$$v_{Cx} = v_{Bx} - \frac{y_B \cdot v_{By}}{x_C - x_B}, \qquad (5)$$

derived from the formula (2) by time-based differentiation. The results of computations are visualized in Fig. 6.

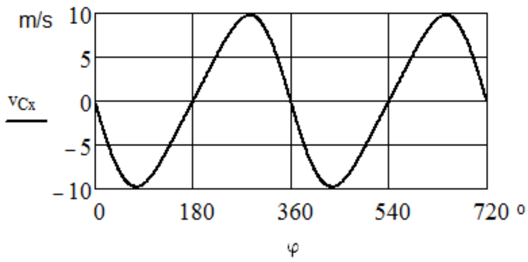

Fig. 6. Pivot C velocity projection v_{Cx} (main piston 3) depending on rotation angle φ

By differentiating the equations (3) and (4) in terms of time one can obtain two linear systems of equations for determining the projections

$$v_{Dx} = \frac{dx_D}{dt}, \quad v_{Dy} = \frac{d\,y_D}{dt},$$
$$v_{Ex} = \frac{dx_E}{dt}, \quad v_{Ey} = \frac{d\,y_E}{dt},$$

of the velocity pivots D and E. Composed linear systems of equations were solved on Mathcad worksheet by using inverse matrix method known from linear algebra. The results of computations are visualized in Fig. 7.

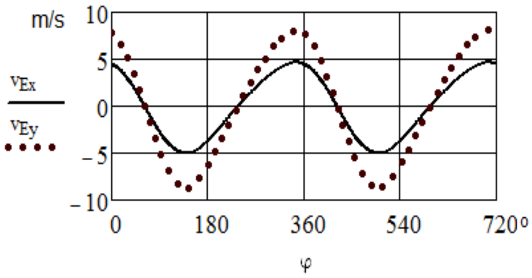

Fig. 7 Pivot E (secondary piston) velocity projections v_{Ex}, v_{Ey} depending on rotation angle φ

5. DETERMINATION OF THE ACCELERATIONS OF PIVOTS

Time-based differentiation of equations (5) gives the following formula to determine the acceleration projection a_{Cx} of pivot C (main piston)

$$a_{Cx} = a_{Bx} - \frac{(v_{By}^2 + y_B \cdot a_{By}) \cdot (x_C - x_B) - y_B \cdot v_{By} \cdot (v_{Cx} - v_{Bx})}{(x_C - x_B)^2}.$$

The results of computations are visualized in Fig. 8.

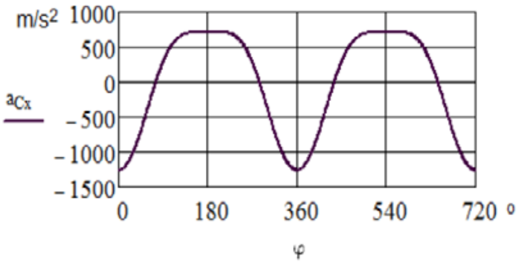

Fig. 8 Pivot C (main piston) acceleration projection a_{Cx} depending on rotation angle φ

When using time-based differentiation of equations (3) and (4) twice one can obtain two linear equations systems for determining the projections

$$a_{Dx} = \frac{d^2 x_D}{dt^2}, \quad a_{Dy} = \frac{d^2 y_D}{dt^2},$$
$$a_{Ex} = \frac{d^2 x_E}{dt^2}, \quad a_{Ey} = \frac{d^2 y_E}{dt^2},$$

where a_{Ex}, a_{Ey} are secondary piston acceleration projections and a_{Dx}, a_{Dy} – the accelerations of the main piston. The results of computations are visualized in Fig. 9.

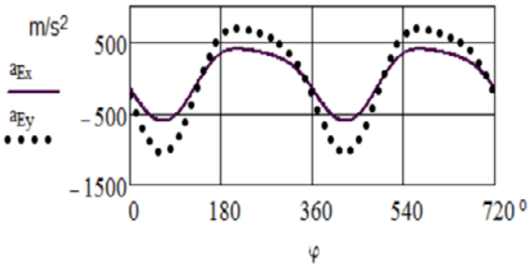

Fig. 9 Pivot E (secondary piston) acceleration projections a_{Ex} and a_{Ey} depending on rotational angle φ

According to [1] links 2 and 4 centres of masses accelerations projections a_{2x}, a_{2y} and a_{4x}, a_{4y} in points x_2, y_2 and x_4, y_4 respectively were determined by the following formulas

$$a_{2x} = a_{Bx} + \mu(a_{Cx} - a_{Bx}),$$
$$a_{2y} = (1 - \mu) a_{by},$$
$$a_{4x} = \frac{a_{Dx} + a_{Dx}}{2}, \qquad a_{4y} = \frac{a_{Dy} + a_{Dy}}{2},$$

where μ =0.27.

6. DETERMINATION OF THE ANGULAR VELOCITIES AND THE ACCELERATIONS OF LINKS 2 AND 4

Let us consider the following equations:

$$x_E - x_D = l_{DE} \cdot \cos\varphi_4, \qquad (6)$$
$$x_B - x_C = l_{BC} \cdot \cos\varphi_2, \qquad (7)$$
$$y_E - y_D = l_{DE} \cdot \sin\varphi_4, \qquad (8)$$
$$y_B - y_C = l_{BC} \cdot \sin\varphi_2, \qquad (9)$$

where φ_4 and φ_2 are the angles between x-axis and connecting links ED (4) and BC (2) accordingly, measured form x-axis counter clockwise. After time-based differentiation of the equations (6) and (9) we have

$$v_{Ex} - v_{Dx} = -l_{DE} \cdot \omega_4 \cdot \sin\varphi_4, \qquad (10)$$
$$v_{By} - v_{Cy} = l_{BC} \cdot \omega_2 \cdot \cos\varphi_2, \qquad (11)$$

where

$$v_{Ex} = \frac{dx_E}{dt}, \qquad v_{Dx} = \frac{dx_D}{dt},$$
$$v_{By} = \frac{dy_B}{dt}, \qquad v_{Cy} = 0,$$

are the projections of the velocities of pivots E, D, B, C, already computed above.
Substitution of (8) into (10) and (7) into (11) gives

$$v_{Ex} - v_{Dx} = \omega_4(\,y_D - y_E), \qquad (12)$$
$$v_{By} = \omega_2(\,x_B - x_C). \qquad (13)$$

From (12) and (13) we can find the following formulas

$$\omega_2 = \frac{v_{Ex}-v_{Dx}}{y_D-y_E}, \qquad \omega_4 = \frac{v_{By}}{x_B-x_C}, \quad (14)$$

that determine the angular velocities of links ED (4) and BC (2) in the case where the positions of pivots and their velocities are known. The results of computations of angular velocities are visualized in Fig 10.

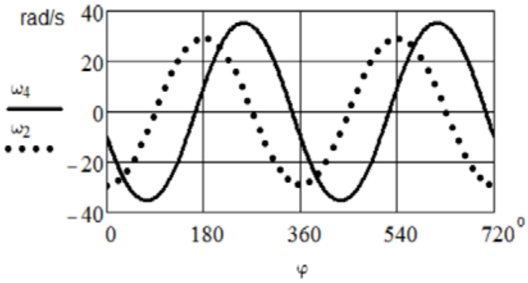

Fig. 10 The dependence of angular velocities ω_2, ω_4 on rotation angle φ

Time-based differentiation of equations (14) gives the following formulas for determination of angular accelerations of links BC (2) and ED (4).

$$\varepsilon_2 = \frac{a_{By}\cdot(x_B-x_C)-v_B\cdot(v_{Bx}-v_{Cx})}{(x_B-x_C)^2}, \qquad (15)$$
$$\varepsilon_4 = \frac{(a_{Ex}-a_{Dx})\cdot(y_D-y_E)-(v_{Ex}-v_{Dx})\cdot(v_{Dy}-v_{Ey})}{(y_D-y_E)^2}.$$

The results of computations of angular accelerations are visualized in Fig. 11.

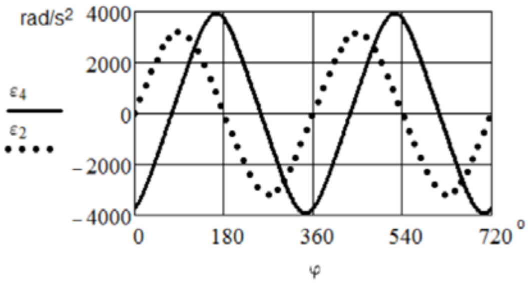

Fig. 11 The dependence of angular velocities ε_2, ε_4 on rotation angle φ

7. DETERMINATION OF REACTION FORCES

Forces applied to the main piston E (3) and the secondary piston E (5) can be find out by using equations

$$F_C = p_C\frac{\pi\cdot {d_s}^2}{4}, \qquad F_E = p_E\frac{\pi\cdot {d_s}^2}{4}.$$

It is supposed that combustion gas pressures are the following

$$\max_\varphi p_C \cong \max_\varphi p_E \cong 4\ MPa.$$

It is assumed that the pressures p_C and p_E, applied to the pistons C (3) and E (5) follow the indicator diagram in Fig. 5.
Before calculating the reaction forces it is necessary to determine the dependence of pressures p_C and p_E on rotation angle φ of the crank AB. Found dependencies are visualized in Figs. 12 and 13.

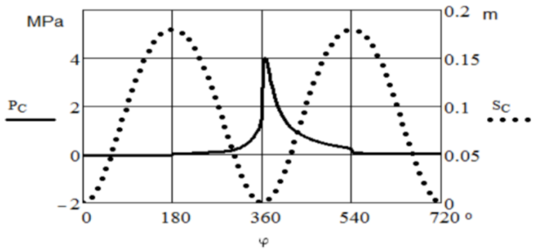

Fig. 12 Displacement S_C of piston C (3) and the pressure p_C in cylinder depending on rotation angle φ

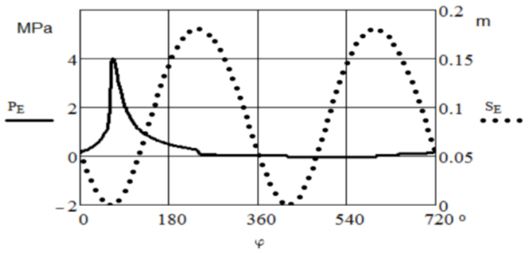

Fig. 13 Displacement S_E of piston C (3) and the pressure p_E in cylinder depending on rotation angle φ

To determine the dynamic reaction forces in pivots and between cylinder walls and pistons, the system of equations on motion for all links was composed according to [13]. Since all accelerations and angular accelerations are determined above, the equations on the motion of links are linear in respect of forces of reaction. The results of computations of reaction forces modules are visualized in Fig. 14.

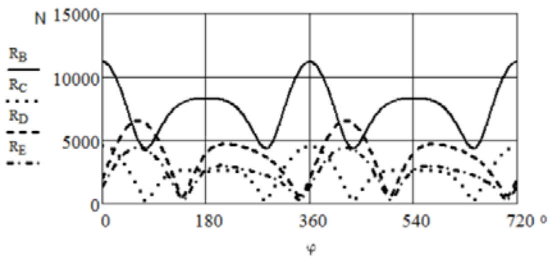

Fig. 14 Reaction forces modules in pivots

8. CONCLUSIONS

1. The Computer Package Mathcad can be considered as a convenient tool for complex analysis of engines.
2. The Computer Package allows the simulation of motion of virtual models of engines.
3. The method presented in this paper can be used in the teaching process of engineering subject "Mechanics of Machinery" and also by engineers of internal combustion engines. This method can also be further developed for more complex and accurate analysis.

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COMPUTER MODELING METHODOLOGY FOR LASER CUTTING PROCESS SUPPORTED WITH EXPERIMENT ON STAINLESS STEEL PLATE

Babalová, E.; Taraba, B. & Duehring, S.

Abstract: *The article is focused to the methodology of computer modeling of laser cutting process on stainless steel plate. Cutting plate of 5 mm in thickness was made in the Laser Center TU Vienna. Computer modeling of the laser cutting process is oriented on gradation of models from simple thermal model to combined thermal-fluid analysis. The results from of the model application with shell elements with killing elements are shown. Energy source geometry and beam penetration influence on temperature field in the cutting area are documented by results from the solid model in ANSYS and SYSWELD code. Authors considered thermal-fluid model whose proposal is in the article as the model closest to reality. Processing of simulation models are supported with obtained data from real experiment.*

Key words: laser cutting, computer modeling, Ansys, Sysweld, methodology

1. INTRODUCTION

Nowdays, laser cutting is an imdustrial process used for cutting all types of materials. Laser cutting has wide application in the field of automotive industry [1]. Continuous-wave CW CO_2 laser is most often used for this application. The assist gas type and pressure have strong influence on the quality of produced cuts. The assist gas is responsible for removing the molten metal from the cut kerfs, and it protects laser optics from beginning damaged by the resulting ejected spatters [2]. The aim of article is numerical simulation laser cutting process specifically to find appropriate methodology of computer modeling. The numerical simulation of laser cutting process was carried out using the solution of an inverse heat transfer problem [3]. 2D and 3D simulation models have been created with emphasis on the comparison of calculated and measured temperatures. For numerical simulation of laser cutting process was used finite element method (FEM). FEM for discrete areas can be characterized as continuous computer-oriented method for solving differential equations [4]. For numerical simulation were used software universal ANSYS and specific SYSWELD. ANSYS was used for creation of 2 D model of laser cutting process with SHELL elements. Methodology for 3D solid model creation was realized with used SYSWELD software. Shell and Solid simulation models were supported with obtained data from real experiment implemented in laser center TU Vienna. The main aim is to help elucidate simulation model creation of laser cutting process.

2. METHODOLOGY FOR SIMULATION MODEL CREATION

Laser cutting process simulation is possible in several methods. Used methods of simulation 2D model shell creation were compared and obtained solution was searched. Subsequently was created 3D solid model. In 3D solid model was applied killing element and his influence on temperature field was monitored. Fig. 1 shows the process of creation simulation model.

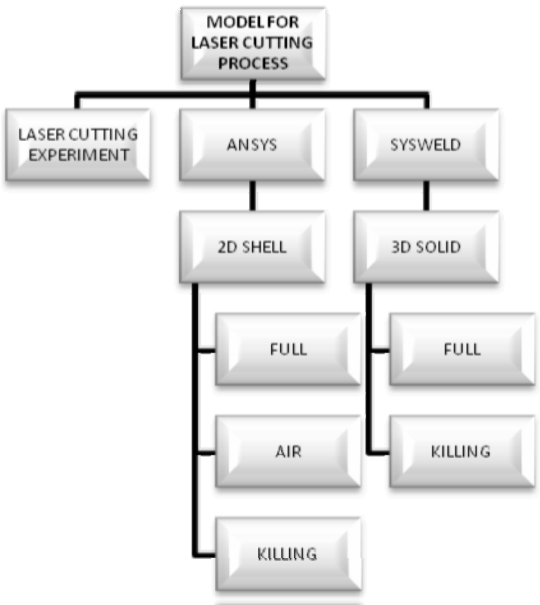

Fig. 1. Process of creation computer modeling

2.1 2D SHELL model

Used element type for 2D SHELL model was SHELL 131 with added material thickness. The base of methodology for input of heat load to the cutting area is the theory of heat transfer and boundary condition definition. Heat load for SHELL model was implemented as an input surface temperature into gap nodes. This is first-type (Dirichlet´s boundary condition of first kind) [°C]. The surface temperature of cutting material may appear as a constant or may depend on the coordinates (distributions function), from time. It is an indirect method. Simulation model was created as plane symmetrical. Half dimensions of the sample were used. Dimensions of sample was 0.100×0.025×0.005 m. The plane of symmetry is central plane of the cut also. Model had attached two thermocouples (TC). The distance of thermocouples from central plane of the cut was 0.002 and 0.0054 m. Distance between them was 0.02 m. Direction of movement laser beam was simulated along central plane of the cut. The temperature measured with thermocouples was recorded [5]. Finite element mesh was refinement direction to the symmetrical plane. Fig. 2 shows model with attached thermocouples from the left side and generated mesh with detail from the right side.

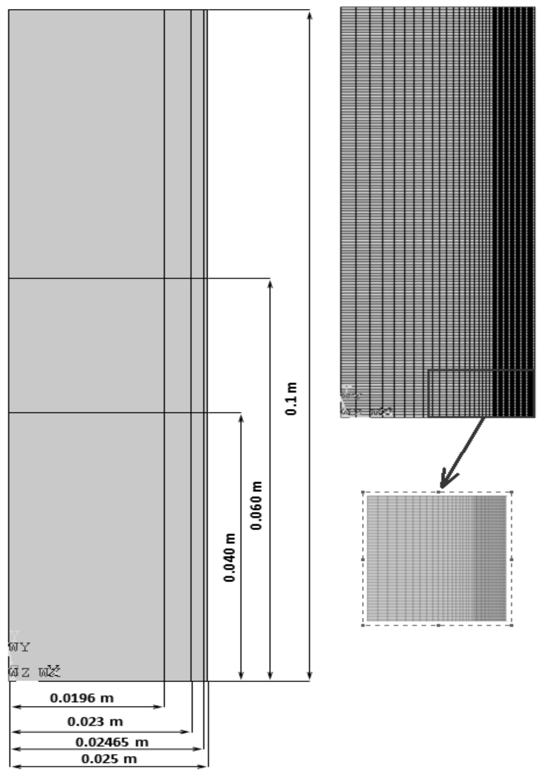

Fig. 2. SHELL model and generated mesh

FULL MODEL

Laser cutting was simulated by the model which was full of metal. After moving of heat source along symmetrical plane of the cut liquid metal remained in laser gap. Heat source movement was simulated sequentially. First, were selected elements with laser gap dimensions. Subsequently selected elements were heat loaded. Heat load was temperature which varies depending on the time of laser beam movement. Gradually were selected and loaded all elements along central plane of the cut.

AIR MODEL

AIR model gradually change metal elements onto air behind laser beam movement. We became model with two materials: metal and air than. All elements along symmetrical plane of the cut were selected and loaded by defined load steps. Function for gradually changing material into air after the movement laser beam was added. Changing was realized with change material properties. Material properties for steel and air were used [6]. Fig. 3 shows changing elements into air after the heat source movement.

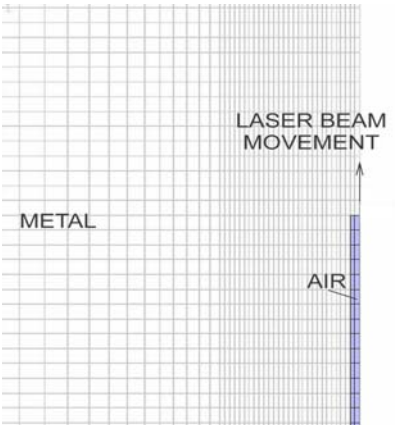

Fig. 3. AIR model with gradually material change properties at the time 4.0 s

KILLING MODEL

Model was created for deactivated (killing) elements [7] after the heat source movement elements were consequence killed. Elements were gradually removed from laser gap. All elements along symmetrical plane were gradually selected, loaded and killed (Fig. 4.).

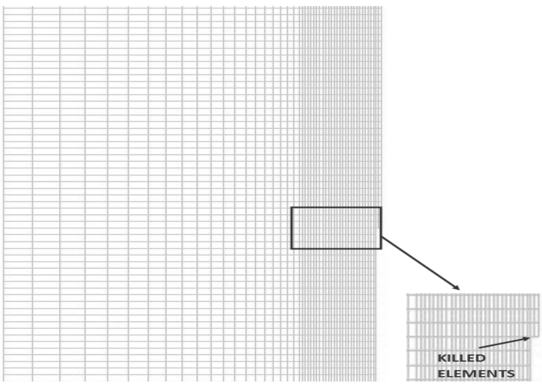

Fig. 4. 2D SHELL model with elements deactivation (killed elements)

2.2 3D SOLID model

3D SOLID model was created with applied SYSWELD software. Model dimension was 0.1×0.050×0.005 m. Finite element mesh was refined in direction to symmetrical plane of the cut. Heat load was realized as an input HEAT FLUX (Neumann's boundary condition of second kind) [$W.m^{-2}$] in to element along cut direction. It is direct task for laser cutting process modeling. For numerical simulation of laser cutting process was used Gaussian moving heat source [8]. Fig. 5 shows Gaussian´s shape of heat source for cutting.

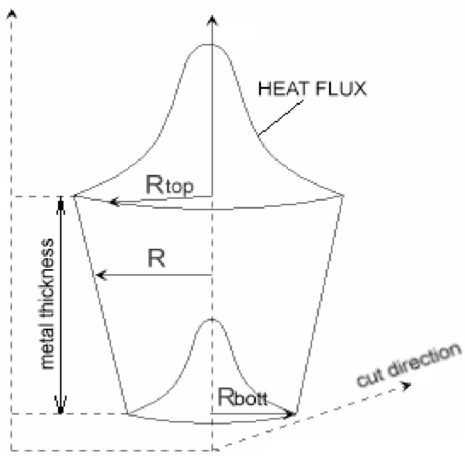

Fig. 5. Used Gaussian's heat source shape for cutting

3D SOLID model was modeled as a FULL model - model full of metal. After movement laser beam along symmetrical plane of the cut material was melted and stayed in laser gap. Element deactivation model was created as second. After the heat source movement were elements gradually removed. Fig. 6 shows simulation 3D SOLID model used by SYSWELD software.

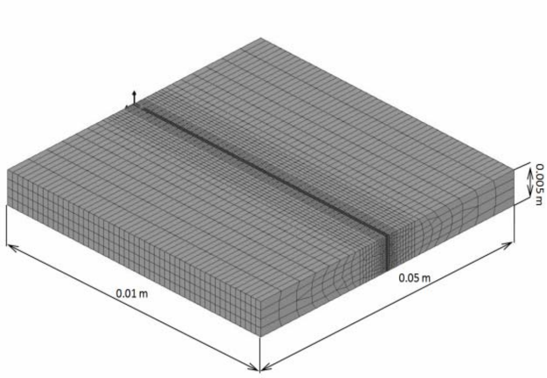

Fig. 6. 3D SOLID model used by SYSWELD software.

3. LASER CUTTING EXPERIMENT

Laser cutting experiments were performed at the Vienna University of Technology. During experiments, plates from stainless steel DIN 1.4301 (X5CrNi18-10) were cut. The main aim of experiments was to find out the transverse temperature distribution. Samples with dimensions of 0.2×0.1×0.005 m were prepared. Each sample had attached two thermocouples (TC) from the left side and two TC from the right side. The experimental equipment consisted of a cutting machine CW: CO_2 OERLIKON Precision Laser CH-1196 Gland, 25 KVA, 10600 nm, 2000 W, nitrogen N_2 as assist gas, modul NI USB 9211 and personal computer. Cutting parameters were used: pressure of assist gas - 13 bar, cutting speed - 0.7 $m.min^{-1}$, nozzle to material distance - 0.8 mm and laser power 1.6 kW. Measured temperature was 229 °C and 68 °C on TC´s [5].

4. OBTAINED RESULTS

2D SHELL model

FULL MODEL

Temperature contour at time 4.0 s shows Fig. 7.

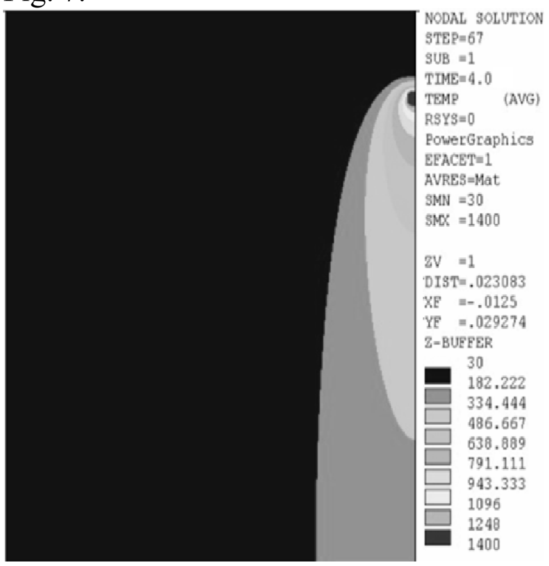

Fig. 7. Temperature contours for FULL model

Obtained temperature on TC-0.0054 m from the central plane of the cut was 203.953 °C and TC - 0.002 m from central plane of the cut 482.334°C.

AIR MODEL

Temperature at time 4.0 s shows Fig. 8. as a contour plot. Obtained temperature on TC - 0.0054 m from central plane of the cut was 164 °C and TC - 0.002 m from central plane of the cut 415 °C.

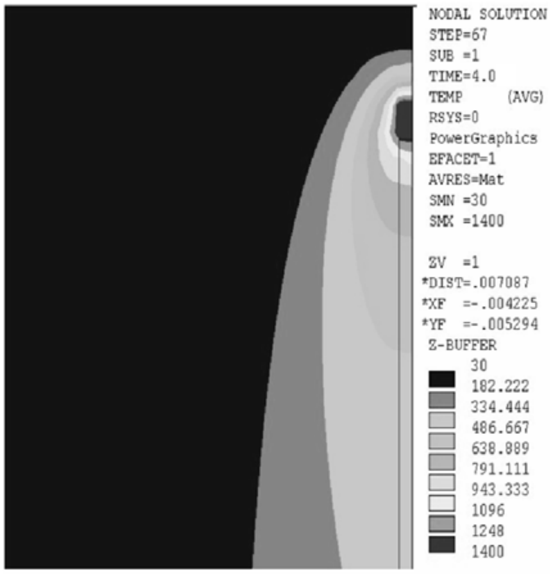

Fig. 8. Temperature field for AIR model

KILLING MODEL

Temperature field at time 4.0 s shows Fig. 9. Obtained temperature on thermocouples TC - 0.0054 m from central plane of the cut was 164.053 °C and TC - 0.002 m from central plane of cut 415.55 °C.

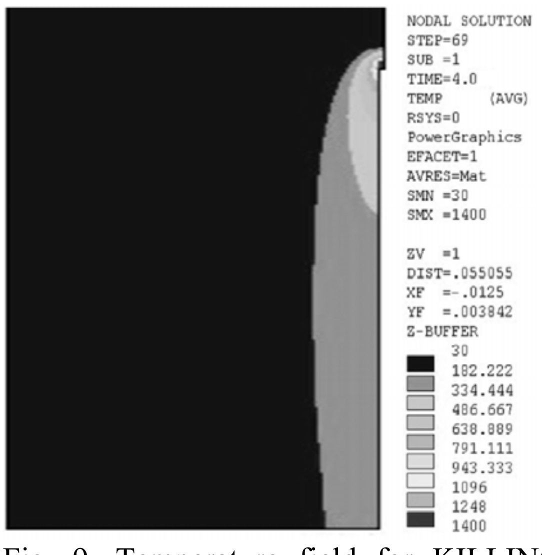

Fig. 9. Temperature field for KILLING model

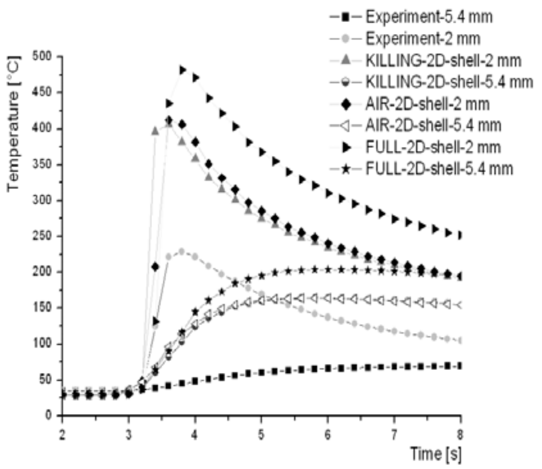

Fig. 10. Time dependence temperatures curves by ANSYS calculation

Compared obtained temperatures with numerical simulation and measured temperatures with real experiment are shown in Fig. 10.

3D SOLID model

FULL MODEL

Temperature field for FULL model at time 5 s shows Fig. 11. Maximum calculated temperature was 1722 °C. Fig. 12. shows time dependence temperature curve for FULL model by SYSWELD calculation.

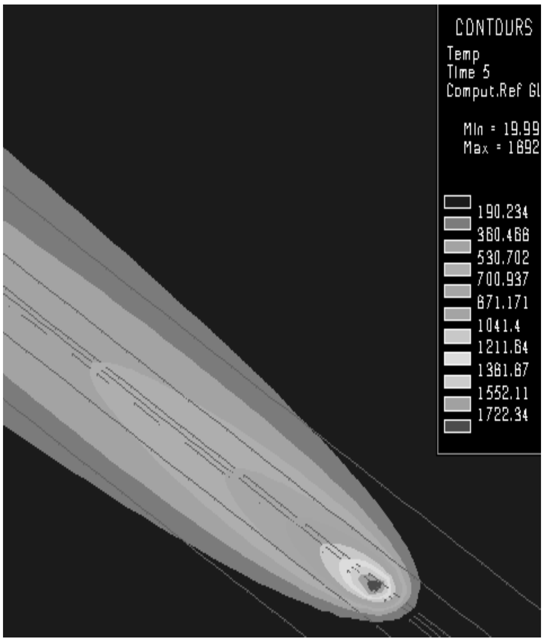

Fig. 11. FULL 3D SOLID model-Sysweld

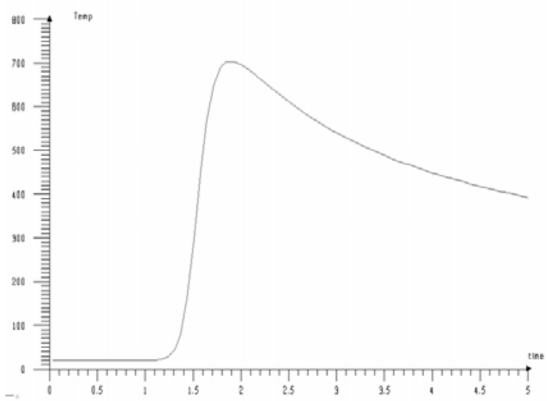

Fig. 12. Time dependence temperature curve for FULL model by SYSWELD calculation

KILLING MODEL

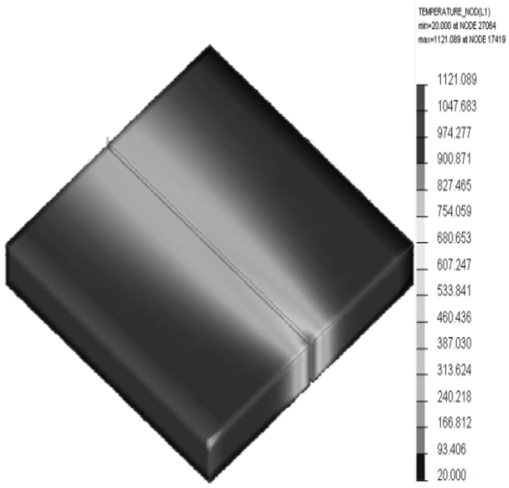

Fig. 13. KILLING 3D SOLID model at time 5.65 s, Sysweld (end of cutting)

5. DISCUSION AND CONCLUSION

Numerical simulation of laser cutting process was performed in two ways. Using the solution of indirect inverse problem and the inverse-numerical-correlation (INC) method the unknown parameters and characteristics of laser heat source was determined. First was used 2D SHELL model specifically FULL, AIR and KILLING model. The results showed temperature difference between FULL model and AIR, KILLING model. Temperature field for AIR and KILLING model showed conformity. Simulation models with ejected elements from the laser gap showed lower temperatures compared with FULL model temperatures. Compared with experiment are measured temperatures values more than half greater. This results in quicker heat conduction into the vicinity during real experiment. During the numerical simulation of laser cutting process is necessary to apply jet impinging cooling effect of assist gas. 3D SOLID model appeared to be independent of way creation simulation model. FULL and KILLING 3D SOLID model shows different temperatures. Calculated temperatures for model KILLING was lower in compared with FULL model. Simulation models were used deactivation of elements showed temperatures lower than FULL models. Heat flux to the vicinity in this case is higher.

In the next step of numerical approach will be using of thermal-fluid model as the model closest to reality. Based on this model the process of laser cutting will be analyzed in details with the aim to optimize parameters of laser cutting.

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LIFE CYCLE EXTENSION FOR USED VEHICLES AND THEIR ENVIRONMENTAL IMPACT

Bashkite, V.; Durmanenko, D. & Karaulova, T.

Abstract: *The idea of this paper occurred in one car dealer sales company in Estonia. The problem is that some vehicles are stagnated in the warehouse for months for some reason. It requires additional resources, retail space on the trading floor and, of course, each day of car downtime reduces it cost on the market. All these circumstances lead the company to the specific losses, what are not acceptable for the used car dealers. In this research the general trends for increasing competitiveness of used cars on the market and reducing their environmental impact will be considered.*

Key words: Life cycle extension, dynamic modelling of used vehicles.

1. INTRODUCTION

This study provides a framework for understanding overall vehicle economics and key economic variables in relation to individual ownership costs, operating decisions and replacement intervals, in combination with a parallel study of vehicle end-of-life possibilities.
The results are considered in terms of annual car sales numbers, stagnated vehicles in warehouse and storage costs for ownership by the company.
The present study considers an annual decision for a vehicle owner: “keep the existing vehicle, or replace it with a new one?” or “how green the customer becomes by replacing the old vehicle“.
Survey of US bying companies showed that the people buying a car take into account quality, price, safety, fuel economy, mileage of car and comfort above all (see Table 1).

Safety	19%	Fuel economy	18%
Quality	18%	Styling	11%
Price	16%	Warranty	15%

Table 1. Customer preference attributes [1]

The main goal of this research is to develop approach for determination of the optimal vehicle retirement age and minimize it environmental impacts. Also must be taken into account interests of cars end users and sales companies.
The optimal vehicle retirement age was estimated through inputs and outputs (emissions and energy consumption), associated with different car models and ages.
It is aldo important to highlight that the energy consumption is growing every year in the world. The price for the every kind of petrolium is growing in the same fast manner. More detailed overview and some forecasts are presented in next chapter.

2. PETROLIUM PRIACE AND NEW TRENDS IN CARS DEVELOPMENT

Several oil market analysis groups produce world oil price and production forecasts. In figure 1 is introduced oil price history [2].
Impact on oil prices depends from growing demand in developing Asian countries. Strong demand kept crude oil benchmarks above the $100-a-barrel mark for most of 2011, despite multiple economic shocks. With limited alternatives, prices will continue to increase in the future with rising demand constraining reserves.

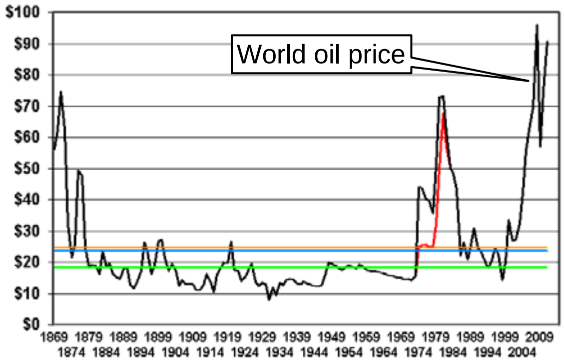

Fig. 1. History of world oil price

Forecasts of the price of oil (and the price of its derivatives such as gasoline or heating oil) are important in modeling investment decisions in the energy sector, in predicting carbon emissions and climate change, and in designing regulatory policies such as automotive fuel standards or gasoline taxes [3,4].

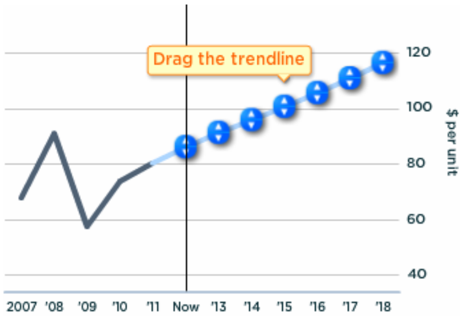

Fig. 2. Forecasts of the price of oil [3]

Most developing nations that are driving global economic growth are highly dependent on energy consumption. Although the U.S., EU, and Japan consume large amounts of energy, these nations have less leverage to the price of oil in relation to their GDP.

Consumer demands and new regulations will heavily influence the development and marketability of innovations in the car industry. First among these demands is fuel efficiency, which will lead to new (or improved) powertrain technology.

Oil price multiplied by Inflation will make Electric vehicles the reality in the nearest future, see figure 3 [5]:

• Electric vehicles will be the minority of auto sales in the short and medium term, but then become the majority.

• EVs will have a 5.5 percent market penetration globally in 2020 and 15 percent by 2025.

• The internal combustion engine will still dominate with 85 percent of the market, but EVs will move from rich man's toy to mass market.

• High oil prices will make EVs more popular and in 30 years EVs will be the bulk of the market.

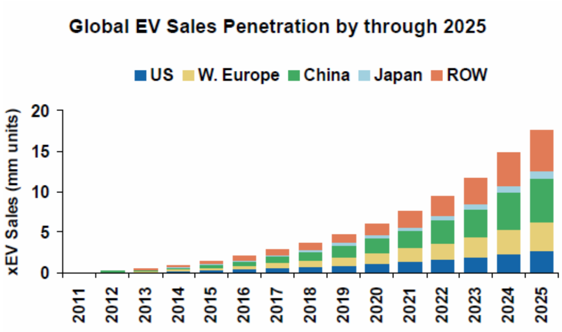

Fig. 3. Electric vehicle sales trend [5]

Green alternatives, such as electric cars will likely find more consumer interest in wealthier countries while flex-fuels, such as ethanol and natural gas will find wider adoption in emerging markets where the local climate or resource base favors these fuels over petroleum.

While consumers await a more EV-friendly world, hybrid vehicles will serve as transition technology in developed and developing markets. Hybrids feature lower carbon emissions, greater fuel efficiency, and are less infrastructure intensive than EVs [1]. They also aid in the switch from full-combustion engines to electric motors.

Due to all above mentioned energy consumption issues, it is very important to plan the used vehicle end-of-life scenarios long before the proposed optimal life cycle. The optimal period of vehicle life cycle can be calculated by using Life Cycle Assessment tool.

3. CARS LIFETIME

Statistic of Automobile Medium Lifetime [9] (shows that cars after 12 years loses his survival rate and needs modernisation.

Data from sales company (figure 4) shows that there are not cars older than 13 years.

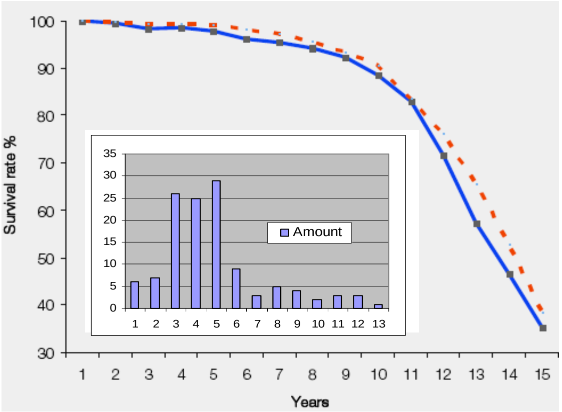

Fig. 4. Automobile medium lifetime

Cars are retired from the service after 20 years of physical life. The average age of passenger cars in EU [7] in 2006 was 7.65 years. The age of passenger's cars has been decreasing primarily on account of the policy of encouraging the replacement of older vehicles with new ones.
An intermediate phase between the purchase of a new car and its eventual scrapping is the sale of the car as a used car. Statistics at an EU level show that the used car market is very active, in most cases larger than that for new cars.

3.1 Stagnated cars in the sales company

As figure 5 shows the longest period of car life cycle is usage time. The environmental aspect is very important, nevertheless the satisfaction level of end user during this whole period is playing significant role. On the one hand the vehicle producers have to follow the restrictions set by governments all over the world, than take into account all the environmental aspects and after all think about the end user satisfaction level.
According to statistics gathered from this car dealer company (figure 5), the vehicles stay in warehouse for more than one month due to they have the wrong cost (the purchase price is higher than the market one), there are certain serious technical problems or the customer is not anymore satisfied with the car options and features.

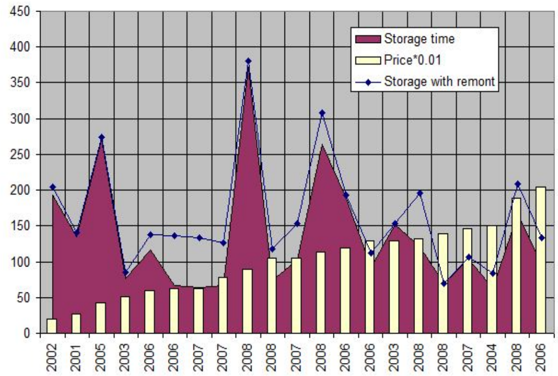

Fig. 5. Stagnated cars in 2011 over 60 days

Normally the used cars have to be resold in one month, but what to do with these problematic units? The best solution has to be found by used vehicles reselling company for car life cycle extension and user satisfaction: reasonable price – optimal fuel consumption – good quality. End users are not thinking about environmental impact. By optimising the fuel consumption and reconstruction internal combustion engines into electric ones the environmental issues will be fulfilled by default. In this paper these factors will be taken into consideration.

3.2 Solutions for used cars

When the product has distinguished the end of its life cycle the proper decision has to be proposed. In fact, the end of product life cycle can be different, based on the optimal cash-flow measure [10]. The totally new solution has to be proposed in order to intrigue the future customer.
The typical problem seems to appear here is that companies do not think about what to do with unsold and returned used cars, their parts, which have left from production, old or obsolete products [11]. Most managers consider it as wastes. But if a one business thinks in 'Green' way, there are several options to follow:

- First one, the smartest: develop or upgrade used car with a possibility to use parts or subassemblies from previous product. In this case study the used car reconstruction into electric car is observed.
- Another option: collect and recycle products, parts, and material. There is a

possibility to recycle old crushed cars what can not be repaired / remanufactured / reused into spare parts with clear history (true readings, year of manufacturer

• Finally, worst and simple option is a landfill. Unfortunately it is the most widely used option nowadays.

4. CARS LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) provides the environmental profile of a system and evaluates the distribution of the burdens and impacts across life cycle stages. LCA uses a systematic and comprehensive approach to assess environmental burdens associated with products, and it has been used as an analytic tool for pollution prevention, life cycle design, and optimization modelling [6]. A vehicle life cycle consists of the following generic stages: materials production, manufacturing, use, maintenance, and end-of-life. The environmental burden of each stage shows different profiles for various categories. For instance mid-sized car, the use phase contributes 85% of the total life cycle energy consumption based on 120000 miles (ca 193 121 km) of service life. On the other hand, the use phase contributes only 19% of the total solid waste produced while the materials production phase contributes 58% [7].

In order to compare the environmental performance between old, retiring vehicles and new replacement vehicles in the context of scrappage programs, LCA models need to be developed for each model year as a function of vehicle age. According to this research the LCA model has to be developed for the specific period of vehicle life cycle.

Vehicle LCA studies have mostly focused on measuring the environmental performance of specific model year vehicles or propulsion systems. However, such methods fall short of describing high or low emitters since these studies report average environmental performances based on functional units (e.g., 120,000 miles of driving) [8]. In order to compare the environmental performance between old, retiring vehicles and new replacement vehicles in the context of scrappage programs, LCA models need to be developed for each model year as a function of vehicle age. In this paper, the dynamic model is developed for the period of time from usage to end-of-life stage.

4.1 LCA model construction

A standard mathematical model to find optimal vehicle retirement policy, as presented in figure 6, is constructed using the following notation:

Assume that, at time *0*, a decision maker tries to minimize the environmental burden of a criterion within the time horizon *N* based on information the decision maker has regarding the environmental performance of future vehicles.

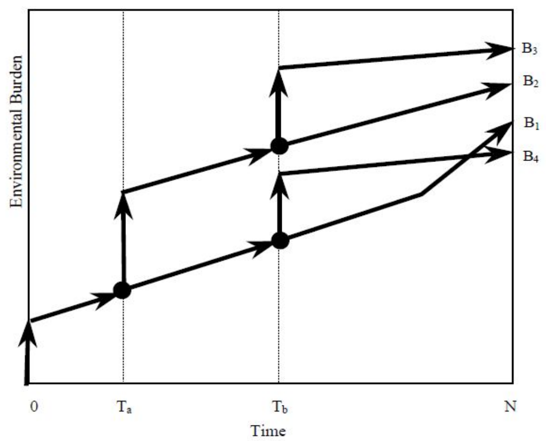

Fig. 6. Schematic example of the life cycle optimization model based on four policies [8]. *B1−B4* represent the final environmental burdens for the four policies.

The decision maker seeks a solution of the form “Buy a new vehicle / upgrade the used one at the start of year *0* and keep it for α years and retire it; then buy a new vehicle at the start of year *a,* and keep it for *b* years and retire it, etc. As an example, consider four policies depending on the decisions at *Ta* and *Tb*. It is assumed that retiring a vehicle and buying a new vehicle occurs simultaneously.

1) If the vehicle owner keeps the initial vehicle throughout the time horizon N, the cumulative environmental burden (*B*) will result in *B1*. The slope change between Tb and N represents vehicle deterioration expected for older cars.
2) If the vehicle owner replaces the initial vehicle with a new vehicle at time Ta and keeps the new vehicle until N, the cumulative environmental burden (*B*) will result in *B2*.
3) If the vehicle owner replaces the initial vehicle with a new vehicle at time Ta and replaces this second vehicle again at Tb, the cumulative environmental burden (*B*) will result in *B3*.
4) If the vehicle owner replaces the initial vehicle at time Tb with a new vehicle and keeps the new vehicle until N, the cumulative environmental burden *(B)* will result in *B4,* which is the minimum possible outcome. With this hypothetical example, policy 4 is the optimal policy and the optimal vehicle lifetimes are *Tb*.

However, in a real-world problem with a longer time horizon, the number of possible policy choices is often enormous. If a decision maker seeks an optimal replacement policy during a time horizon *N* with a new vehicle at the beginning of year *0*, and the vehicle replacement decisions are made at the beginning of every year from year *1*, the number of possible outcomes is 2^N. In addition, the environmental profiles of *N* different model years need to be considered based on vehicle age.

The figure 6 shows *n*, first year of the study; *N*, last year of the study; M, maximum physical life of a vehicle; *BM(i)*, environmental burden of the materials production of model year *i* vehicle; *BA(i),* burden of the manufacturing of model year i vehicle; *BU(i,j),* burden of the vehicle use during year *j* of model year *i* vehicle's service; *BR(i,j),* burden of the maintenance during year *j* of model year *i* vehicle's service; *BE(i,j),* burden of the end-of-life stage of model year *i* vehicle retired at the end of year *j*; and *u(i,j)*, burden of purchasing (producing) a new vehicle at the start of year *i* and keeping it for *j* years. For any model year *i, u(i,0) = 0* and represents the case in which a new vehicle is not purchased in year *i*. [8]

u (i,j)= (1)

$$B_M(i) + B_A(i) + B_E(i,i+j-1) + \sum_{k=1}^{j} (B_U(i,k) + B_R(i,k))$$

4.2 LCA for car modernization

In current research is considered car modernization instead car replacement. In the mathematical model in this case we not take in account burden of the materials production $B_M(i)$ and manufacturing $B_A(i)$, of vehicle. But use new parameter $B_V(i,k)$, environmental burden of the vehicle modernization. Value of this parameter is more less than $B_A(i)$.

This model helps to focus more attention on possible end-of-life strategies analysis.

$u_m(i,j)$= (2)

$$B_E(i,i+j+1) + \sum_{k=1}^{j} (B_U(i,k) + B_R(i,k) + B_V(i,k))$$

Schematic example of the environmental burden influence for vehicle modernization is shown in figure 7.

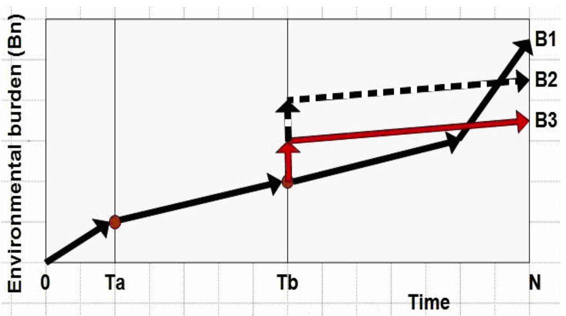

Fig. 7. Schematic example of the life cycle optimization by car modernization

The dynamic programming optimality equations are constructed as follows: *f*(*i*) be the minimum possible burden accumulated from the start of year *i* through the end of year *N* given that a purchase is made at the start of year *i*. Then:

$$f(i) = \begin{cases} \min\limits_{x_i \in \{1, 2, ..., M\}} \{u(i, x_i) + f(i + x_i)\} \\ 0 \end{cases} \quad (3)$$

Where, x_i is the decision variable representing the number of years owning vehicle of model year *i*.

For each criterion, this model seeks to minimize the burden from the life cycle of model years *n* to *N* by deciding how long to keep each vehicle before purchasing a new vehicle or reconstructed one.

5. CONCLUSION

The amount of vehicles, needed for society, constantly grows in operation. However, the used vehicles impact to the environment is enormous throughout the life cycle, for instance: energy and resource consumption during the use phase, waste management during new products manufacturing, and disposal at the end of its life. In this research the approach for determination of the optimal car lifetime was introduced. The mathematical tool was represented in order to find the right moment for old car replacement or modernization. This way of thinking priorities the possible upgrade of used vehicles from the energy saving point of view. It gives additional advantages to cars sales companies to increase competitiveness on used cars market by offering unique services and products.

6. ACKNOWLEDGEMENTS

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THE IMPACT OF HUMAN RESOURCE PROFESSIONAL DEVELOPMENT ON THE SMEs PERFORMANCE. EVOLUTIONS AND CHALLENGES

Bercu, AM.; Roman, A.

Abstract: *One of the key factors for growth and performance of firms in the new knowledge economy is the professional development of human resources, professionalism and competitiveness and enhance value to adapt constantly to new conditions of economic and socio-professional environment. Particularities of SMEs activities require people well trained, able to meet the challenges and determine growth and economic performance. The purpose of our research theme is to identify and assess the impact of professional development of human resources on the performance of the SMEs sector in Romania. The results show that it is very hard for SMEs to sustain the professional development in order to increase their performance, but is the condition to succeed.*

Key words: HRM, effectiveness, labour, SMEs, strategic capital.

1. INTRODUCTION

In most states, small and medium enterprises (SMEs) are vital for economic and social development because they provide a significant contribution to creating added value and jobs. The purpose of our research theme is to identify and assess the impact of professional development of human resources on the performance of the SMEs sector in Romania.

Our analysis is based on statistics and surveys provided mainly by the National Council of Private Small and Medium Enterprises in Romania, European Commission and some empirical studies.

Our paper is structured as follows: Section 2 presents the conceptual framework on human resources system; Section 3 highlights the main features of SMEs sector in Romania and especially its role in creating jobs. In Section 4 we aim to highlight some correlation between the performance of SMEs and quality of human resources, and Section 5 reflects the economic and financial performance of SMEs sector in Romania. Our study ends with conclusions.

2. HUMAN RESOURCE SYSTEMS. CONCEPTUAL FRAMEWORK

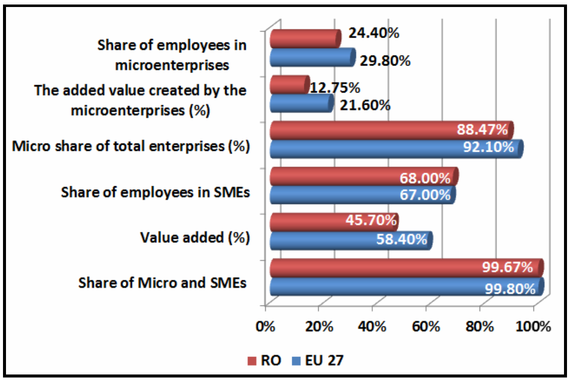
One of the main objectives of human resource management is to create conditions that latent potential employees can be attained, while ensuring their commitment to the causes of the organization [1]. As shown Harrison [2], human resource development is an "idea resulting from a clear vision and potential capacity of people, framed in the general strategy of the enterprise". This perspective reflects the belief that human resources are a major source of competitive advantage.

Obtaining organizational performance by competent human resources, training, open approach to knowledge and involved in company growth status on a fierce competitive market is a point of interest for enterprise management. Performance means both behaviours and results. Behaviour emanates from individuals (performer) and performance make the abstract notion into concrete action, as

defined in the literature the so-called "model-mixed" [3] of performance management, covering both levels of competence and achievements, and establish and analyze the results.
For SMEs human resource management in order to get organizational performance requires an approach in two directions. First, regarding human resources practices, which should be considered rather as a coherent set of measures and techniques, but taken individually, and the second, relating to resource management system human, involving an integrative approach to environmental factors, organizational and technological development through which the system.
Performance of SMEs can be distinguished by comparing the degree of innovation [4] pro-activity [5] and the capability to calculate and take risks [6]. Interdependence of these factors is achieved through human resource employee, able to provide the expertise and competence, to get involved and perform in the organization, to take risks and bring added value to the effort of maintaining and developing the competitive market.

3. CHARACTERIZATION OF SMEs SECTOR IN ROMANIA. AN OVERVIEW

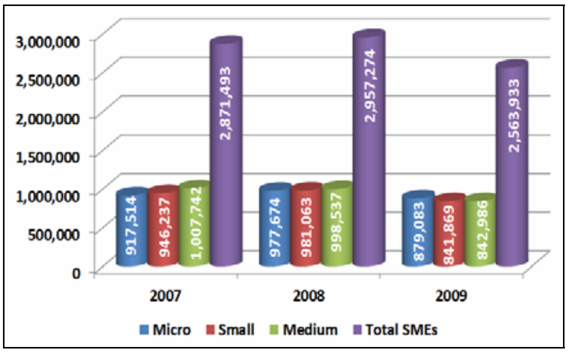
SMEs constitute the dominant form of business organization in the European Union, each with over 99% of the total number of enterprises. SME sector is considered the spine of the European economy, the engine of economic and social development and has a crucial importance for economic growth and creating jobs. Crucial importance of SMEs for the European economy resulting from their dynamism is considered an engine of innovation and growth and also an important source of job creation.
According to the standardized European Union definition, SMEs are businesses with 10 to 250 employees, with less than € 50 million in turnover and less than € 43 million in balance sheet total.
Of economically and socially point of view, SMEs sector generates about 60% of the value added to the European economy and provide 67% of the total employment (see figure 1). In all European businesses, the overwhelming share of microenterprises owned (92.1% concerned), which produce about 22% of value added and represents approximately 30% of total employment. Compared to Romania, SMEs account about 47% of the value added and 68% of the total employment and micro enterprises is 88.47% in total, 24.40% of total employment and only about 13% of business value added.



Source: own simulation based on the dates provided by [7]
Fig. 1. Key indicators for SMEs in the EU and Romania, 2010 (estimates)

Supporting small businesses to develop and promote business has legal support in Romania [8] giving facilities for micro start-ups, led by young entrepreneurs (aged up to 35 years), which perform for the first time the economic activity, through a limited company. On the other hand, the prevalence of micro, a long period of time may indicate a standstill in the development of micro enterprises.
Amid major problems facing the SME sector in Romania is noted for the year 2009 a reduction of intake of this sector to create jobs. Thus, based on statistical data (see figure 2) it is shown a reduction of number of the total SME sector employees

by 13% in 2009 compared to 2008. Depending on company size, the reduced number of employees is directly proportional to firm size increases and 10% for micro, 14% for small firms and over 15% for medium-sized companies. Survey conducted by National Council of Small and Medium Sized Private Enterprises in Romania (CNIPMMR) shows that in 2010 compared to 2009, there was a reduction in employment and number of employees in the SME sector.



Source: centralized data based on [9, 10, 11]

Fig. 2. Evolution of the number of employees and its structure by size categories of SMEs

CNIPMMR survey carried out by a sample of 1723 firms micro, small and medium [9] shows that in 2010 compared to 2009, there was a reduction in employment and number of employees in the SME sector, in close correlation with firm size.

Based on survey of CNIPMMR is noted that a large proportion of SMEs (94.17%) have employed more than 5 people and only 0.78% of companies have committed between 11 to 20 people, which highlights extremely negative impact of the crisis in terms of contribution of SMEs to create new jobs.

4. ASSESSMENT OF CORRELATION BETWEEN THE PERFORMANCE OF SMEs AND THE QUALITY OF HUMAN RESOURCES

SMEs performance can be analyzed by highlighting human resource practices and results, in terms of behaviour and performance. Improved performance by reference to productivity, quality and innovation is closely correlated with the development of motivational behaviour by staff, the cooperation and involvement, to assume the roles and responsibilities within the company, as their absence leads to absenteeism, labour, customer dissatisfaction and loss of confidence in business services. (see table 1).

HRM practices	**HRM outcomes**	**Behaviour outcomes**	**Performance outcomes**
Selection	Commitment	Effort / motivation	*High:*
Training			Productivity
Appraisal	Quality	Cooperation	Quality
Rewards			Innovation
Job design	Flexibility	Involvement	*Low:*
Involvement			Absence
Status and security		Organisational citizenship	Labour turnover
			Conflict
			Customer complaints

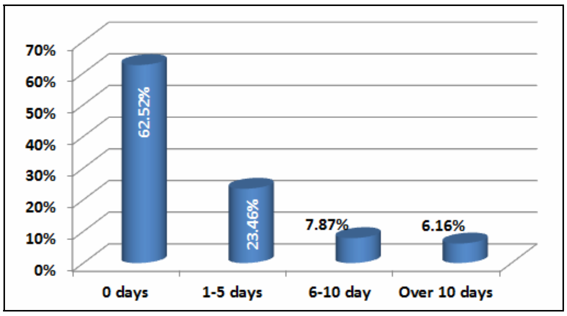
Source: [12, p. 20]

Table 1. Linking HRM and performance

In full compliance with the above, the performance of SMEs in Romania is quantified according to criteria of appreciations of the employees by the entrepreneurs, in conjunction with organizational performance objectives (productivity, efficiency, stability). Thus, the results of investigation conducted by CNIPMMR [9] highlights the most important criteria: experience (over 66% of firms), knowledge and skills held (approximately 55%), the spirit of responsibility (47%), competence in activity (approximately 46%) degree of involvement in the company (over 41%) and conscientiousness (40%).

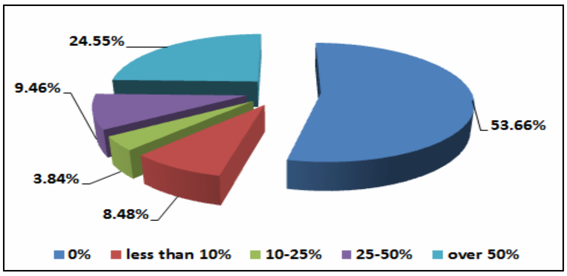
For the management of SMEs in Romania, the results presented above highlight the concern for hiring qualified human resources with a strong professional

background who has the knowledge and skills necessary to fulfil job duties and responsibilities. This is because the costs of training and professional development are greatly diminished. Maintenance employees and development capabilities and provide new knowledge and skills is a novel direct responsibility of the employer (by the Labour Code, Law no. 41/2011). Lack of financial resources as barriers for SMEs managers who either do not invest in training and improving their employees or prefer the simplest forms of providing new knowledge and practices in the field (short training sessions held at the company, the job rotation , call the experts in the field).
The results of CNIPMMR survey made in the year 2010 show a concern limited to the SME sector for the development of training activities (see figure 3). Thus, over 60% of companies have implemented training activities during 2010, accounting for 24.46% of SMEs have dedicated training 1-5 days per employee and only 6% of total SMEs have developed training programs over 10 days per employee.



Source: [9, p. 232]
Fig. 3. SMEs structure depending on the duration of employees training

In terms of percentage of employees in the SME sector which have benefited over the years of training programs, the results achieved by the year 2010 CNIPMMR shows that over 53% of companies have not conducted training activities and only 24.55 % of SME investigated were trained over 50% of employees (see figure 4), which shows that in Romania is given little attention to improving employee productivity and major implications on organizational performance.



Source: [9, p. 238]
Fig. 4. Share of SME employees have received training

5. ECONOMICAL AND FINANCIAL PERFORMANCES OF SMEs IN ROMANIA

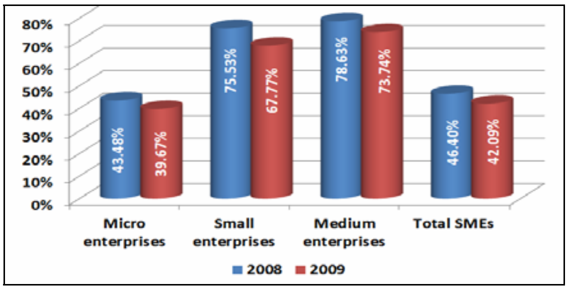
To highlight the economic and financial performance of the SME sector in Romania, we especially consider turnover, labour productivity and financial results.

	Turnover (million RON)		Share of total turnover (%)	
	2008	2009	2008	2009
Micro	167430	173980	28.58	33.49
Small	200230	170070	34.17	32.73
Medium	218250	175530	37.25	33.78
Total SMEs	585910	519580	100	100

Source: [processed data based on 9, 10]
Table 2. The distribution of turnover depending on the size of the firm

On the basis of data in table 2, we can notice the decrease in turnover for all categories of SMEs, except for micro, in 2009 compared to 2008. SMEs across the sector, the data of table 3 show that turnover decreased by 11.32%, while the decrease was 15% for small firms and 19.57% for medium-sized companies. Amid these developments due to the manifestation of the economic crisis is found, in the year 2009 compared to 2008, a distribution of turnover relatively balanced across the three types of firms.

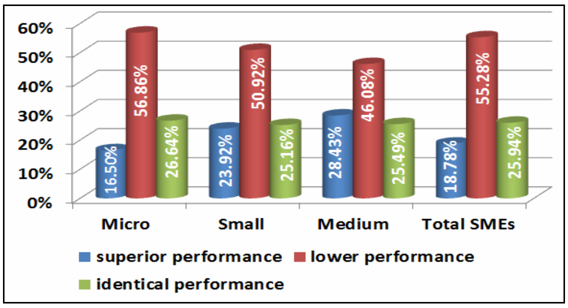
One of the most conclusive indicators to express the efficiency and profitability of SMEs is the level of labour productivity or the productivity per employee, determined as the ratio between turnover and the number of employees. We can notice that labour productivity increased for all categories of SMEs, but the highest productivity was registered for medium-sized enterprises, about 10,32% higher in 2008 than the average of all SMEs [9, 10].
On the whole SMEs sector in the year 2009, the labour productivity per employee was stood at 202,650 RON to 198,125 RON in 2008, representing an increase of only 2.28% [9, 10].
Labour productivity per employee has increased for all categories of SMEs, but the highest productivity was recorded in the medium-sized enterprises, which in 2008 was by 10.32% over the average of SMEs sector. Depending on company size is noted a decrease in labour productivity per employee indicator in the small and medium companies, with 1.02% and 4.73% respectively. For micro, the indicator increased by 15.57%, mainly due to increased turnover, as mentioned above.



Source: [9, p. 310]
Fig. 5. Evolution of profitable share of companies in 2008-2009

Economic and financial performance of the SME sector can be accessed on the basis of the net financial results, which reflect a deterioration of its situation as the current crisis started to be felt in Romania, since the last quarter of 2008. Thus, we can notice, on one hand, the decrease in the share of firms with positive net financial results from about 46.4% in 2008 to 42.09% in 2009.

Considering the firm's size, we can see that within medium and small enterprises the share of profitable companies is significantly higher (73,74% and 67,77% respectively) than within micro enterprises, which have been below the psychological threshold of 40% (see figure 5). Overall, damage also business means developments in Romania under the impact of current global crisis.
If we analyze the overall performance of the SMEs sector in 2010 compared to 2009, it appears that the results achieved were higher in only 18.78% of companies while 55.28% of the company's results were lower. Depending on company size (see figure 6), it is worth noting that the share of firms with superior results increases with increasing size of firms. Such a situation is explained by the existence of a correlation between firm size and their ability to cope with economic recession period.



Source: [9]
Fig. 6. Dynamic performance of the SMEs sector, on size class, in 2010 compared to 2009

The survey conducted by the European Commission and ECB, between 22 August 2011 and 7 October 2011 [13], for a sample of over 15,000 companies in 38 countries, shows that the availability of skilled staff or experienced managers are among the most important problems faced by European SMEs. Thus, the question - What is currently the most pressing problem is facing your firm? 14% of European SMEs and 5.1% of SMEs in Romania mentioned availability of skilled staff or experienced managers.

6. LIMITS AND CONCLUSIONS

Our study was aimed at highlighting the impact of professional development of human resources on the performance of SMEs, by evoking the experiences and challenges of business environment in Romania, which is mainly based on SMEs.

A major role in creating, supporting, innovation and development of any company rests with the human resource involved: in its capacity as employer or employee. Human resource practices complement pathways by which performance analyzed in terms of knowledge, skills, behaviours and outcomes can be measured in economic and social.

For SMEs, the global financial crisis has posed new obstacles to developing and maintaining on a competitive market. In Romania, the percentage used by SMEs to prepare professional managers and human resource development is very low, leading to poor performance and inability to maintain quality standards of goods and services.

The research is innovative for our country and stand at the exploratory level. Thus, we propose a view to further research and started to highlight particular aspects of human resource development and organizational performance reporting.

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INCREASING THE VALUE OF ERGONOMIC DESIGN OF WORKPLACE IN COMPLIANCE WITH LIMIT COSTS

Broum, T.; Gorner, T.; Kleinova, J. & Simon, M.

Abstract: *In actual market situation, when the supply mainly highly dominate over demand, the companies have to minimize costs and increase quality. Human factor can influence quality significantly. Improvement of working environment is the task of ergonomics. Application of ergonomics can reduce defects, so it can reduce the costs and increase the quality. When company wants to implement the ergonomics there are also financial requirements for implementation. To spend only necessary costs and also reduced costs of ergonomic changes can be used Target Costing methodology. Using of Target Costing in Ergonomic design of workplace is the topic of the article.*
Key words: Target Costing, Ergonomics, Costs, Workplace

1. INTRODUCTION

In order to be able to describe the reason for the application of Target Costing and Ergonomics in workplace design, it is first necessary to define some terms.

Ergonomics is an interdisciplinary scientific discipline system, which comprehensively addresses the human activity and its link with technology and environment, in order to optimize the psychophysical burden and ensuring the development of his personality [13]

Target Costing is a pricing method used by firms. It is defined as "a cost management tool for reducing the overall cost of a product over its entire life-cycle with the help of production, engineering, research and design". A target cost is the maximum amount of cost that can be incurred on a product and with it the firm can still earn the required profit margin from that product at a particular selling price. [9]

2. ERGONOMIC DESIGN OF WORKPLACE

The classical approach of the ergonomic industrial engineer to designing a workplace can be divided into two basic procedures:

- design of a new workplace,
- evaluation of an existing workplace.

Modified procedure of ergonomic design of workplace by value analysis is in table 1. It is based by classic approach that is described in literature [10].

When evaluating an existing workplace, the ergonomist is limited by many factors:

- technical characteristics of the production system,
- environment,
- technology,
- material flow - arrangement of the layout of production,
- financial resources and so on.

If the arrangement of production and individual links between workplace are not respected, this can lead to errors. A localized modification to the design of a workplace may only shift the problem to another site. It is therefore necessary to understand the whole system as a process with inputs and outputs.

Phase	The job plan of ergonomic design	
Preparatory	1	Identify specification ergonomic task
	2	Determination of the desired ergonomic data
	3	Identify the population group
	4	Analysis of the work task
	5	Provide the required documentation
Value	6	Determine the answers to 5 questions
Project	7	Select evaluation method
	8	Evaluate the project
	9	Review the results of the analysis
Test	10	Evaluate the project with the worker
	11	Evaluate the project with the worker - changes
Final	12	Establish training requirements
	13	Realization
	14	Summary and conclusions

Table 1. New job plan of ergonomic design [15]

3. TARGET COSTING

Target Costing is originally from Japan, it was introduced in the 1960's. The method is based on the fact that product cannot be sold with a higher price than the acceptable price for the customer. Therefore the target cost must be determined to achieve the target profit while the price is still at an acceptable level for the customer. Target costs cannot be exceeded. After we have the target cost, we can divide the product into functions that the product has. Then costs of the functions are compared to their benefits. The aim is to reduce the costs of functions with small benefits compared to their costs.

Steps of Target Costing

Target Costing can be described in the next steps [12]:

1. Definition of product and making of a rough proposal of the product.
2. Determination of target price and target costs that are resulting from target price. It is necessary to do it with respect to results of market research, analysis of competition and customer needs.
3. Finding of product functions and allocation of the target costs to individual functions. The allocation is based on identified requirements of customers.
4. Decomposition of costs related to each function to the product components and control of components in terms of costs compliance.
5. Achieving of target costs with simultaneous engineering tools, Kaizen, etc.

4. PROPOSED METHODOLOGY

This is a modified Target Costing methodology with a focus on ergonomic design of workplaces. In proposed methodology target costs represent the costs limit of ergonomic workplace adjustments. The limit is determined by management of enterprise. Compared to classic Target Costing methodology the proposed one has a difference in the conception of the product. The product is a workplace in proposed methodology. Assembly groups of product are replaced by individual ergonomic workplace adjustments.

The proposed methodology is focused on steps or their parts of Target Costing methodology from step two to step five.

Steps of proposed methodology:

The proposed methodology consists of steps:

1. Decomposition of total ergonomic workplace adjustment to individual

ergonomic adjustments and allocation of the costs to individual ergonomic adjustments. If there is only one implementation of one ergonomic adjustment, then the adjustment can be divided into several main parts and then assign the costs to these parts.

2. Determining the benefits of ergonomic adjustments and determine their contribution to the total benefit for the enterprise.
3. Determining of the percentage of contribution of each ergonomic adjustment to meet the required benefits of ergonomic adjustments.
4. Determination of total benefit for the enterprise in accordance to ergonomic adjustments.
5. Determination of target costs index.
6. Comparison of actual costs of ergonomic adjustments to target costs determined by the benefits for the enterprise.

5. EXAMPLE OF CALCULATION

1. Decomposition of total ergonomic workplace adjustment to individual ergonomic adjustments and allocation of the costs to individual ergonomic adjustments.

Decomposition can be mainly done by ergonomist. The cost part is result of qualified estimate by ergonomist with the help of economist.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	PERCENTAGE OF TOTAL COSTS
E1	45%
E2	15%
E3	22%
E4	18%

Table 2. Example – Step 1

2. Determining the benefits of ergonomic adjustments and determine their contribution to the total benefit for the enterprise.

Determining can be done for example by staff survey of the workplace, by ergonomists or by requirements of certification. Assignment of contribution significance is done by method of sequence or method of pairs. Description of these methods can be found for example in the literature [7].

BENEFITS OF ERGONOMIC ADJUSTMENTS	PERCENTAGE OF TOTAL BENEFIT
U1	20%
U2	15%
U3	25%
U4	30%
U5	10%

Table 3. Example – Step 2

3. Determining of the percentage of contribution of each ergonomic adjustment to meet the required benefits of ergonomic adjustments.

The determination is performed by group of experts. Members of the group assign percentage of ergonomic adjustment to individual benefits. Results are averaged that the sum of percentage is 100 for individual benefits.

	U1	U2	U3	U4	U5
E1	30%	60%	30%	30%	45%
E2	13%	-	20%	-	25%
E3	30%	40%	10%	40%	14%
E4	27%	-	40%	30%	16%
SUM	100%	100%	100%	100%	100%

Table 4. Example – Step 3

4. Determination of total benefit for the enterprise in accordance to ergonomic adjustments.

Now the total benefit for the enterprise in accordance to ergonomic adjustments is determined. It is based on next formulas:

The benefit of ergonomic adjustments = sum (percentage of ergonomic adjustments to the required benefits x scale)
Scale = coefficient of partial benefit to the total benefit

	U1	U2	U3	U4	U5	∑
E1	6 %	9 %	7,5 %	9 %	4,5 %	36 %
E2	2,6 %	-	5 %	-	2,5 %	10,1 %
E3	6 %	6 %	2,5 %	12 %	1,4 %	27,9 %
E4	5,4 %	-	10 %	9 %	1,6 %	26 %
∑	20 %	15 %	25 %	30 %	10,0 %	100 %

Table 5. Example – Step 4

5. Determination of target costs index.

The target costs index is determined in this step. The index is calculated by formula below.

index = benefit of ergonomic adjustment / percentage of total costs

Table of this step of example is divided into three parts.

The benefits in table 6 is result of table 5.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	BENEFIT OF ERGONOMIC ADJUSTMENT
E1	36%
E2	10,1%
E3	27,9%
E4	26%
SUM	100%

Table 6. Example – Step 5- part1

The percentage of total costs in table 7 is based by table 2.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	PERCENTAGE OF TOTAL COSTS
E1	45%
E2	15%
E3	22%
E4	18%
SUM	100%

Table 7. Example – Step 5- part2

In table 8 the index is calculated.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	TARGET COSTS INDEX
E1	0,8
E2	0,67
E3	1,27
E4	1,44
SUM	-

Table 8. Example – Step 5- part3

If the index value is below one it means that costs are higher that benefit for enterprise. If the index value is above one it means that costs are lower that benefit for enterprise, then costs are justifiable.

6. Comparison of actual costs of ergonomic adjustments to target costs determined by the benefits for the enterprise.

The target costs are determined in this last step. Also deviations from target costs to the actual calculated costs are determined. Target costs are determined by benefits for the enterprise.

Table of this step of example is divided into four parts.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	ACTUAL COSTS (EUR)
E1	7650
E2	2550
E3	3740
E4	3060
SUM	17 000

Table 9. Example – Step 6- part1

The benefits in table 10 is result of table 5.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	BENEFIT OF ERGONOMIC ADJUSTMENT
E1	36%
E2	10,1%
E3	27,9%
E4	26%
SUM	100%

Table 10. Example – Step 6- part2

Target costs in table 11 are calculated by the percentage of benefit of ergonomic adjustment with the total costs = 16 000 EUR. It is suggestion of cost reduction from the total calculated costs = 17 000 EUR that are in table 9.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	TARGET COSTS (EUR)
E1	5760
E2	1616
E3	4464
E4	4160
SUM	16 000

Table 11. Example – Step 6- part3

The deviations are calculated in table 12.

INDIVIDUAL ERGONOMIC ADJUSTMENTS	COVER/ UNCOVER
E1	- 1890
E2	- 934
E3	+724
E4	+1100
SUM	- 1000

Table 12. Example – Step 6- part4

Then it is necessary to focus on individual ergonomic adjustments and reduce their costs according to table 12.

It is necessary to focus on ergonomic adjustments that have in the field cover/ uncover negative values and reduce their costs.

6. CONCLUSION

The main benefit of new approach is reducing costs of ergonomic design of workplace. Then the ergonomic design of workplace will be more affordable for company. Application of ergonomics can reduce defects, so it can reduce the costs and increase the quality. To spend only necessary costs and also reduced costs of ergonomic adjustments can be used Target Costing methodology.

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CORPORATE CULTURE INFLUENCE ON INDUSTRIAL ENTERPRISE PERFORMANCE

Cambal, M.; Caganova, D. & Sujanova, J.

Abstract: *Present environment full of turbulent changes in all fields of social life influenced by globalisation and world economic crisis, creates completely new conditions for activities of industrial enterprises. In order to make enterprises capable to secure their long-term sustainable development, it is necessary to optimize their efficiency significantly. Key factor of enterprise efficiency optimisation in stated setting is the integration of all enterprise systems, processes and sources. To secure the practical application of differently constructed models of industrial enterprise performance management, it is necessary to pay systematic attention to corporate culture. This article deals with identification and description of the key stages within the process of corporate culture optimisation in industrial enterprises.*

Key words: performance, corporate culture, sustainability, competitiveness

1. INTRODUCTION

Present environment full of turbulent changes in all fields of social life (society, economics, people, technologies,…) influenced by globalisation, world economic crisis and natural disasters, creates completely new conditions for activities of industrial enterprises. In order to make the industrial enterprises capable to respond on the stated changes and secure their long-term sustainable development this way, it is necessary to optimize their efficiency significantly.

Within the industrial enterprise praxis, it is possible to notice the growth of applying the differently constructed models of staff performance management. Application of them usually leads to permanent "overloading" of specific staff groups what preferentially endangers health (psychical and physical) and so the efficiency of the staff. Finally, from the long-term point of view, it also endangers the efficiency and competitiveness of given enterprises.

In addition, satisfying solution of this problem is complicated to find also because of the fact that the growing influence of globalization does not refer only to macro-economic environment, but it also influences significantly the in-plant processes. By this reason, it is necessary to regard the multicultural aspects while designing the models of organisation performance management. [1]

Nowadays, the above mentioned reasons are crucial why to pay attention to corporate culture (CC). Thus, corporate culture becomes the key factor of industrial enterprise performance optimization. It is the appropriate CC that enables human resources to activate the other resources of an ente*rprise and so optimize their utilization.*

2. PRESENT STATE OF KNOWLEDGE IN THE FIELD OF ORGANISATIONAL PERFORMANCE

2.1 Organisational performance and labour performance

When using and explaining the term "performance" (in connection with human resource management in enterprises, it is regarded as „labour performance“), it is possible to find different approaches by many different authors. However, it is still possible to identify two main directions of understanding. The first approach (classical theory of human resources management) regards labour performance as a result of an individual's activity, team or whole organization; it means labour performance is the amount of work done by a certain time unit. [2] With regards to this kind of understanding the term „performance" connects it with the results of employee's behaviour, meaning that the evaluation of the performance will be focused on the past more than on planning the future. [3]

The second approach (new concept of human resources management) understands the term labour performance in much wider context. It refers to the level of task performance, forming the scope of employment of a certain employee. Therefore, it means not only the amount and quality of work, but also the behaviour, willingness, approach to work, absence and injuries frequency, relationships with people in connection with work and many other characteristics of an individual that are considered as significant within the context of work performance. Labour performance is then a result of connection and mutual relation of its basic elements:

- competencies – knowledge, abilities, skills and attitudes as personal characteristics of a given employee,
- task understanding – it is conditioned mainly by effective bidirectional communication between the manager and employee,
- effort – is a reflection of motivation. [4]

It is necessary to realize that all the above mentioned attributes of labour performance can be significantly influenced by the manager of a given employee:

- competencies by means of selection and following development of employees,
- understanding the task by means of applied management and communication style,
- effort by means of motivating the employees.

When defining the term „labour performance", we come out of the premise that it is a more general and long-term expression of labour performance referring to a certain employee. [5]

2.2 Organisational performance management

The term "organizational performance management" is understood as constant, continual process of identification, measuring and development of individual performance of the staff in accordance with strategic goals of organization.[6] To reach the required organizational performance, many different performance management models have been created recently. In spite of the fact that it is possible to identify different approaches, all of these models contain one clear element and that is the individual employee, employee with his abilities, skills, knowledge, attitudes, inner motivation, effort to work and willingness to deliver certain performance and reach certain level of performance.

Following the aforesaid, it is obvious that if an industrial enterprise wants to reach the required level of its performance from the long-term point of view through the performance of its employees, it also needs to deal with the quality of labour conditions, attractiveness of labour standards, level of labour climate etc., it means individual attributes of CC.

3. REASEARCH FOCUSED ON THE FIELD OF ENTERPRISE PERFORMANCE MANAGEMENT

In the period from 2010 – 2011 was carried out the research by the Institute of Industrial Engineering, Management and Quality at the Faculty of Materials Science and Technology in Bratislava with seat in Trnava. The aim of this research was to analyse contemporary state of management performance practical application in conditions of the Slovak industrial enterprises. The research was carried out on the sample of 300 industrial enterprises of different size (14% small, 79% medium and 7% large enterprises), which are active in the territory of the Slovak Republic.

Following the results evaluation, this key knowledge was identified in the field of real application of performance management in the conditions of industrial enterprises:

1. majority of industrial enterprises (86%) of respondents think that performance management has a positive impact on the performance of enterprises;

- 58% of respondents think that performance management enables staff to understand the strategic goals of enterprise;
- 69% of respondents think that performance management improves the abilities of line managers to manage people effectively;
- 74% of respondents think that performance management helps individuals to improve their abilities and enables them to develop their careers;
- 79% of respondents think that performance management has a positive impact on the individual performance of an employee.
- 50% of respondents think that it has a positive influence on wellbeing of staff while fulfilling their tasks.

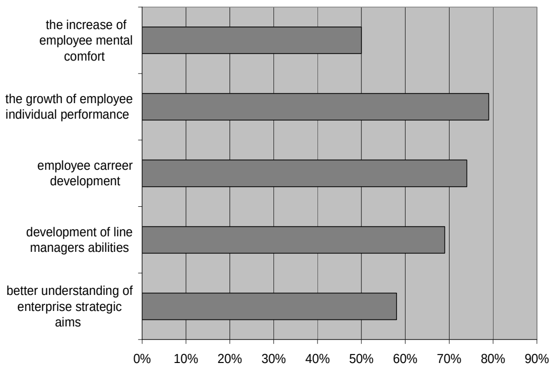

Fig. 1. Influence of performance management on enterprise particular areas

2. 62% of respondents stated that the enterprise they work for carries out staff performance management. However, only 23% of them chose (from given answers) those activities that really belong to the process (e.g. 29% respondents consider only evaluation interviews as employee performance management).

3. only 43% of enterprises have established a „functioning“ model of performance management (mainly large companies, with majority of foreign capital).

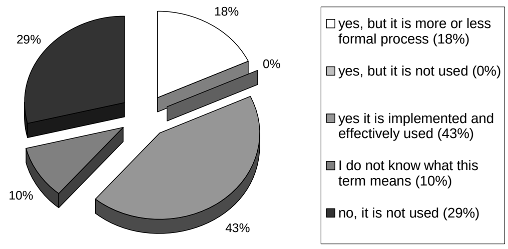

Fig. 2. Enterprise performance management model utilisation

Following the interpretation of the mentioned (and further) data gained from the research, it is possible to state that:

- ✓ enterprise performance management presents significant presumption of its long-term sustainable development and competitiveness,
- ✓ in spite of this fact, enterprise performance management in conditions of the Slovak Republic is not realized systematically (industrial enterprises know and partially carry out the activities belonging to the performance management process, but on the other hand, they do not utilize them as complex and the ties between them are not realized explicitly),
- ✓ when individual enterprises manage their performance, performance management is often applied in a wrong way, mainly in the field of creating the conditions for systematic formation of human potential, supporting his positive relation and loyalty to enterprise and motivation to reach high performance.

For reasons given, it is obvious that the key presumption of effective application of industrial enterprises performance management nowadays is optimisation of their CC focused on reaching high performance of their employees.

4. PROPOSAL OF SYSTEMATIC APPROACH TO CC OPTIMISATION

On behalf of reaching the required level of enterprise performance by means of corporate culture optimisation, following key stages of this process were specified:

a) Corporate culture audit
b) Defining the philosophy of corporate culture change
c) Focus of corporate culture change
d) The corporate culture change process itself.

a) Corporate culture audit

First step in the process of corporate culture change is its audit that will enable the knowledge of in-plant situation, opinions, attitudes, values and expectations of employees. When auditing the corporate culture, it is necessary to decide between the internal or external audit.

The internal audit is usually carried out by project team directly subjected to enterprise management. As a source of information is especially used enterprise information and control system. However, from the employees as well as whole enterprise point of view as more suitable is regarded the external audit. It is usually carried out by a team of specialists who are able to utilize in practice many different theories and methods regarding the character of particular situation in enterprise. Information that needs to be gained from employees is often of discreet character. Moreover, external audit will guarantee anonymity of individual responses during the data collecting and after the termination of the research.

b) Defining the philosophy of corporate culture change

Subject matter of a change is a shift from initial state to the final one. In case of corporate culture change, the initial state is the situation when the ideas, approaches and values shared and developed by employees are not in compliance with the ideas, approaches and values presented by management of the enterprise in the interest of reaching the required performance. If corporate culture audit identifies (or more precisely confirms) such a state, it is necessary to define essential heading (or philosophy) of the considered change. Philosophy of corporate culture change should unambiguously come out of the defined vision, mission and "key messages" of corporate strategy.

c) Focus of corporate culture change

Direction of CC change is, to a high extent, dependent on individual circumstances, character of conventional culture and other effecting factors. In spite of that it is possible to identify elementary focuses of change in industrial enterprises: on customer, innovations, team work etc. [7] Nowadays the focus of change is on reaching the required performance of enterprises.

d) The corporate culture change process itself

The process itself of shift from the initial state to the final state of corporate culture change should consist of following stages:

- ***Defrosting of conventional corporate culture***

It involves doubting of shared but at the same time unwanted ideas, approaches and values.

- ***Sorting of interests and attitudes***

It is mainly realization of those connections, ties, chances, risks and forces which are on the side of change and those which are against it.

- ***Influencing***

It is targeted influence on conventional culture to dismantle everything what is not wanted and preserve and strengthen everything what is necessary and suitable for further building.

- ***Harmonization***

It is searching for the maximum possible number of integrating elements in the features of strategically necessary CC.

- ***Development***

It is monitoring of the harmonic state between approaches and values declared by people and those that are required for further prosperity of enterprise.

5. CONCLUSION

In present conditions of turbulent market, the competitive advantage of enterprises is based mainly on full utilization of knowledge, abilities and skills of their employees. Through them, it is possible to utilize effectively all other resources of enterprise and by that reach the required goal – long-term sustainable performance and competitiveness of enterprises. This goal is not possible to reach effectively without the fundamental change in the field of CC approach, because it is the culture of each enterprise that can be either resource of its strength and carrier of its competitive advantage or it can become a brake for development of enterprise, or even the source of its destruction.

Enterprises have now understood that performance management is the key presumption of sustaining their competitiveness. However, if enterprise performance management is about to bring the expected contribution, its application in the conditions of real practice needs to be realized as complex and system.

From the point of view of further research, the mentioned problem is significantly dynamic. In near future, it will be necessary to solve the field of enterprise performance management also from the view of multicultural aspects, because the growing influence of globalization does not refer only to macroeconomic environment, but it significantly influences the processes within each enterprise and so their performance, too.

This paper has been solved within the project "The Identification of Sustainable Performance Key Parameters in Industrial Enterprises within Multicultural Environment" (VEGA 1/0787/12) and "HCS Model Concept 3E vs. Corporate Social Responsibility Concept" (APVV LPP-0384-09)

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RISKS IN PLM – PLANNING

Čechová, L.; Horejc, J.

Abstract: *This paper deals with risk that can occur during planning of the technical system, i.e. the first phase of the product life cycle. Article also contains division of this phase into individual steps, description of all these steps and assignment risks to each step.*

Key words: Risk, risk management, PLM, planning.

1. INTRODUCTION

Risk management is an important activity of every progressive thinking organization. Risk management during product life cycle enables in–time prediction of risks that can occur during each phase. The company can decide on basis of this prediction, either run the risk and continue in the PLM or stop it, because the risk is too high. Risk management allows further reductions of risk`s likelihood and its impact in individual phases.

2. Risks

The concept of risk is always connected with uncertainty in not meeting the objectives. If it is possible to define the likelihood of not meeting the objectives and its impact, than it is risk.
There is no united definition of risk in available literature.
For example Czech standard CSN 31000 defines risk as an effect of uncertainty on objectives.
There are generally two types of risk:

• threat – risk having only negative effect,
• opportunity – risk having both negative and positive effect.

3 Product lifecycle

Each product has limited life time. During this time it passes through several phases. Sequence of theses phases makes up the product lifecycle – PLM.
The lifecycle can be seen from several points of view such as marketing view, in terms of execution, in terms of impact on the environment and others. In terms of risk management the most considered is the view in terms of transformation processes. For this reason the following model used by prof. Hosnedl is applied in my work.
This model is also suitable for usage, because it defines five operators that influence all phases of PLM. These operators are: human system, technical system, environment, information system, management system.
These operators can be considered as resources of risk causes.

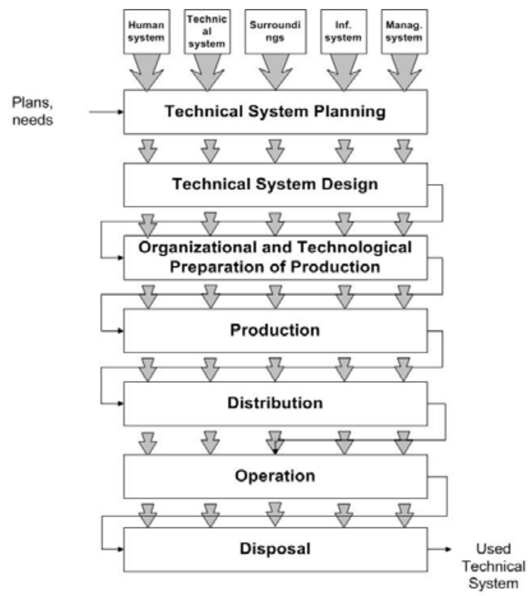

Fig. 1. Product Lifecycle

4. Risk Management in Planning

Concept of the product is formed during pre-production stages (especially planning). Therefore it is necessary to pay sufficient attention to this phase - create and collect as many documents and find as many risks for deciding about this concept. Approximately 10 to 20% of total number of risks occur during pre-production stages covering 80 - 90% of potential impacts.

4.1 Planning

As shown in the PLM, model planning is the first phase of product lifecycle.
The starting point for planning is the vision of the company that reflects the mission of the company. An analysis of the company has to be made based on this vision – its strengths and weaknesses, and analysis of company's environment – opportunities and threats.
After this analysis complex strategy should be created. This strategy consists of several sub–strategies for example business and technical or manufacturing strategy.
Based on these sub–strategies product planning can begin.

4.2. Technical System Planning

Technical system planning must be based on business, technical and economical inputs resulting from the company's strategy.
First step of technical system planning is the definition of the product. In this step basic parameters, basic functions, target markets, customers, competitors and possible barriers of the product should be established.
Next step is to specify the financial assignment. This step includes: estimation of sales of the product and their volume, investments needed for product developing and manufacturing, determining of maximum total costs, maximum production costs, price estimation, total revenues assumption and creation of cost management plans.
Technical system planning should also include time specification. In time specification should be defined: prediction of total time needed, forecasts of time product will be set on market, setting of intermediate milestones and schedule of the management plan.
In addition to financial and time specifications planning has to include staffing assignments. In this step project manager, number of team members and structure of the team should be determined.
After the definition of the product, financial, personnel and time specification is necessary to approve the concept to the leadership of the company.
After approval of the concept a team should be created and PLM can continue in other pre-production stages – design and technical and organizational preparation of production.

4.3 Risks in Planning

For identification of all risks in planning it is useful to proceed in individual steps of planning mentioned above and causes that are based on operators from chosen product lifecycle.
After the modification of these operators there are 8 groups of causes of risks:

- causes of risks due to inputs,
- causes of risks due to transformation processes,
- causes of risks due to human system,
- causes of risks due to material- technical system,
- causes of risks due to information system,
- causes of risks due to management system,
- causes of risks due to feedbacks,
- causes of risks due to outputs.

First group of risks causes are causes due to inputs. These are financial, human, material, energy and information inputs. This group can be divided into:

- causes of risks due to prime inputs,
- causes of risks due to supportive inputs,
- causes of risks due to undesirable inputs.

Further group of causes of risks is transformation process. Transformation processes can be divided into major,

supportive and undesirables. Subgroups are thus:
• causes of risks due to prime transformation process,
• causes of risks due to supportive transformation process,
• causes of risks due to undesirable transformation process.

Risks rising from human system can occur as a result of the decision of a human not to accept the technical system. It can be on basis of human's inner values, of threat human's health or claims to the senses of man. Subgroups of causes due to human system are:
• causes of risk due to general and specific human values,
• causes of risk due to threat to human's health (safety, hygiene and ergonomics),
• causes of risks due to human senses and perception (hearing, smell, touch, taste, knowledge ...),
• causes of risks due to human behavior and decision making.

Risks relating to the material-technical system may occur from the technical suitability of the available technology or technical means, working environment and labor means. Subgroups of risks causes are thus:
• causes of risks due to technology,
• causes of risks due to technical means,
• causes of risks due to working environment,
• causes of risks due to material item.

Another area of risk is information system. Risks due to technical information, trade and economic, regulatory and informal information occur here. Subgroups of causes risks are thus:
• causes of risk due to technical information,
• causes of risk due to commercial and economic information,
• causes of risks due to regulations,
• causes of risks due to informal information.

Risks are present also in the management system. The causes of the risk in management system can be broken down into:
• causes of risk due to general environment,
• causes of risk due to field environment,
• causes of the risk due to management system (planning system, management...),
• causes of risk due to behavior and influence from management decisions
• causes of risks due to company's general values.

Risks may occur on the basis of poor feedbacks. They are:
• causes of risks due to prime feedbacks,
• causes of risks due to secondary feedbacks.

The last group of causes of risk is outputs. They are financial, human, material, energy and information outputs. Subgroups are:
• causes of risks due to the main outputs,
• causes of risks due to supportive outputs,
• causes of risks due to undesirable outputs.

By linking these two areas (individual steps in planning phase and causes of risk) arises map of all risks that may occur during the planning.

4.4. Risks in the individual steps of planning

Some causes of risks may occur during all phases of product life cycle, some are specific for individual phase.

Causes of risks that may occur during all phases of product life cycle are shown below.

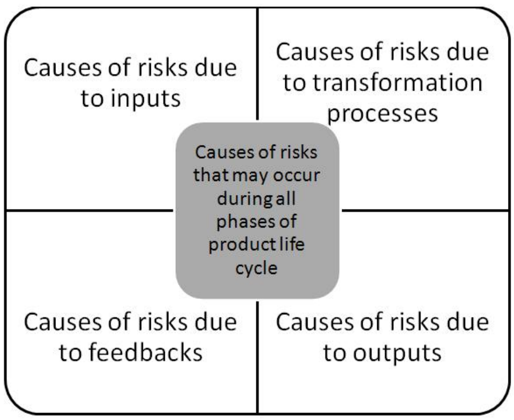

Fig. 2. Causes of risks that can occur during all phases of product life cycle

It is always all subgroups of causes of risks mentioned above.
Causes of risks that are specific for individual phases are described below.
Largest number of causes of risks can occur during planning. That is because during planning has to be all threats considered. In additional to the causes of risks that can occur during all phases of product life cycle are that some causes of risks due to human system, material – technical system, information system and management system.

Fig. 3. Causes of risks in definition of the product

Next step of planning is financial specification. Here can occur, besides causes of risks that can occur during all phases, some specific subgroups of causes of risks due human system, information system and management system. These specific causes are described in picture below.

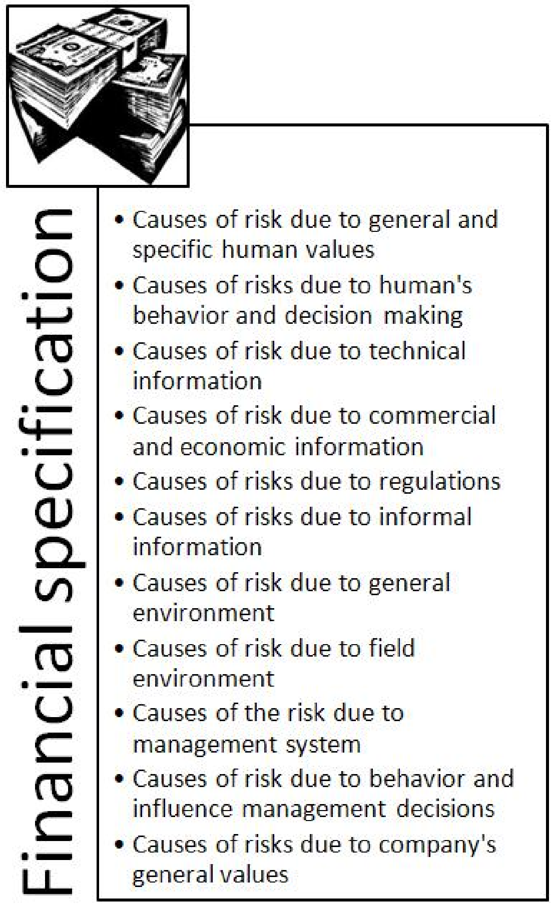

Fig. 4. Causes of risks in financial specification

Third step of planning is time specification. Moreover can during this step occur some causes of risks due to human system, information system and management system. Specific causes are shown in picture below.

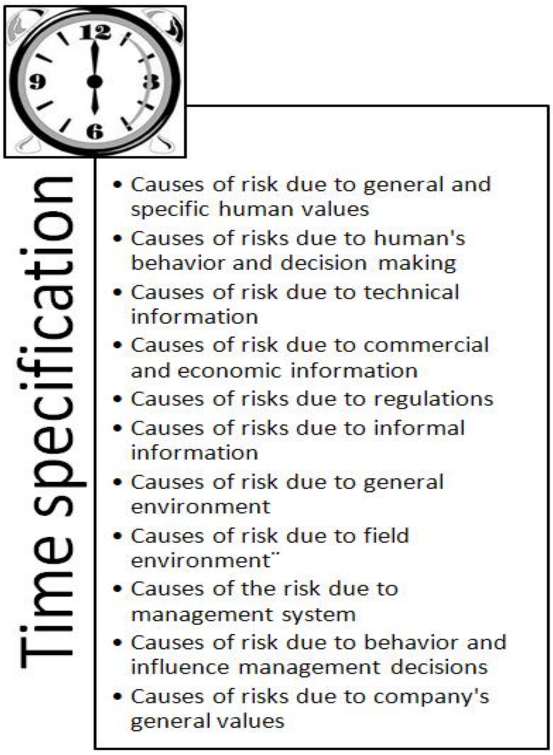

Fig. 5. Causes of risks in time specification

Following step of planning is specification of stuffing assignments. Here can further occur some of causes of risks due to human system, information system and management system. Specific causes are shown in picture below.

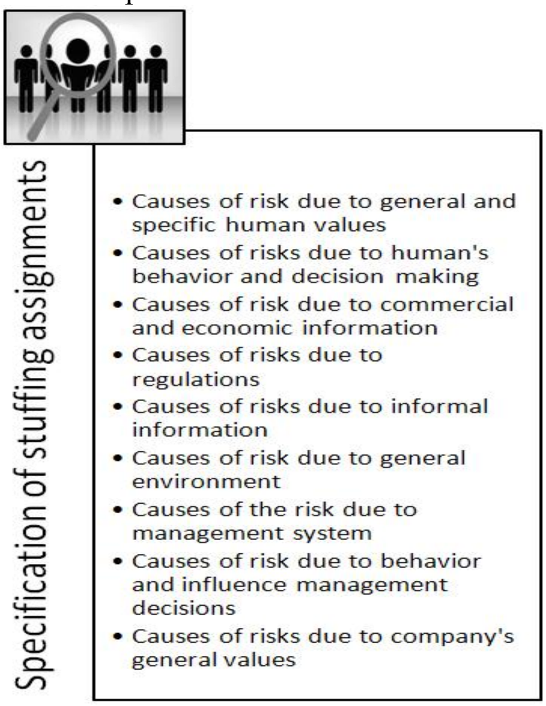

Fig. 6. Causes of risks in specification of stuffing assignments

Second-to-last step of planning is approval of the concept. Specific causes of risks are shown in following picture.

Fig. 6. Causes of risks in approval of the concept

Final step of planning is creation of a team. In this step can occur only 6 causes of risks. These are described in the picture.

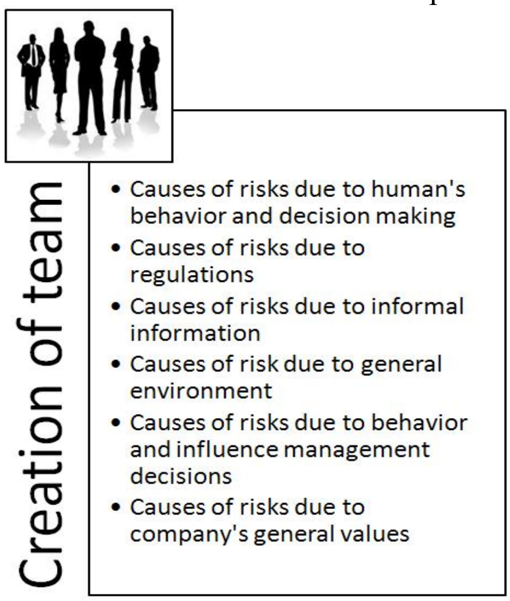

Fig. 7. Causes of risks in creation of team

5.Conclusion

Assigning individual causes of risks to each step of planning, i.e. the first phase of product life cycle, arises a integrated system. This integrated system helps to identify all risks that might occur during individual steps of technical system planning. This process is systematic therefore prevent forgetting some risks better.

If it were possible to assign to each cause of risk its likelihood and size of its impact, it would possible to determine risk of each step. The risk is determined by multiplying these two indicators. The risk throughout the planning phase is simple sum of risks of individual steps.

This indicator can help companies to decide, either run the risk and continue life cycle of the product, or stop it, because the risk is too high.

Comparing this index in more variants of the same project also allows deciding which variant is less dangerous for the company.

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THE PROBLEM OF OPTIMAL PARTNERS SELECTION IN DISTRIBUTED MANUFACTURING SYSTEMS

Cigánik, M.; Úradníček, J. & Valčuha, Š.

Abstract: *This paper describes the issues of searching and selection of partners in distributed manufacturing systems (DMS). For solving of this problem the multi-criteria optimization algorithm using Monte Carlo method is proposed. The development of the multi-criteria optimization algorithm (MOA) to support the configuration of DMS in the virtual breeding environment (VBE) is described specifically. The proposed model deals with the minimization of fixed and variable costs and compliance of the due date.*

Key words: Distributed Manufacturing System (DMS), Multi-criteria Optimization Algorithm (MOA), Virtual Breeding Environment (VBE), Monte Carlo

1. INTRODUCTION

In the age of globalization and the continued development of information and communication technologies (ICT), manufacturing is entering a new era in which the time-to-market significantly reduced in addition to continuous changes in products and customer orientation. This era is characterized by continuous changes in products and customer orientation whereas time-to-market is greatly reduced.
If manufacturers want to keep up with competitive environment they are forced to develop more complex and agile products in shortest possible time and for lowest possible costs.
However, for most of them, these requirements are too difficult to fulfil within their own capacity, know-how, and financial resources.
It is clear that development and manufacturing of products includes increasing number of manufacturers, suppliers, subcontractors, distributors or customers which implies increasing need for establishing joint partnerships. Dispersion of production functions, the development of information and communication technologies and customer orientation have become one of the main factors that contributed to the emergence of new organizational structures, such as virtual organization (VO) / Distributed Manufacturing System (DMS), which have over traditional organizations several advantages as a flexible structure and rapid response to market changes.
It is obvious that choosing the right partners is essential for the successful establishment and operation effectiveness of DMS. Selection of partners in DMS is currently constantly studied in various scientific papers. This paper deals with the problem of search the partners in the Virtual Breeding Environment (VBE) and their selection to the DMS. In particular, the selection of partners to support the DMS using the multi-objective optimization methods based on Monte Carlo algorithm is studied.
The rest of the paper is organized as follows. The second chapter presents an overview of the current state of the art of searching and selecting partners on inter-corporate level. The third chapter describes the methodology for the selection of partners in the DMS, limiting conditions and the definition of optimization methods to support the selection of partners. Also in this chapter an illustrative example is

presented to show the application of the proposed algorithm. The last chapter presents the achievements and areas for further research.

2. BACKGROUND

Despite the literature and Internet sources offer several types of alternative terminology, the term of distributed manufacturing systems is widely accepted not only in industry but also in academia sphere. Represents a grouping of geographically distant and systemically integrated companies involved in the creation of a common product. The basic difference between classical and DMS business is in a distributed deployment of participants and information processing. The present author defines distributed manufacturing systems (virtual organizations) as follows:

„Virtual Organization (DMS) is a temporary association of companies that are formed in order to exploit changing market opportunities. In virtual organizations, individual companies can share costs, expertise and market access, each of which is involved in co-operation in the most efficient manner." (Byrne, J.A., Brandt, R. & Port, O., 1993, p. 36) [1]

All definitions DMS / VO can be found in the literature [2].

Based on the available definitions it is possible to identify a set of common characteristics of DMS:

- The aim of DMS is utilize business opportunities, to increase competitiveness and profit making.
- It is a temporary consortium - resulting in a relationship between the control company and its partner companies.
- Companies use information and communication technologies (ICT).
- They are variously geographically and culturally distributed.
- There is a management company - usually the one that saw a business opportunity, providing search, selection and management of partner companies.
- Structure and partners of DMS are product-oriented.
- Interested companies should be presented to a third party as a unified organization.
- Grouped enterprises can dynamically change or maintain its stability.
- Each of the participating companies are involved in co-operation in the most efficient way.

On the basis of shared characteristics the new DMS definition can be created as follows:

"Distributed manufacturing system can be characterized as a temporary linked businesses, institutions or individuals, culturally diverse to each other, geographically distributed and interconnected through information and communication technologies in order to exploit business opportunities. The managing company provides searching, selecting and managing of partner companies which are involved in co-operation in the most efficient manner."

DMS members cooperate and jointly take advantage of business opportunities that, given its market position have not been able to achieve.

Successfully meeting the needs of customers requires effective cooperation and coordination between partners. Businesses should be prepared to work at the moment of finding a business opportunity. The underlying assumption of preparedness is a long term cooperation "participation" in the joint associations of undertakings, also referred to as a virtual breeding environment (VBE). According to (Afsarmanesh, Camarinha-Matos, [3]), VBE can be characterized as:

"Association of organizations and their supporting institutions that have adopted an agreement on long-term cooperation, adopt a common operating principles and infrastructures in order to increase their potential and readiness for cooperation."

VBE is an open but controlled limited association of undertakings. Its main objective is to improve the readiness of member companies to join the DMS. In addition, VBE can include other types of organizations such as. (research institutes, universities, associations, development centres, state-sponsored organizations, etc.,).

2.1 Related work

Based on the literature review, it was observed that until 2002 there was not clear criteria for selecting partners to DMS consortium and also was not fully understood the whole process of DMS design. As regards the process of forming DMS, Carvalho et al.(2003) proposes dividing the process of DMS design in four activities: specification and analysis of business opportunities, partner search, selection of partners and generate work breakdown in DMS. With regard to selection criteria, this work also does not constitute a significant improvement. In this case, DMS designer uses information obtained by the broker to select the organizations which better meet the demands of CO. Camarinha-Matos et al. (2005b) presented a much more detailed process of DMS design, which identified seven different activities: identification and characterization of CO, DMS rough plan, search and selection of partners, negotiation, detailed planning of DMS, contracts and run the DMS [4].

When selecting partners in DMS for the business opportunity, there are many factors to be taken into account. These factors include price, quality, trust, product delivery time, reliability, and more. However, key factors that need to be addressed include cost and time. As pointed out by Jagdev and Browne [5], high quality products is necessary but not sufficient condition for market entry, which implies that the cost and time-to-market can be considered as a basis of competitive advantage. In a study of Brucker et al. [6], the issue of partner selection is part of the planning project. In the study of Wang et al. [7] the cost and time of completion of the subproject are taken into account and genetic algorithm is used for problem solution.

In DMS, partners are diverse cultures and are geographically distributed, therefore besides the cost and time required for performing the manufacturing tasks, transportation costs and times can't be ignored. These costs and time are so important that it cannot be ignored. With the transportation cost and time considered, the partner selection problem is much more complicated. Taking the processing cost and the transportation cost into account, Wu et al. [8] modelled the partner selection problem by a network model and an efficient algorithm was presented to solve it. However, in that model, the time factor is neglected.

In order to minimize transportation and subprojects costs Wu et al. [8] proposed an integer programming method for solution of network partner selection. Ip et al. [9] studied the problem of partner selection and proposed integer based program. This model is similar to the model of project planning with due dates and to find optimal solutions the B&B algorithm is used. Addressing the selection of partners this is not easy task due to the inherent complexity of the problem such as imposed restrictions, discrete decisions, different cost structures and risk factors. The complexity of the problem has been described by many researchers to develop various heuristic algorithms, which are for example taboo search algorithm [10], genetic algorithm [11], B&B algorithm [12] and exchange procedure [13] to find the nearest optimal solution for different variants of the problem of partner selection. The number of researchers are addressing the problem of selection of partners used quantitative analytical methods [14, 15], but quantitative analytical methods are still a challenge. In the case of DMS mathematical formulation and module designs optimization methods of selecting the right partners is very important.

3. EXAMPLE OF PARETO MULTI-OBJECTIVE (MO) OPTIMIZATION OF PARTNER SELECTION PROBLEM

Suppose that the attractive business opportunity has been detected. However, enterprise which detected this business opportunity doesn't have sufficient capacity to ensure the manufacture process, assembly and distribution of the product it decided to build a DMS. During the design process of DMS, managing company divides project into the several subprojects and tries to select optimal partners for each subproject.

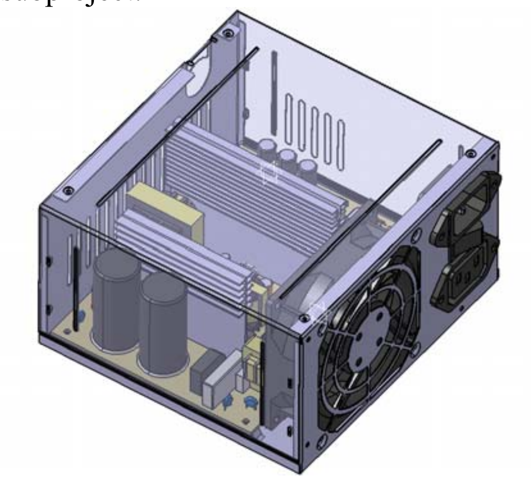

Fig. 1. CAD model of PC power supply unit.

Manufacturing process of the computer power supply (PSU) (Fig.1) is studied in the numerical example. Manufacturing of the PSU includes five operations. Each operation can be performed by one partner. Five partners are considered for each operation in this case. Problem of determining the most efficient cooperation among potential partners is considered. Following criteria are assumed: (a) resulting time of manufacturing process and (b) price of manufacturing process. Since shorter manufacturing process means bigger manufacturing costs and vice versa, these criteria are contradictory. During the optimization process optimal partner consortium and optimal compromise between time and price is calculated.

The objective of MO optimization is to find the set of acceptable solutions to choose among them.

To compare candidate solutions to the MO problems, the concept of Pareto dominance is used. This concept assures that the solutions belonged to the Pareto set is not dominated by any other solution that can improve at least one of the objectives without degradation any other objectives [16].

Problem is solved using "classical" multiobjective optimization method where MO problem is transformed into multiple single objective (SO) problems. SO problem is than solved using Monte Carlo computational algorithm relaying on repeated random sampling of solutions. Each SO solution that represents single variation of consortium arrangement. According to this, best variation is finally chosen.

The objective to select the optimal combination **X** of the partners for all operations to minimise the total cost of the project and the overall time of manufacturing process. The following variables are defined:

$x_i = j$ operation *I* is performed by company *j*, $j \in \{1,2,\dots,m_i\}, \quad i = 1,2,\dots,n$

m_i - number of companies for operation *i*

n – number of operations

$cost_{i,j}$ – cost of operation *i* performed by candidate *j*

$time_{i,j}$ – time of operation *i* performed by candidate *j*

Then, the problem can be describe as the following model:

$$\min_{x} J(X) = \sum_{i=1}^{n} cost_{ix_i} + time_{ix_i} \qquad (1)$$

If functions $f_{ix_i} = f(time_{ix_i})$ are defined for i-th company performing j-th job, then multiobjective optimization problem can be transformed into single objective problem:

$$\min_{x} J(X) = \sum_{i=1}^{n} f_{ix_i} \qquad (2)$$

3.1 Define the model parameters

Number of partners: 25 (5 partners for each operation), number of operations: 5

Design Variables: Time for each manufacturing operation - *To*, Price for each manufacturing operation - *Po*.

MO problem is transformed into SO problem assuming that the *Po* is function of *To*. Linear function *Po*=*f*(To) is defined for each partner. Function *f* has decreasing character where price for operation is decreasing with time for operation. Slope *k* of *f* function is defined for each partner. Five potential partners for each operation are considered. Every partner is constrained to perform only one operation.

Design variable space is constrained by the rule that each *To* value is randomly generated by ±10% deviance of defined average *Toa* value with normal distribution.

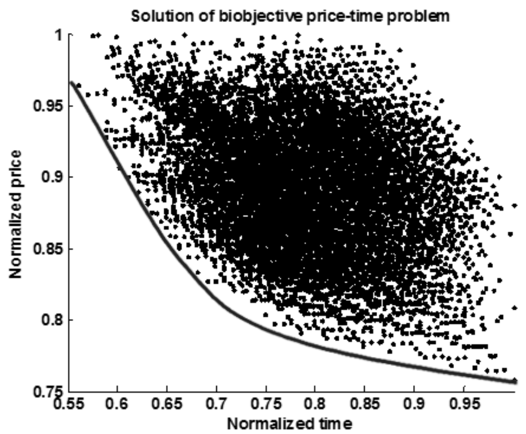

Fig. 2. Illustration of Pareto solution of the bi-objective optimization problem

Fig.2 depicts a Pareto set for a two-objective minimization problem. Potential solutions that optimize *manufacturing price Po* and *manufacturing time To* are shown on the graph. Overall manufacturing time and price are normalized to their maximum values. The red line represents Pareto front of the optimization problem. According this Pareto front, the compromise solution can be chosen. In considered example best compromised solution is obtained for the set of following partners which are responsible for operations:

[4, 5, 2, 5, 2]

Optimal overall time is 292 s -> optimal comprise between time and price.

Maximum time is 462 s -> cheapest and slowest manufacturing process.

Minimum time is 247 s -> most expensive and fastest manufacturing process.

All numerical calculations have been performed in the MATLAB® environment.

4. CONCLUSION

In this paper, multi-objective optimization method for the partner selection in DMS is presented. An illustrative example of partner selection process for manufacturing of computer power supply unit is discussed. Robustness of Monte Carlo Method has shown a effective approach for solution of constrained multi objective problem. Based on the results of optimization process, the optimal variation of the partner consortium, overall manufacturing time and overall manufacturing costs have been selected. During the optimization process the times and costs related to logistics haven't been considered. Given the fact that logistics may largely affect the time and cost of DMS production, it is very important to take it into account in the further research.

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CONTRIBUTIONS TO THE DESIGN AND ANALYSIS OF THE MATERIAL FLOW AT AN INTELLIGENT MANUFACTURING CELL

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Abstract
The Institute of Production Systems and Applied Mechanics has been working in the design, development and improvement of a Flexible Manufacturing Cell within the frame of research and academic purposes. Due to the scope of new projects and the need of turning this cell into a more flexible, autonomous and intelligent one, i.e.: Intelligent Manufacturing Cell, the present paper emerges with the main aim of contributing to the design and analysis of the material flow of such a cell under the new "intelligent" denomination. For this, besides offering a general description on how the material flow should be, some principles to consider in the functioning of the cell, some possible alternative scenarios and the states of the cell are also offered. For a better comprehension, all these elements are supported by a detailed layout, figures and a few expressions which help obtaining necessary data. This data and others will be used in the future when simulating the scenarios in the search of the best material flow configuration.
Key words: *Flexible/Intelligent Manufacturing System/Cell (F/IMS/C), material flow design, layout, reverse and direct flows.*

1. INTRODUCTION

The last decades have witnessed a significant migration from traditional production systems to a more flexible and intelligent manufacturing. These still rather emerging FMS are capable of processing different types of products in an arbitrary sequence with insignificant setup delays between operations, and are mainly distinguished from other types of manufacturing systems by the following characteristics: high degree of functional integration, complex tool management and complex control software. Such systems as well all their most modern fellows, e.g.: Intelligent, Holonic and Agent-Based Manufacturing Systems are relatively expensive and thus and even when it is becoming better over the years, just a few companies can get to their implementation. As for solving these cost matters, a growing tendency to develop and use just smaller versions, e.g. I/FMC, is taking place both with real life production intentions or as research projects helping to evolve the field, [1, 2, 3 and 4].
Conscious of this, the IPSAM consists of a FMC. This cell is composed of several subsystems, i.e. Cartesian robot (CR) and Shelf-storage system (SS), and in a very close future of others like a small robot for the transportation of the parts and finished pieces inside the cell (Robotino), and another one dedicated to the palletization and despalletization (ABB robot). At present this FMC is still subject for further improvements and under a constant changing process towards a more intelligent, evolved and autonomous cell, i.e.: IMC. Changes related to such migration already encompassed most of the design and acquisition of new needed

devices, and are currently being mainly focused in the design, analysis and projection of its material flow, hence from this point on; it will be referred to as the IMC. The reminders of this paper will be organized in section 2: Initial design, description and analysis of the material flow at the IMC, section 3: Some basic principles to consider during the material flow design, section 4: Other possible alternative scenarios, section 5: States of the cell, and section 6: Conclusions and further research issues.

2. INITIAL DESIGN, DESCRIPTION AND ANALYSIS OF THE MATERIAL FLOW AT THE IMC

The future material flow is intended to function as described below, useful analysis and viewpoints related to this section could be found in [5, 6, and 7]. For the sake of comprehension in **Fig. 1** the design of the IMC layout is shown:

The material flow begins at the Palletization area with buffers (PAB), where unsorted part, i.e.: pistons and cylindrical housings wait to be manipulated. An ABB robot inside the area will select and place the right parts in the right position on the pallets as well as the assembled pieces in the boxes during the reverse flow. Such robot is intended to collaborate in a close future with camera so as to make possible these tasks. Such camera will identify the 3 types of cylindrical housings and 2 types of pistons, it will be located in the same PAB consisting on a high quality source of light, so as to unequivocally enable the identification of the colors of such housings, and then select the right one according to need of the batch being produced as commanded by the computer controller; colors of the cylindrical housings are silver, black and red. In a future such camera is also supposed to be making some surface quality control either of the parts or the assembled pieces, as well as to be helping in the selection of specific parts needed for a certain batch, when being these spread and mixed with different ones all over the area. The camera will be effectively located (inclined) so as to visualize the parts in 3 dimensions. **Fig. 2** shows some pictures of the parts intended to be assembled in principle inside the IMC:

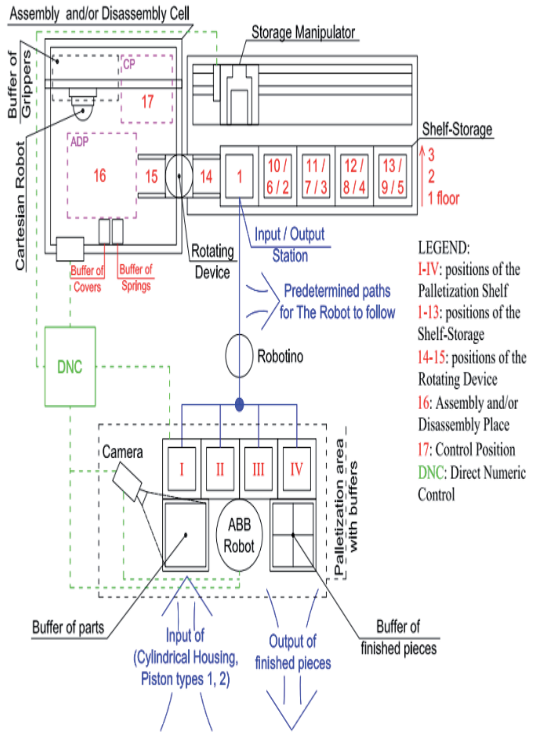

Figure 1. Detailed Layout intended for the IMC.

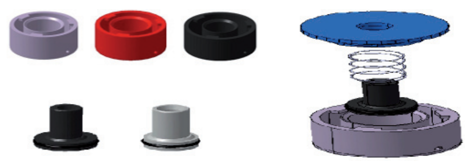

Figure. 2. Parts integrating the piece intended to be flowing through the IMC

The shelf at the PAB where the pallets will be located consists of 4 positions that will be used either for the direct flow of parts or the reverse flow of the pieces. Once the pallets and their parts are ready, each pallet having one and only one part, these are handled by another smallest robot (Robotino), which moves between such PAB and the SS. This second storage area consists of 12 positions and an input/output one (I/O) where in a simple and first approximation, all parts must be placed when coming from the PAB, and pieces or empty pallets when going either from SS to the PAB or directly from the Rotating Device (RD) to the PAB, in case these are not stored in the SS before being transported. The SS is supposed to have in principle 2 available positions so as to avoid any kind of collision, this number could vary in dependence of the operating scenario and once the cell starts running, time standards must be determined so as to more mathematically justify such number of needed empty positions for which it could be useful the use of Simulation.

Parts being placed by Robotino at the I/O can either be moved into SS having to wait, or directly moved by a Manipulator (M) to the RD, for which the M must have stored the previous pallet(s) from the RD into SS first (it could be a pallet with an assembled piece, a piston's pallet or both of them). The selection of one of the 2 previous alternatives, besides having to do with the importance of the order being processed or simply the will of prioritizing the direct flow of parts or the reverse flow of pieces, could be better justified in future work when having the time standards of Robotino and its combination the ABB robot to take parts towards the SS, and the time standards of the M, RD and the assembly process; this and the possible combination of all these time standards at their different operative speeds which are at present unknown, could differentiate other working scenarios.

The RD either takes parts into the Assembly place (AP) or takes the pieces out from it when assembled. Once the parts are in the AP, first the cylindrical housing and then the piston which is also transported by Robotino, different grippers from the 3 existing ones are taken for the realization of the assembly process. The assembly process begins with arrival of the cylindrical housing which is fixed, then the piston is introduced, right after the spring, and finally the cover, the last 2 ones are in buffers located in the same AP. Assembled pieces just like any empty pallet, can either remain in the RD waiting till the incoming part being transported by Robotino from the PAB is stored in the SS, or be directly moved into the SS while the incoming part takes its place in the RD, the course of action decided will lie on the elements explained in the last paragraph. In any of the cases, pieces and empty pallets taken by Robotino when coming back to the PAB are placed in the 4 places shelf, and then pieces are taken by the same ABB robot into the proper boxes as it can be seen in **Fig. 1.**

3. Some basic principles to consider during the material flow design

1. There must be predetermined paths for Robotino to follow between the PAB and the SS (optimized paths), such paths could depend on the decided operating scenario. In principle and in the most simple of the cases, there must be predetermined paths for Robotino between each of the 4 positions of the shelf in the PAB and the I/O
2. The PAB and the SS must be as close as possible
3. The I/O position should be always kept available for any Robotino ingoing movement (RIMj) from PAB
4. It must be a priority not to unnecessarily keep pieces in the SS and that Robotino never comes back empty
5. Manipulations of the M and rotations of the RD should be optimized to a minimum so that less energy and time are used as well as less complexity added to the system
6. Robotino should not wait for a part being still assembled to come back when having stored ready to return pallets in the SS
7. The M should never wait for the a part coming with Robotino to assemble a piece if having available parts in SS

8. The speed of the devices in the cell should tend to the maximum always that the quality keeps being as desired, this would increase the throughput. The combination of all possible operative speeds could yield a hard combinatorial problem that could be better analyzed in further research
9. The material flow must be as simple and linear as possible
10. The computer controller and the pallet identification system software must collaborate so as avoid unnecessary movements and anticipate some actions, e.g.: a. Robotino should not load a piece and take it towards the I/O when there will be a collision and it would have to take it back, b. every time Robotino is coming back from the I/O at least 1 position must be available, why to place a pallet and mount a part if it would create a collision and would have to be removed back from the shelf. Elements of intelligence like these are intended to be added to the cell
11. It should be kept empty in a first approximation and as a security measure against collisions in the cell, 2 positions between the SS and the RD. In case there is only 1, which could be a minimum bound, no collision takes place anyway
12. The position Robotino takes the pallet from should be kept available so that when it comes back at any Robotino Outgoing Movement (ROMw), there is a free position to place. By preference and under the concept of reducing variability, it is desired to keep such same position but in case there is another finished piece to dismount, the position Robotino took the pallet from could be optionally occupied since there will be a free position anyway. Notice that $w = \overline{1,o}$ and can be also referred to as the number of empty pallets (eps) plus the number of finished pieces (fpc) returned back from the I/O. Then regarding each ROMw takes one and only one pallet back, and that $s = \overline{1,l}$ and $c = \overline{1,d}$, it can be stated that:

$$ROM_W = ep_S + fp_c \qquad \textbf{[1]}$$

This previous expression, if considering the number of pieces of bad quality in the cell, let us call them by bqb where $b = \overline{1,q}$, and also knowing the value of eps, could be turned out to obtain the Throughput (T) of the cell at any time, i.e.:

$$T = ROM_w - bq_q - ep_S \qquad \textbf{[2]}$$

Although most of the principles are proper from this paper, it was useful to analyze some rules, see 8 and 9, from [3, 4], as well as the whole paper itself of [6].

4. Other possible alternative scenarios

Some other possible scenarios could occur and be analyzed in future work. Some of these are briefly mentioned as follows:

1. The normal working scenario described in heading 2, plus the consideration of a time buffer based on the future analysis of the time standards, e.g.: Robotino, the ABB robot, the M and the SS could be assumed to start working sooner so as to have a certain number of parts when the systems starts, it would propitiate a more balanced cell in case Robotino is verified as the bottleneck
2. The normal working scenario described in heading 2, plus the operation of Robotino in all 4 first level positions of the SS besides the I/O, this could eliminate manipulations and favor the direct and reverse flows
3. The normal working scenario described above with the combination of both of the last 2 previous considerations
4. Another different scenario to the explained in heading 2, where there would be possible to transport both the cylindrical housings and covers on the same pallet. It would keep containing as sub-scenarios the previous 3 ones.

It is important to outline, that each one of these variants could also include others regarding the possible different operational speeds assumed for each resource, their combinations and the prioritizations, etc., this way, even when not being in the most complex of the cases, the problem presents itself as a combinatorial one which are usually non-polynomial-hard (NP-hard), meaning that the time required to find the optimal solution, increases exponentially as the problem size increases linearly, for which the use of heuristics, metaheuristics or even approximation approaches are worth taking into account. The following expression 3 has a great value of use and is a good starting point to get to another one that in future papers, helps determining the total number of scenarios or combinations to be explored and compared in the targeted IMC.

Such future expression will be used for each original scenario initially identified, so that, either making vary one of its elements (devices of the IMC) through all its possible discreet values or, several devices at the same time, the number of combinations derived from each original scenario, let us call them Subscenarios, can be determined. Notice that the term Subscenario will be just used to indicate where they come from, at the end each of them will be assumed as a another configuration of the MS to be further simulated and analyzed in the search of a better material flow.

$$C(n,k) = \binom{n}{k} = \frac{n!}{(n-k)!k!} \qquad \textbf{[3]}$$

where:

n: total number of scale values that the elements of cell (devices) being searched for combinations, have together in their discreet or discretized varying scales

k: number of varying devices being searched for combinations

However, despite the previous expression offers all the combinations and give an insight on what must be calculated, it does not distinguish between the combinations inside the same set and those among sets, being just the last ones which are needed and possible, given the characteristics of the problem and goal of this research, i.e.: it is neither possible nor logical to have at the same time 1 device operating at 2 or more different speeds. To help discerning on this inconvenience, it is useful to have a look into the pair-wise combinations field which fits part of the research need of strictly searching among different sets. Similarly, the graph theory and specifically the complete bipartite graph problem help also understanding the nature of the needed future expression and how to get to its final formulation; from its perspective, each pair of sets must be simply seen as complete bipartite graph.

However, these theories themselves do not exactly match or totally cover the requirements of our needed expression, and as in most of the practical applications, either some modifications should be made to let them fit or they can just be used to partially address the problem. From these analyses, the authors allow themselves to decide on a final expression to be proposed in future work. The same will be just intended in a first approximation, for the particular use case addressed through this paper.

5. The possible states of the cell

The cell could be empty, with remaining capacity, full but not under collision, under collision and interrupted:

- The cell is full but not under collision, always that being full 3 of the 4 positions at the PAB, there are 2 other empty ones among the RD, SS and the I/O. Otherwise a collision could occur
- The cell has remaining capacity when there are at least empty 2 places among the SS, RD and the I/Ois also empty. Any other additional empty positions on the shelf in the PAB can besides contribute to this state

- The cell may be under collision when (1) it is not possible at any RIMj to place parts in the I/O since this is full by any relocation process, this could be solved if existing at least 2 or more empty positions, among the RD and SS, otherwise the collision remains. Other possibilities of collision are: (2) being empty the I/O there are no other empty spaces to push the pallet forwards, i.e.: the SS and RD are both full, and (3) at any ROMw the 4 position shelf in the PAB is full. All of these possibilities even when mentioned are supposed to be stopped from happening if the system executes and follows the principles and thus acts and reacts intelligently
- The cell is interrupted when by any circumstance and without a collision, it is not running. The interruptions can be partial, planned, not planned, casual or due to others reasons.

6. Conclusions and further research

Through this paper it was contributed in a first approximation, to an initial design of the material flow at the IMC of the IPSAM. As for helping comprehending some of the descriptions and situations, both a figure, a detailed layout of the IMC and some expressions accompanied the sections. The paper creates a basis for a broader research project which includes the migration till the phase of functioning, to an IMC. Further research ideas are related but not limited to the improvement of the material flow described herein.

Acknowledgments

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COST PREDICTION OF DESIGNED TECHNICAL PRODUCT USING SIMILARITY BASED REASONING

Dvorak, J., Hosnedl, S.

Abstract: *Prediction of product properties especially of product costs is very important task for engineering designers. This design activity enables early and thus very efficient elimination of odd costs of the designed technical product. In the intended paper we would like to present, compare and evaluate two different approaches applied on early prediction of costs of designed technical products. The first approach is based on traditional mathematical statistics methods, the second one is our recently developed Similarity based Reasoning (SbR) method. These two approaches were verified and validated with use of the same sample of data corresponding to real technical products. Evaluation and comparison of quality of both approaches will be presented using database for a standardized machine part.*

Key words: prediction, parameter, driver, regression, machine part

1. INTRODUCTION

Each designer should notify that each his proposal of a dimension or even radius causes costs. So it is advantageous to know which drivers have the most important impact on costs of the designed product Thus the primary focus of our approach was to find drivers of a technical product regarding costs. Statistic functions correlation coefficient and linear regression were being tested for those drivers identification and following cost prediction. Technical data which are being used for cost prediction are taken from database or they are simulated.

2. PROCEDURE

Technical products have usually many parameters. The key ability for properties prediction is ability to find out which parameters of investigated technical product affects cost mostly. Our hypothesis that key drivers can be determined by using statistic function correlation several technical products were considered. In this paper case study with sliding bearing is presented.

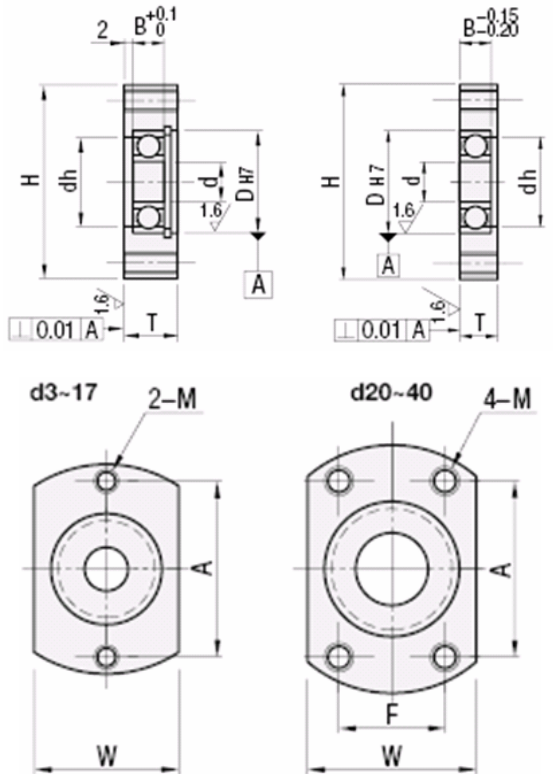


Fig. 1. Sliding bearing with sleeve

Technical products have usually many parameters. Correlation refers to any of a broad class of statistical relationships involving dependence. Correlation means mutual relation between two processes or values. If one of them changes, the second one changes and back. If correlation between two processes or parameters is found out, it is probable that they depend to each other but it does not mean that one driver of them is a cause and that second one is consequence. But correlation itsef is not able to decide it. Relation between two characteristics or quantities (x, y) could be positive if (approximately) y = kx or negative (y = - kx). A value of correlation coefficient r = −1 means quite indirect dependence (anti-correlation). In other words as much as values of one characteristic increase thus values of second characteristic reduce. If value of correlation coefficient r equals +1 (Fig. 1) means direct dependence. For example if diameter increases then for example costs increase. If value of correlation coefficient r equals +1 (Fig. 1) the relationship between two characteristics is linear.

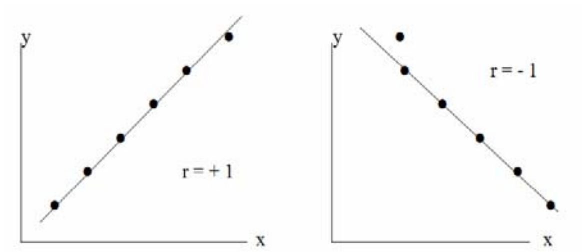


Fig. 2. Direct (left) and indirect (right) expression of correlation coefficient r

By using correlation coefficient function, we obtained values of correlation coefficient r for some respective parameters (Tab. 1).

d	D	b	H	T	dh
0,97	**0,92**	0,79	0,89	0,61	**0,93**

Tab. 1 Some drivers of sliding bearing with sleeve, key drivers are depicted bold

We found out the most important property drivers regarding costs from this case study in this way (Fig. 3). These are: d, D and dh.

The rest of other investigated parameters behave with positive dependability too but only parameters with most impact on costs were selected. So we found out the key drivers with the highest impact on cost (Fig. 3).

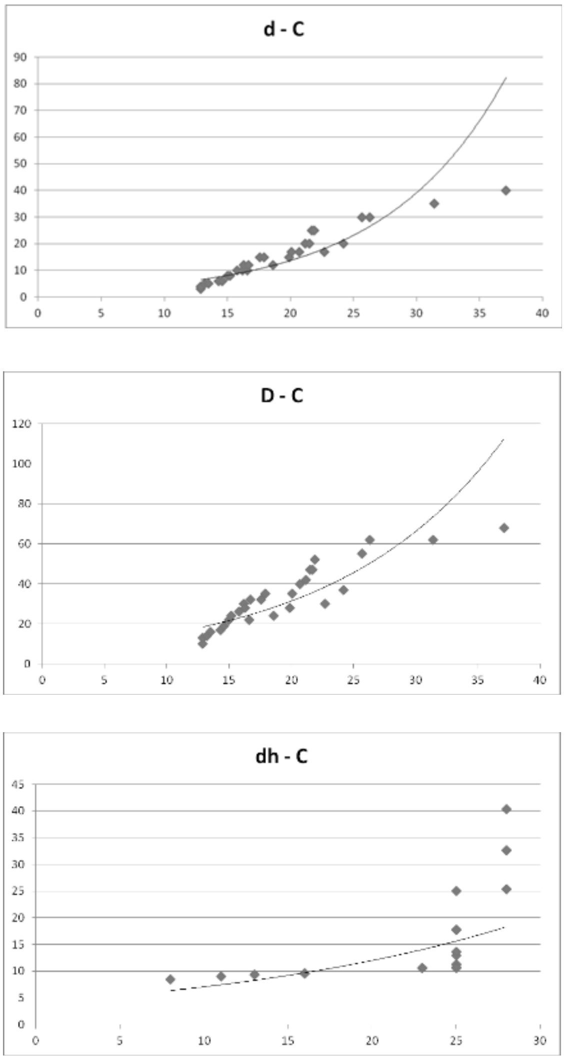


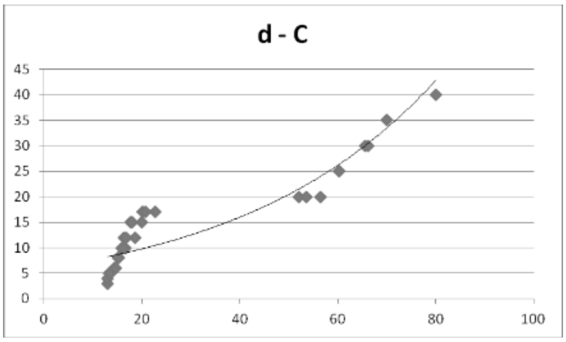
Fig. 3 Investigated parameters of above mentioned sliding bearing with the sleeve which mostly affects costs of product

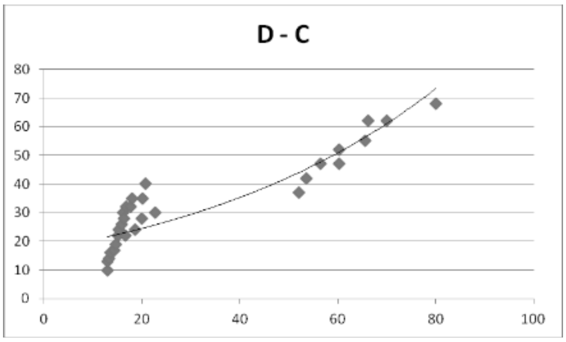
The next step of cost prediction approach is based on hypothesis that by knowing key drivers and using linear regression (LR) it is possible to predict product costs. This is able only if it is possible to use database of product costs we would like predict. Used data has to be valid – it means that data have to represent comparable products only (e.g. same producer, same year etc.). In general, the goal of linear regression is to find a line that optimally predicts a parameter Y depending on a parameter X. Linear regression does this by finding the line that minimizes the sum of the squares of the vertical distances of the points from the line. The sample test set of cases and their results we obtained is shown in Tab 2.

d[mm]	D[mm]	dh[mm]	C[CZK]	C_{PRED}[CZK]	Δ[%]
3	10	7	12.9	12.88	0.14
4	13	9	12.9	13.06	-1.21
5	14	10	13.2	13.76	-4.21
5	16	12	13.5	13.38	0.91
6	17	13	14.3	14.08	1.56
6	19	15	14.6	13.70	6.18
8	22	18	15.0	14.91	0.61
8	24	20	15.2	14.53	4.41
10	22	19	16.6	16.84	-1.42
10	26	22	15.8	15.93	-0.83
10	30	24	16.2	14.88	8.15
12	24	21	18.6	18.24	1.96
12	28	24	16.3	17.33	-6.32
12	32	26	16.7	16.28	2.52
15	28	25	19.9	20.15	-1.24
15	32	28	17.6	19.24	-9.33
15	35	29	17.9	18.38	-2.68
17	30	27	22.7	21.55	5.08
17	35	31	20.1	20.45	-1.76
17	40	34	20.7	19.21	7.19
20	37	34	24.2	22.89	5.42
20	42	36	21.2	21.50	-1.42
20	47	40	21.5	20.41	5.08
25	47	41	21.7	25.00	-15.22
25	52	45	21.9	23.91	-9.17
30	55	48	25.7	27.79	-8.12
30	62	55	26.3	26.46	-0.62
35	62	55	31.4	30.91	1.56
40	68	60	37.1	34.07	8.16

Tab.2 Comparison of entered costs and predicted costs with using linear regression

In this case data being used (entered costs) are almost smooth. In the next step simulated data of the same product with again the same key drivers are tested. Entered data as were set in previous example are shown here. But this time uneven data are being used. Sometimes it is obvious that some sets of technical products could be i.e. manufactured by using the different machines or technology. So it could happen that costs of all produced product of one company could differs a lot because for example operational costs of some machines could be much higher and that is why manufacturing of those products is more expensive. In the Figure 4 the same cost dependency of drivers is shown. From those dependencies it is easy to see rise of costs in set of products.





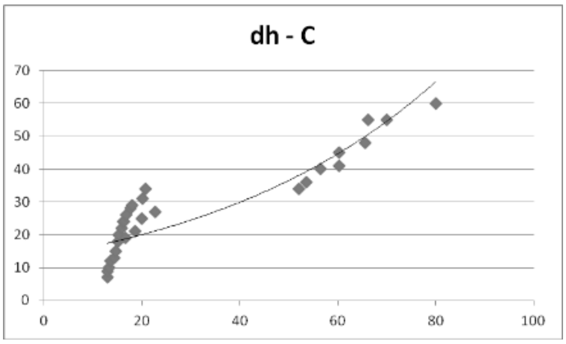


Fig. 4 Investigated parameters d, D and dh of above mentioned sliding bearing with the sleeve which mostly affects costs of product

This investigation have shown that if entered samples (data) are uneven the obtain results lose accuracy. Predictions of costs can differ from real costs almost in 80% in comparison with entered samples.

From our experiences it was found out that the crucial boundary stone for cost prediction is indication of key drivers in our example, drivers which affects costs mostly. Our presented method works but this method is not doesn´t work accurately when entered data are uneven as it is obvious from Tab. 3. In the other words this system doesn´t work accurately when shape of costs is leaping.

d[mm]	D[mm]	dh[mm]	C[CZK]	C_{PRED}[CZK]	Δ[%]
3	10	7	12.9	4.04	68.70
4	13	9	12.9	8.12	37.03
5	14	10	13.2	10.17	22.99
5	16	12	13.5	9.41	30.30
6	17	13	14.3	11.45	19.91
6	19	15	14.6	10.70	26.74
8	22	18	15.0	14.40	3.98
8	24	20	15.2	13.65	10.21
10	22	19	16.6	16.44	0.94
10	26	22	15.8	17.73	-12.23
10	30	24	16.2	21.82	-34.6
12	24	21	18.6	20.53	-10.37
12	28	24	16.3	21.82	-33.84
12	32	26	16.7	25.90	-55.11
15	28	25	19.9	26.28	-32.05
15	32	28	17.6	27.56	-56.62
15	35	29	17.9	32.03	-78.93
17	30	27	22.7	30.36	-33.75
17	35	31	20.1	31.27	-55.58
17	40	34	20.7	34.98	-68.99
20	37	34	52.0	34.98	32.74
20	42	36	53.6	41.48	22.60
20	47	40	56.4	42.39	24.83
25	47	41	60.2	51.70	14.13
25	52	45	60.3	52.60	12.76
30	55	48	65.6	63.57	3.09
30	62	55	66.2	60.93	7.97
35	62	55	70.0	73.03	-4.32
40	68	60	80.0	85.66	-7.07

Tab.4 Comparison of entered uneven data of costs and predicted costs with using linear regression

All calculations were made in MS Excel

3. SIMILARITY BASED REASONING METHOD (SbR)

Let us have a set of m samples stored in a database. The number of samples m is constant for a given task but can generally change for any next task according to the development of situation. Each sample (i = 1–m) is described by a vector Ai of n parameters ("independent variables" – usually but not exclusively values of the "descriptive property indicators" mentioned above) denominated from Ai1 to Ain. The concept of the method can accept that some of these parameters may be originally given in the vague/linguistic form. However the appropriate fuzzy set method for their quantification should have to be applied first. If there is n parameters is considered, each sample i can be represented by the corresponding vector within the n-dimensional virtual space. Let each sample (vector) Ai has assigned value f(Ai) (or maybe more values f(Ai,k)) of the "dependent "function" variable(s)" which thus depend(s) on values of the above mentioned "independent variables (parameters)" Aij = Ai1 - Ain of the vector. Let us consider now, that these (values) f(Ai) of the stored samples have been found by an unknown or very complicated "black box" like way which is not easy or is "even impossible" to find and accommodate it for effective and first of all prompt reuse during design engineering, etc.. Now let us have any next (of course compatible) "examined" vector Ax with known values of its "independent variables (parameters)" Axj = Ax1 - Axn however with not known value(s) of its "dependent ("function") variable(s)" f(Ax), and the task is to infer it. Our approach to the solution of the task based on the hypothesis outlined in the introduction has been as follows. Although the n-dimensional space is in question, above mentioned requirements led us to concentrate on possibilities how to estimate the value f(Ax) using only surrounding, i.e. the closest and most similar TS stored vectors. We have established as a crucial idea that the value f(Ax) can be linearly interpolated from the values f(Ai) of those stored samples i whose vectors Ai have the nearest similarities sim(x,i) to the new case (vector) Ax. Given the distance d(x,i) (of the examined vector Ax and individual vectors Ai) and a maximum distance dmax the mutual similarity between the couples of vectors Ax and Ai can be calculated:

$$sim\ (x,i) = 1 - \frac{d(x,i)}{dmax_{PI}} \qquad (1)$$

The question is, how many vectors Ai "closest" i.e. "the most similar" to the vector Ax to take into consideration. The idea mentioned above led as at the beginning to the simple approaches based on interpolations among the two or three vectors Ai "closest" to Ax. When on marks all mutual absolute distances (converted to the similarities) of the corresponding vectors AB, AX and BX (in the first case) or AB, AC, BC, AX, BX and CX (where points A, B, or C correspond to the two or the most close/similar vectors Ai and X to the examined vector Ax) then the interpolation/inference task has been transformed into 1- or 2-dimensional solution space respectively. The results were quite promising in some cases, however the obvious strong "over-determination" of the 1- or 2-dimensional models corresponding to the most close/similar vectors have caused not rare unacceptable interpolation/inference mistakes. However we early found further positive potential of the third dimension "above" the triangle ABC, which is capable to involve even the third most close/similar sample stored in the available database. Resulting 3-dimensional interpolation/inference model in a form of the tetrahedron with apexes marked A, B, C and D (representing the four most close/similar sample vectors with known values f(A), f(B), f(C) and f(D) of the "dependent "function" variables") respectively and the point X (representing the examined vector with the unknown value f(Ax) of its "dependent "function" variable(s)") is depicted in Fig. 5. The developed procedure of the interpolation/inference of the value f(Ax) is based on the linear space interpolations of the known values of functions at the apexes of the tetrahedron A, B, C and D to the point X within the depicted 3-dimensional space. The realisation of this strategy is possible both in 3D graphical and numerical forms. The numerical form can be then realized in a geometric, vector, and/or matrix forms. All these methods have been used during development and verification of the outlined algorithms. Of course the graphical form is not suitable for software implementation of algorithms however in spite of it the graphical representation is very user friendly form for depiction of "what is it for" for each solved case during the numerical inference. It has been found that the optimal combination of two last two numerical approaches is the most "robust" regarding the often peculiarities and singularities caused by special space con-figurations of the four mentioned points. These are for example position of the point X out of the tetrahedron A, B, C, D, configuration of all these points in a plane or on a straight line, etc. which is necessary to take into account to avoid instability or even collapse of the inference algorithms.

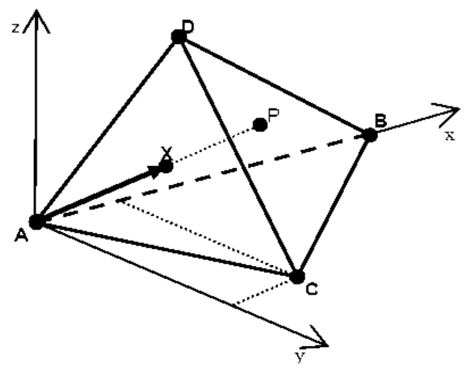


Fig. 5 Simplified model of the inference tetrahedron within 3-dimensional space

The method outlined above has been converted to algorithms and implemented as a trial software for computer use. Due to easy debugging, user-friendliness and large usage in practice the generally available MS Excel has been chosen as the first. For those methods comparison we selected database of uneven samples. This time we want to predict costs of fictive set of products with chosen parameters by using method based on statistic functions (SF) and also by using SbR method (Tab. 5).

d	D	dh	SF	SbR
3	10	7	4.04	12.90
17	40	30	46.18	22.00
20	35	35	27.33	53.00
25	50	45	47.76	67.00
37	64	57	77.11	80.00

Tab.5 Comparison of two mentioned method/approaches of product costs

5. CONCLUSION

It is advantageous that the developed inference method is independent on a way how the values related to the respective stored samples have been acquired (i.e. if it was achieved by estimation based on knowledge and experience, by any type of calculations, by any type of experimental measurement, from inquiries, by stochastic methods, etc.), and that it flexibly operates with any number of the stored samples. It has been proved that the developed inference algorithms as well as their trial software implementation can provide users with sufficiently high and even the highest accuracy (up to 100%) if the number of the stored samples is high or if the examined sample is identical to a stored sample or if it is very close/similar to any of them. It has been also proved that the algorithms and their software implementation have successfully got over all faced singularities of the solved tasks. This method could be as the useful tool for engineering design and management. We verified and then validated those methods on real examples from engineering practise (sliding bearings, pulley etc.). In the next step we would like to endeavour to transfer algorithms into suitable software environment.

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COST ANALYSIS IN SMALL WIND PROJECTS

M. Fera, R. Iannone, R. Macchiaroli, S. Miranda

Abstract: *In the last years an increasing attention has been paid to distributed energy production from small wind turbines (i.e. < 200 kWp). The market, especially in Italy, has grown up very rapidly in the last years (basically not existing since 3-4 years ago, now it counts approximately 8 MWp). The main purpose of the paper is therefore to provide a reliable cost analysis reference to design, plan and control a project, which also includes a correct estimation of the financial risk incurred by both EPC contractors and investors. For the firsts, it also represents a cash flow analysis tool useful for financial planning, while for the seconds it's useful for financial control.*

Key words: resource management; costs management; small wind business.

1. INTRODUCTION

So far, the green energy production market has been mainly focused on large projects in the PV and wind sectors. These two sectors have developed very fast and at the moment they have reached a quite large extent worldwide; this is confirmed also in the Italian market where photovoltaic has a cumulative installed power which, after an extremely rapid growth, has reached 1.2 GWp in 2010, while for the wind farms the level of 5 GWp was overcome [1]. On the other hand the small wind sector grew up very rapidly not only in Italy but all over the world; as underlined by the European Wind Energy Association (EWEA), the small wind farms installed in 2009 in the world reached a total power of 42.5 MWp, 20.3 MWp of which only in US [1]. It is also important to note that the cumulative power installed in US is 100 MWp and more than the 50% of this power comes from the past three years of installation.

In wind energy production currently most part of the Italian territory is covered by big sized machines. Nowadays, the land availability for big wind farms and also the capacity of medium voltage (MV) and high voltage (HV) electric grids have almost been saturated. Actually, high voltages grids often incur into saturation and/or unavailability because they were originally built for energy dispatching from a central source to all end users, and were not intended to support distributed and intermittent energy production from renewable sources and because their development has not correctly followed the extremely fast increase in the development of wind farms. Small wind production plants, instead, are connected to MV grids, usually offering more availability because of their thorough diffusion, or even to low voltage (lv) grids.

Another advantage of small wind farms when compared to large ones is related to timing of planning application and authorization; in case of large wind farms the complete authorization process has reached in Italy an average value of 3,5 years, while in the case of small wind farms it takes around 6 months on average. The main reason for this relates to the different authorization processes. In case of large wind farms Italian Law 387/2003 requires the involvement of several parties, like civilian and military entities, environmental protection agency, etc .... who all need to give their authorization, while in case of small installations that law does not apply and permissions are granted by municipal or province authorities. This circumstance does not apply, to our knowledge, to all European countries (in UK, for instance, it is our knowledge that planning processes are not as simplified as just described).

The financial income structure is also quite different in the cases of large and small wind farms. In the first case, each kWh produced is sold to the grid at a variable market price and give right to a "green certificate", which can be sold on its market. Latest decisions and/or wills of Italian government, related to the automatic buying of unsold certificates by the government itself and to the future introduction of an auction sale mechanism, has introduced big uncertainties on the market. In the second case, instead, a Feed-In-Tariff mechanism applies and each kWh produced is simply rewarded with a 0,30 €/kWh price, which represent nowadays almost twice the market price for energy produced by large wind farms.

Another evident difference is not only related to the machine's size (usually over 1 MWp in the case of large turbines and below 200 kW in case of small ones), but also on their typical unit prices (around 1,500 €/kWp in the first case, over 3,000 €/kWp in the second one). This has obvious implications in terms of capital needs and also poses some serious questions in terms of risk allocation, since the distribution of a general risk (related to timing of construction, wind conditions, grid connection issues, availability, etc. ...) over an increased number of smaller initiatives is clearly able to reduce the corresponding financial risk.

For these reasons, in Italy and in all Europe, the energy production market from small wind turbines is growing up very rapidly in the last years. Such increase of this energy sector gave the investors new possibilities to develop the market and, when coming from other sectors, to easily differentiate their business, given the lower capital needs to start the business and the shorter time to start production [6]. Aim of this work is to present an outline of the small wind production sector, which can be hopefully useful for investors, project managers and all stakeholders to understand the cost of the different activities usually related to a small wind farm project, as outlined in another work of the authors [7] which instead mainly focuses on timing aspects.

2. LITERATURE REVIEW AND OPEN ISSUES

In the first part of the study, we focused our attention on best practices and analyses reported in previous research works or on industrial cases presented in the relevant international scientific literature. Some works were found about the importance of small wind production farms when production districts and/or units are located in isolated areas. Nouni et al., 2007 [2] described all technical and economic issues related to the installation of 19 wind turbines in India; these small scale turbines were installed on sites where energy was needed for local industrial plants. Naturally, this kind of project is deeply different from the ones we want to discuss and analyze here, which mainly stem from financial perspectives rather than industrial needs.

Also other works about small wind farms performance evaluation were found in the literature. Abderrazzaq, 2004 [4] analysed the 6-years performance of a small wind farm in Jordan. This work also points out that this small wind farm is capable to cover about 50% in mean of the load demand by users around this area. This evidence proves that also the small wind farms have a financial as well as an environmental justification.

Other works are focused on the social issues related to the small wind energy production. In particular Dimitropulos and Kontoleon, 2009 [5] addressed a study about the main factors for the stakeholders in the evaluation of an initiative in small or large wind farms. A wind farm in Aegean area is considered and the problem of the relationships of the initiative with the territory and the local people is recognized. In spite of what could be easy to think, this problem does not concern geometrical or lay-out issues, but the relationships of the initiative with the territory and the local people. This work confirms the success of the small wind power generation, also due to the fact that the investment initiatives come directly from the people of the territory. Naturally, giving more importance to social than to technical issues does not mean that these latter ones are not important, but that all the environmental regulations have to be respected firstly.

After this analysis of the existing literature, when coming to project management issues, we had to conclude that in the analysed scientific and operational literature there are very limited references related to a particular and important sector like the small wind energy production. The development of this work has thus been also justified and strengthened by this literature lack. A first attempt on this side was proposed in Fera et al., 2011 [7] where the standard timeline for small wind project was given. The main goal of this paper, instead, is to define a point of reference to work on project costs issues in this specific field, being helpful in the investment analysis, giving a reliable idea of the costs related to small wind projects and on the application of standard project management tools and techniques to monitor and control cost and financial issues.

3. THE PROJECT COSTS

The 29 construction projects analysed took place from January to October 2010, while the previous phases were performed from February to December 2009. For all these projects we had the opportunity to analyse reports and to collect relevant cost data. A list of the activities of the projects with their mean execution times is summarized in Table 1 and 2 [7].

We were able to collect all relevant cost data related to those activities and we could compute their average values, as reported in Table 3. This was important to assess their typical values in standard projects as the ones observed in our study. Further, the collection of such relevant costs allowed to compute and draw the standard cost curves usually employed also in project management cost control techniques, i.e. the budget cost and the actual cost.

WP	ACTIVITY	PEOPLE Nr.	SATURATION
1	Windy Studies	1	100%
2	Geological studies	4	50%
3	Civil Engineering	2	100%
4	Electric Engineering	1	100%
5	Purchasing and Logistic	1	100%
6	Field Operations	4	100%
7	Commissioning	2	100%
8	Structural authorization	-	-
9	General Permit	-	-

Table 1. Activities and involved people

WP	TIMES [days]		SEQUENCE DEPENDENCE
	MEAN	ST. DEV.	
1	6	0.84	No
2	30	5.39	WP1
3	5	1.41	WP2
4	2	0.5	WP1
5	40	8	WP3;WP4
6	38	4.07	WP5;WP8;WP9
7	1.5	0.8	WP6
8	77	59.5	WP3
9	56	34.4	WP8

Table 2. Execution times and sequence

It is worth to note that there are some activities which are recognized as strategic, like sites search and investigations, negotiation with the electric grid managers and grid connection design, installation, connection and commissioning of wind turbines; these activities are all performed by people internal to the Engineering, Procurement & Construction (EPC) firm in

WP	ACTIVITIES AND SUB-ACTIVITIES	MEAN DURATION	SCHEDULED	ACTUAL	COST TIMING
1	**WINDY STUDIES**	**6**	**€1,500.0**	**€510.0**	**End**
1.01	*Wind data set collection*	*1*	*€250.0*	*€85.0*	
1.02	*Data validation*	*0.5*	*€125.0*	*€42.5*	
1.03	*Simulation*	*4.5*	*€1,125.0*	*€382.5*	
2	**GEOLOGICAL INVESTIGATION**	**30**	**€4,500.0**	**€4,760.0**	**End**
2.01	*Site characterization*	*2*	*€187.5*	*€170.0*	
2.02	*Soil empirical analysis*	*14*	*€3,000.0*	*€3,400.0*	
2.03	*Data analysis*	*14*	*€1,312.5*	*€1,190.0*	
3	**CIVIL ENGINEERING**	**5**	**€1,000.0**	**€770.0**	**End**
3.01	*Foundation design*	*3*	*€600.0*	*€600.0*	
3.02	*System design*	*2*	*€400.0*	*€170.0*	
4	**ELECTRIC ENGINEERING**	**2**	**€4,000.0**	**€170.0**	**End**
4.01	*Definitive electric design*	*2*	*€4,000.0*	*€170.0*	
5	**PURCHASING AND LOGISTIC**	**40**	**€3,650.0**	**€3,540.0**	**End**
5.01	*Civil works parts purchasing*	*35*	*€250.0*	*€170.0*	
5.02	*Electric parts purchasing*	*40*	*€250.0*	*€220.0*	
5.03	*Crane rental*	*7*	*€2,500.0*	*€2,500.0*	
5.04	*Generator and load bank rental*	*1.5*	*€650.0*	*€650.0*	
6	**FIELD OPERATIONS**	**38**	**€70,960.0**	**€60,941.3**	**End**
6.01	*Site preparation*	*6.5*	*€18,000.0*	*€17,000.0*	
6.02	*Excavation for foundation*	*1*	*€4,200.0*	*€3,570.0*	
6.03	*Piles rebar*	*1*	*€7,800.0*	*€6,630.0*	
6.04	*Piles pouring*	*0.8*	*€15,100.0*	*€12,193.3*	
6.05	*Piles curing*	*8*	*€1,400.0*	*€850.0*	
6.06	*Plinth rebar*	*2*	*€5,660.0*	*€4,811.0*	
6.07	*Plinth pouring*	*1*	*€7,600.0*	*€6,137.0*	
6.08	*Plinth curing*	*15*	*€2,800.0*	*€1,700.0*	
6.09	*Tower installation*	*1.5*	*€1,800.0*	*€637.5*	
6.10	*Nacelle Installation*	*0.5*	*€600.0*	*€212.5*	
6.11	*Electric connection*	*0.7*	*€6,000.0*	*€7,200.0*	
7	**COMMISSIONING**	**1.5**	**€6,500.0**	**€6,500.0**	**End**
7.01	*Commissioning*	*1.5*	*€6,500.0*	*€6,500.0*	
8	**STRUCTURAL PERMIT**		**€350.0**	**€350.0**	**Start**
9	**GENERAL PERMIT**		**€1,200.0**	**€1,200.0**	**Start**
		TOTAL	**€93,660.0**	**€78,741.0**	

Table 3: Mean scheduled and actual costs of the project

order to ensure a controlled and good quality level of the work performed and to keep the know-how in-house. There are then some other activities, like the foundation design and calculation (WP 3.1), for which this logic does not apply,

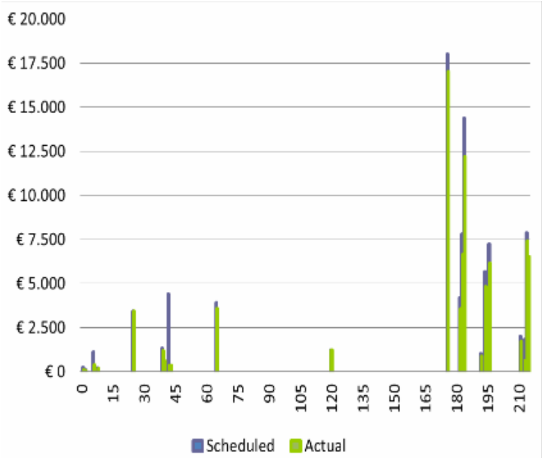

Figure 1: Financial requirements during the project time

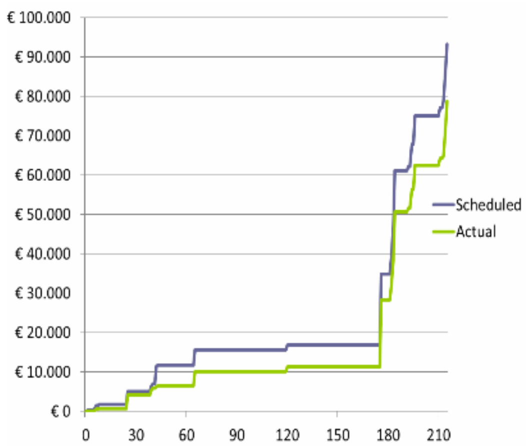

Figure 2: Cumulative curves of scheduled and actual costs

and this is due to the fact that data needed to design the foundation are common and the replication is fairly easy, so not much effort to preserve this know how needs to be spent, given also that the designer has subscribed a non-disclosure agreement.

The analysis conducted allowed to compute budget variances at the end of the project, reported in Table 4, and to analyse the instants when financial outcomes occurred, reported in Figure 1 and 2. These figures also report the scheduled and actual cost curves, as defined before.

The measured budget variance reduction is about **€ 14,198.75,** or in percentage form, of **-16%**, which represents an average over the 29 analysed projects. It is worth to note that the schedule variance is fairly low, thus implying that schedule is well respected, so that it does not represent a criticality. At the same time they show that cost variance has a significant value (a reduction of around 15%), mainly related to field operations and thus implying that field costs estimation can be improved.

Figure 1 reports costs (budgeted and actual) timings. So, it is possible to understand how cash flows occur over time.

Figure 2 shows that most cash outflows occur after approximately a 75% of project completion time; this implies that the financial risk are incurred at the end of the initiatives.

Before concluding it is worth to comment an important assumption we made about the cost structure of the project, which has been certainly noticed by a careful reader: in the costs and activities list reported in Table 3, we included all costs for procurement management, engineering, field operations and commissioning but we deliberately omitted to mention the wind turbine purchasing cost. Actually, this cost represents more than 65% of the total project cost. Standard payment terms include a 10% of total cost due when the procurement contract is signed, an additional 75% at the arrival of the turbine at the destination port (generally this happens after the 150th day of the project), and the last balance payment (i.e. 15%) after the commissioning. The main reason why the wind turbine purchasing cost was not included in Table 3 is because its entity and payments terms are strongly related on the bargaining power of the two commercial counterpart, not related to any project management issue and so of no general use.

4. CORRESPONDING ADDRESS

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5. CONCLUSION

Standing the comparatively small amount of literature found on cost and resource management in small wind projects execution, this paper focused on the analysis of the main cost and cash flow issues related to these projects' completion.

The paper intended, indeed, to give a contribution about cost and cash flow analysis for the installations companies, studying cost variances and cash outflows occurrence timing on set of data from 29 projects. Moreover, it also intended to represent a first approach in project and resource management in this application area which seems actually so promising and still quite neglected in the project management literature.

The outcomes of our study can be summarized as follows:

- since most cash outflows occur after 75% completion of the project, this helps in minimization of financial risks;
- the financial terms of the wind turbine purchasing contract usually do not allow any optimization activity from the part of the EPC contractor;
- a residual financial risk can be identified in terms of the impact of possible delays in the project when the cash outflows related to the turbine purchase are fixed;
- the budget variance is quite good, i.e. 15%, revealing a possible improvement in terms of cost planning.

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KNOWLEDGE MANAGEMENT MATURITY ASPECTS IN INDUSTRIAL ENTERPRISES

Gabriš, P.; Bielik Marettová, M.; Pavlenda, P.; Ličko, M.; Šujanová, J.

Abstract: *Researchers in the area of the knowledge management are oriented on different aspects and represents different approaches. The article introduces knowledge management maturity research results from the industrial enterprises in Slovak Republic. Objectives of the research were to identify key knowledge management dimensions that could influence maturity of the knowledge processes. The research methodology was based on the modified Capability Maturity Model.*

Key words: Knowledge Management, Maturity Models, Knowledge culture, ICT

1. INTRODUCTION

In the 21st century, successful organizations are competitive, fast-paced, first-to-market, and global in nature. Creating strategic advantage requires a new type of organization that has the capability to create knowledge to maximize organizational competitiveness and strategic success [1].

Knowledge management covers a broad spectrum of activities and operates at many levels, from the individual to the enterprise, between enterprises (as in virtual organizations). Much of the focus of a knowledge management programmes is at enterprise level, i.e. knowledge management across an organization. However, many of the approaches and techniques of organizational knowledge management are equally applicable at several levels. The table below shows a hierarchy of levels and gives examples of factors addressed at each level [2].

Level	**Typical Programme**	**Examples of Focus**
International	Various	Accounting standards (intangible assets), WIPO
Governments	Knowledge economy	Stimulating innovation, setting public sector KM standards, innovation scorecards
Intra-Organizationa	Collaborative alliances	Pooling knowledge, new product development, market access
Enterprise	Organization-wide KM programme	Sharing best practice, intranet portal, CoPs
Team or Department	KM Project (localized)	Business improvement, specialist knowledge base, virtual working
Individual	PKM (Personal Knowledge Management)	Skills development, time management, IM, PC and networks use

Table 1. Knowledge management levels
Source: [2]

2. KNOWLEDGE MANAGEMENT MATURITY

To recognize the potential gains from systematically and professionally developed knowledge management at all levels, requires application of evaluation methods. One of those methods is the application of maturity models.

Maturity models have the following properties [4]:

- The development of a single entity is simplified and described with a limited number of maturity levels (4 to 6).
- Levels are characterized by certain requirements which the entity has to achieve on that level.
- Levels are sequentially ordered, from an initial level to an ending level of perfection.
- During development, the entity progresses forward from one level to the next. No levels can be skipped.

Most of the knowledge management maturity models (Siemens' KMMM, Paulzen and Perc's Knowledge Process Quality Model (KPQM), Infosys' KMMM, Kulkarni and Freeze's Knowledge Management Capability Assessment Model (KMCA)) are based on the Capability Maturity Model Integration (CMMI) that supports both - a staged representation and a continuous representation. Maturity level 1 (Initial) is characterized by ad hoc and chaotic processes. Maturity level 2 (Managed) is characterized by processes that are planned and executed as per the policy. Maturity level 3 (Defined) is characterized by standardized processes that are used to establish consistency across the organization. Maturity level 4: (Quantitatively Managed) is characterized by managing the process performance through quantitative objectives. Maturity level 5 (Optimizing) is characterized by continual improvement of process performance through continual and innovative process and technological improvements [5].

The difference between KMM models is not only in the definition of the maturity levels, but also in the selection of the key process areas (KPA) that are taken into the consideration. Majority of KMM models uses as a KPA: Culture, Technology, People, Infrastructure, Processes and Content.

3. KNOWLEDGE MANAGEMENT MATURITY RESEARCH RESULTS

The main goal of the research was to analyse the level of the knowledge management implementation in industrial enterprises and to identify KPAs for the knowledge maturity model application. The research was realized in Slovak industrial enterprises in the form of the questionnaire. The questionnaire was distributed into the 350 industrial enterprises, where 86 questionnaires have included for the final analysis. In the analysis we have used descriptive and relational questions. Most of the questions where multiple choice, close – ended questions with the list of predetermined choices and the possibility to add a not listed category. For the identification of the level of the confidence with different statements we have also used nominal scaled questions. This type of the questions was applied for example for the evaluation of the organizational culture. The analysis areas where: knowledge management strategy, knowledge management tools, type of the organizational culture, key enterprise knowledge areas, impulses for the knowledge management implementation, areas where the asset of knowledge management has been recognized, accessibility of enterprise information and others.

In one of the questions we have analysed the attitude of the enterprises to the knowledge management (Fig. 1.). About 19% of enterprises does not apply knowledge management, nearly 23% of enterprises consider knowledge management as an indual activity, same percentage of enterprises have knowledge management projects, 24,5% of enterprises have knowledge strategy and about 10,84% of enterprises stated that their business activities are based on the knowledge management.

Although more than 50% of enterprises have knowledge management activities (for example existence of knowledge strategy, knowledge policy, knowledge culture or knowledge management tools like knowledge maps, databases for best practices or lessons learned), only about 38% of enterprises stated that they have recognized positive influence of the knowledge management on the business performance (Fig. 2.).

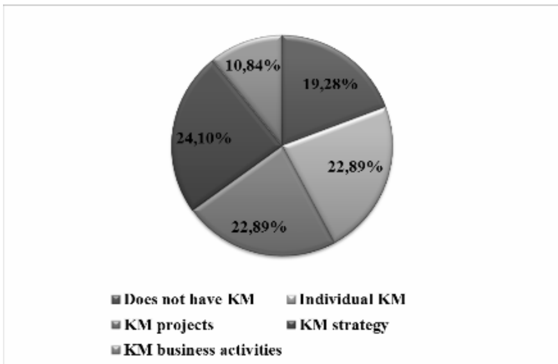

Fig. 1. Knowledge management in Slovak industrial enterprises

Differences have been also in the level of the knowledge accessibility where about 57% of respondents stated that in their companies they have good and very good access to the enterprise knowledge (Fig. 3.) and nearly 15% have poor or very poor access to the enterprise knowledge.

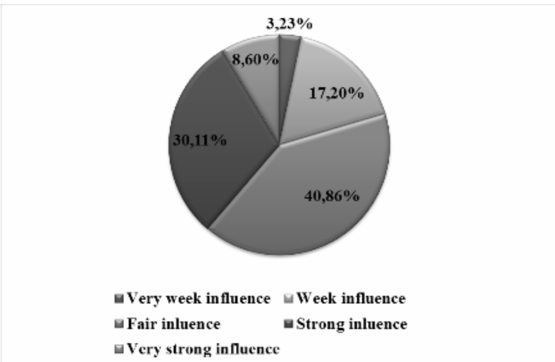

Fig. 2. Knowledge management influence on business performance

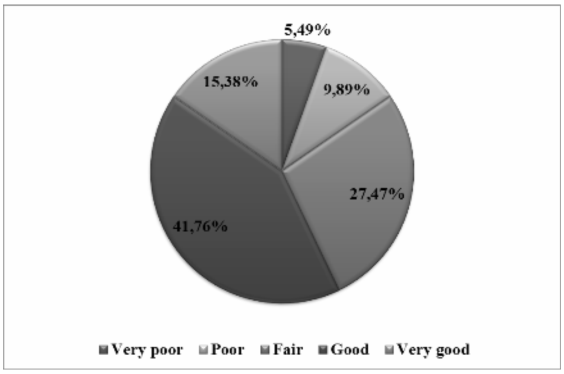

Fig. 3. Access to the enterprise knowledge

In many researches from the knowledge management area was identified clear relationship between the organizational culture and knowledge management [5, 6]. In our research we have analysed information culture orientation (Fig. 4.). About 30% of enterprises have culture oriented on information sharing and information-functional culture.

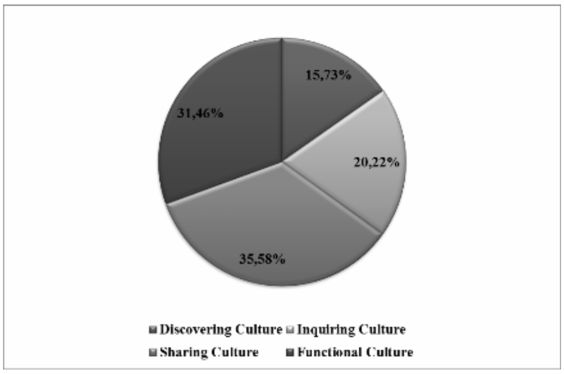

Fig. 4 Information culture orientation

Crucial for the knowledge management implementation is the support of the top management. This support is materialized not only in the knowledge management strategy, but also in the financial support for different knowledge management initiatives and projects. In the Slovak enterprises the level of the knowledge management support from the top management side is deficient: in about 43% enterprises top management does not support knowledge management strategy and in only 4,3% it is the CKO who is responsible for the knowledge management strategy implementation (Fig. 5.).

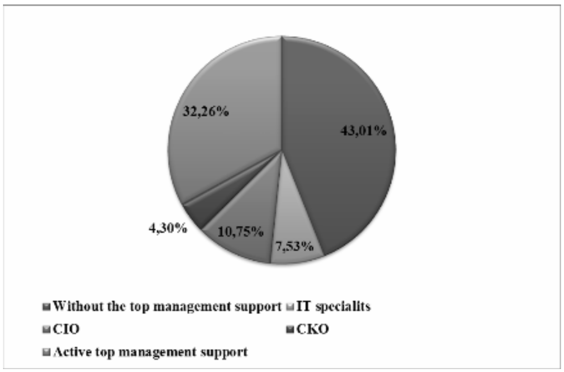

Fig. 5. Participation at the knowledge management strategy implementation

4. CONCLUSION

Results of the KMM in Slovak industrial enterprises have shown disproportions in knowledge management implementation. On one side there are enterprises that have clear knowledge management strategy and also support of the top management, on the other side there are still enterprises where knowledge management was not recognised as a competitive advantage. Approximately same percentage of the companies that have stated that knowledge management has positive influence on the business performance have knowledge sharing culture orientation.

As a result of the researches on the knowledge management and multicultural management in industrial enterprises [7] at the Institute of Industrial Engineering, Management and Quality we came to the conclusion that it is necessary to analyse KMM in broader context in the areas of the innovations and knowledge management interfaces.

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MULTI-POLE MODELING AND INTELLIGENT SIMULATION OF TECHNICAL CHAIN SYSTEMS (PART 1)

Gunnar Grossschmidt and Mait Harf

Abstract: *Composing of multi-pole models and simulation of dynamic responses of a technical chain system is considered in the paper.*
Part 1 of the paper discusses difficulties arising in using existing simulation tools. A methodology is proposed that seems to be free of most of these disadvantages. Modeling of electro-hydraulic servovalve is considered as an example of chain system. An intelligent simulation environment CoCoViLa supporting declarative programming in a high-level language and automatic program synthesis is used as a tool for modeling and simulation.
In Part 2 multi-pole mathematical models of functional elements are described. Computing transient responses of the servovalve are considered.
Key words: *multi-pole model, electro-hydraulic servovalve, intelligent programming environment, simulation.*

1. INTRODUCTION

Most of technical systems are chain systems. Chain systems are e.g. various machines with drives (electromechanical, hydraulic, pneumatic) and automatic control systems, vibroisolation and amortization systems etc.
The most wide spread general purpose simulation tool Matlab/Simulink [1] posses-ses variety of built-in simulation engines. The simulation process is flow-based i.e., all the connecting arcs are directed and all the ports are either inputs or outputs.
Bond graphs are used in simulation of chain systems as well. The key of bond graph modeling is the representation (by a bond) of power as the product of efforts and flows with elements acting between these variables and junction structures to put the system together [2]. Bond graphs are oriented to bond graph elements. It makes the models complex and not easy understandable. Bond graph elements are expressed as two-pole elements, feedbacks cannot not be described and taken into account correctly.
Modeling and simulation tools in existence such as SimHydraulics™, ITI SimulationX, DSHplus, Dymola, HOPSAN, VisSim, AmeSim, 20-Sim, DYNAST, MS1™, HYVOS 7.0 etc. [3, 4] are object-oriented (systems are described as functional or component schemes) using equations with fixed causality or equations in non-causal form for each object.
Using only two-pole models for mechanical and hydraulic systems is not correct, as components of such systems exert feedback actions. The obtained large equation systems usually need checking and correcting to guarantee solvability. It is very complicated to debug and solve large differential equation systems with hundred of variables. The special integration procedures must be used in case of stiff differential equations. Mostly the observed systems are subjects to simplification. Usually models simplified to 3th…5th order are used in simulations. Often the models are linear. When using such models dynamics of all components can’t be taken into account adequately.
In the current paper an approach is proposed, which is based on using multi-pole models with different oriented

causalities and oriented graphs of functional elements [3].
A special technique is used that allows avoid solving large equation systems during simulations. Therefore, multi-pole models of large systems do not need considerable simplification.
An intelligent simulation environment CoCoViLa [5] supporting visual programming and automatic program synthesis is used as a tool for modeling and simulation. Designer do not need to deal with programming, he can use the models with prepared calculating codes. It is convenient to describe simulation tasks visually, using prepared images of multi-pole models with their input and output poles.

2. MULTI-POLE MODELS

In general a multi-pole model [3] represents mathematical relation between several input and output values (poles).

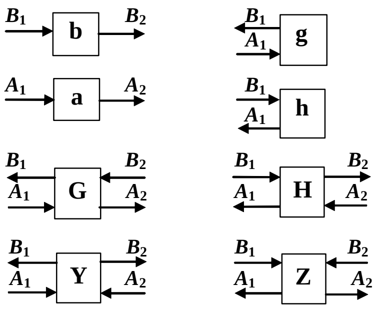

Fig. 1. Two- and four-pole models of technical system functional elements

The two-pole models (Fig.1) express the relations between flow variables $\boldsymbol{B_1}$ and $\boldsymbol{B_2}$ (form **b**), potential variables $\boldsymbol{A_1}$ and $\boldsymbol{A_2}$ (form **a**), potential variable $\boldsymbol{A_1}$ and flow variable $\boldsymbol{B_1}$ (forms **g** and **h**). Dependences between variables in two-pole models of elementary functional elements (inertia, damping, resistance, elasticity) are expressed by one equation.
The four-pole models show the relations between pairs of potential and flow variables ($\boldsymbol{A_1}$, $\boldsymbol{B_1}$ and $\boldsymbol{A_2}$, $\boldsymbol{B_2}$). One of the variables in pair must be as input. Models of this form express the physical content of processes with feedback. Four forms of such four-pole models, or otherwise, four forms of mathematical causalities exist. They are denoted by letters **G**, **H**, **Y** and **Z**. Dependences between variables in four-pole models of elementary functional elements are expressed by two equations.
Further in the paper only multi-pole models are considered that express relation between at least two input and two output poles. Using such models enables to express both direct actions and feedbacks as it occurs in hydraulic and mechanical systems.
Each component of the system is represented as a multi-pole model having its own structure including inner variables, outer variables (poles) and relations between variables.
The oriented mathematical dependences between inner variables of components are convenient to express as oriented graphs.
Using multi-pole models allows describe models of required complexity for each component. For example, a component model can enclose nonlinear dependences, inner iterations, logic functions and own integration procedures. Multi-pole models of system components can be connected together using only poles. Using multi-pole models enables methodical, graphical representation of mathematical models of large and complicated systems. In this way we can be convinced of the correct composition of models and we don't need to check the solvability. It is possible directly simulate the statics or steady state conditions without using differential equation systems.
Implementing the multi-pole models for each component gives us possibility to use distributed calculations. The integration is performed in each model separately. Solving smaller equation systems is required instead of solving large equation systems. The multi-pole model of the whole system doesn't need substantial simplification. So we can perform simulations, taking the performance of all components into account adequately. In case of loop dependences between poles of component models the iteration method is used.

2. ELECTRO-HYDRAULIC SERVOVALVE

Electro-hydraulic servovalve has control function in electro-hydraulic servo-systems. The history of significant references in the area of electro-hydraulic servo-systems is given by Maskrey and Thayer [6] and Gordić et al. [7]. In servo-analysis and system synthesis it is often convenient to represent an electro-hydraulic servovalve by a simplified, equivalent transfer function [6-11]. Difficulty in assigning simplified, linear transfer functions to represent servovalve response is that these valves are highly complex devices that exhibit high-order, nonlinear responses. These approximations to servovalve response have resulted in such expressions as “the equivalent time constant of the servovalve is – seconds” or “the apparent natural frequency of the servovalve is – radians /second” [6]. The simplified block diagram is a third order system consisting of the armature/flapper mass, damping and stiffness, together with the flow-integration effect of the spool [6].

Servovalve dynamic response is described in terms of the logarithmical amplitude ratio and phase angle lag of the output in response to a sinusoidal input of varying frequency.

Functional scheme of the electro-hydraulic servovalve is shown in Fig. 2.

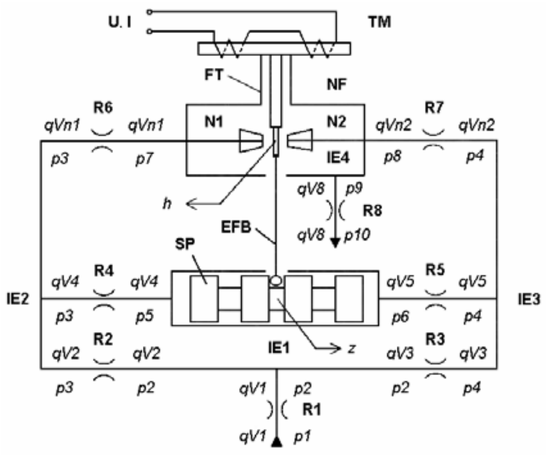

Fig. 2. Functional scheme of an electro-hydraulic servovalve

Electro-hydraulic servovalve consists of the following functional elements and subsystems: torque motor **TM** with flapper, flexure tube **FT**, nozzle-and-flapper valve **NF** with nozzles **N1** and **N2**, hydraulic resistors **R1**...**R8**, interface elements (tee couplings) **IE1**...**IE4**, sliding spool **SP** and elastic feedback **EFB** (as elastic conic rod) from spool to flapper. Structurally working slots of sliding spool belong to the servovalve. Functionally it is appropriate to consider working slots as separate subsystem when modeling and simulating a servo-system.

Input variables: input voltage ***U*** for the torque motor and the pressures ***p1*** and ***p10***.

Output variables: current to the **TM** ***I***, position of the flapper ***h***, position of the sliding spool ***z*** and volumetric flow rates ***qV1*** and ***qV8***.

Inner variables: pressures ***p2...p9,*** volumetric flow rates through nozzles ***qVn1*** and ***qVn2***, volumetric flow rates through resistors ***qV2...qV7***.

Scheme of mechanical parts of an electro-hydraulic servovalve is shown in Fig. 3.

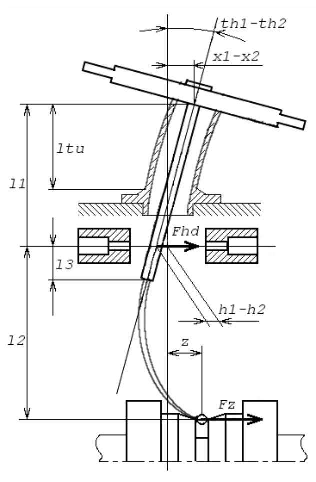

Fig. 3. Scheme of mechanical parts of an electro-hydraulic servovalve

The anchor of the torque motor is fixed on the flexure tube. The anchor turn angle ***th1*** transmits to the stiff rod, which gives flapper the moving ***h1*** between the nozzles. Difference of pressures at the ends of sliding spool causes the spool shift ***z***. Elastic feedback rod bends, the flapper moves in opposite direction on size ***h2*** and

the anchor turns in opposite direction on the angle ***th2***.
Flapper takes position ***h = h1 – h2*** and the anchor takes angle ***th = th1 – th2***. Anchor gets horizontal move ***x = x1 – x2***. The force acting to the sliding spool is ***Fz*** and the hydrodynamic force of fluid jets of nozzles is ***Fhd***. The geometrical distances ***l1, l2, l3, ltu*** are also shown.

3. MULTI-POLE MODEL OF AN ELECTRO-HYDRAULIC SERVOVALVE

The multi-pole model is decomposed into three components – torque motor with flapper **TM**, nozzle-and-flapper valve **NF** and spool in sleeve with elastic feedback to flapper **SP.** The model is presented in Fig.4

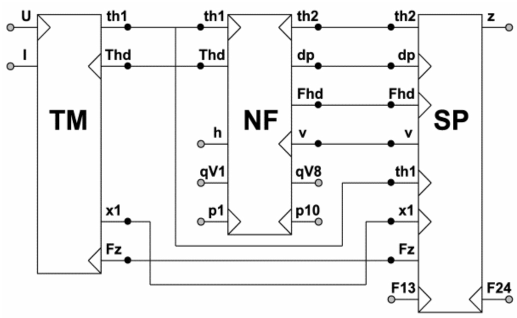

Fig. 4. Multi-pole model of an electro-hydraulic servovalve

The inputs of the multi-pole model of an electro-hydraulic servovalve are voltage ***U***, pressures ***p1***, ***p10*** and hydrodynamic forces of fluid jets ***F13***, ***F24*** against sliding spool. The outputs are current ***I***, displacement of the flapper ***h***, displacement of the sliding spool ***z*** and volumetric flow rates ***qV1***, ***qV8***. Torque evoking through hydrodynamic force of the fluid jets ***Thd***, difference of pressures on the ends of sliding spool ***dp*** and velocity ***v*** of the sliding spool are used as well.
Representation of the model bases on the following assumptions: an ideal current source (infinite impedance) is used; deformations of the rod from anchor to flapper are negligible.
Multi-pole models of components **TM**, **NF,** and **SP** are described more detail in Part 2 of the paper.

4. SIMULATION ENVIRONMENT

CoCoViLa is a flexible Java-based simulation environment that includes both continuous-time and discrete event simulation engines and is intended for applications in a variety of domains [5]. The environment supports visual and model-based software development and uses structural synthesis of programs [12] for translating declarative specifications of simulation problems into executable code. The environment is developed as an open-source software, its extensions can be written in Java and included into simulation packages. CoCoViLa is implemented in the Institute of Cybernetics at the Tallinn University of Technology. The CoCoViLa environment is free and platform-independent.
CoCoViLa (Fig. 5) supports a language designer in the definition of visual languages, including the specification of graphical objects, syntax and semantics of the language. CoCoViLa provides the user with a visual programming environment, which is automatically generated from the visual language definition.

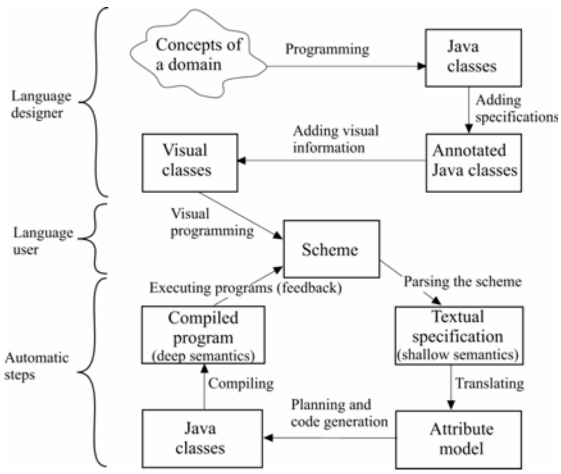

Fig. 5. Technology of visual programming in CoCoViLa

When a visual scheme is composed by the user, the following steps – parsing, planning and code generation – are fully automatic. The compiled program then provides a solution for the problem specified in the scheme, and the results it provides can be

feedback into the scheme, thus providing interactive properties.
Structural synthesis of programs is a technique for the automatic construction of programs from the knowledge available in specifications [12]. The method is based on proof search in intuitionistic propositional logic.
The synthesizer (planner) determines computational paths from initial variables to required goal variables (i.e., tries to solve a given computational problem "find values of V from given values of U", where U and V are sets of input and output variables). The planner's task is not only to construct a linear dataflow, but also to solve subtasks (higher-order dataflow) [13].
From a user's point of view the CoCoViLa framework consists of two components: Class Editor and Scheme Editor. The Class Editor is used for defining models of components of schemes as well as their visual and interactive aspects. The Scheme Editor is a tool for the language user. It is intended for developing schemes and for compiling (synthesizing) programs from the schemes according to the specified semantics of a particular domain. It provides an interface for visual programming, which enables one to compose a scheme from shapes of classes. The environment generated for a particular visual language allows the user to draw, edit and compile visual sentences (schemes) through language-specific menus and toolbars. The Scheme Editor is fully syntax directed in the sense that the correctness of the scheme is forced during editing. Drawing syntactically incorrect schemes is impossible.
When the visual classes have been built by software developers who must understand the problem domain as well, the language user need not be a software expert, but can work on the level of visual programming, arranging and connecting objects to create a scheme. Manipulating the scheme – a visual representation of a problem, is the central part of the user's activities.

5. COMPUTING PROCESS ORGANIZATION

Using visual specifications of described multi-pole models of technical chain system components one can graphically compose models of various chain systems for simulating statics, steady state conditions and dynamic responses.
When simulating statics or steady state conditions chain system behavior is simulated depending on different values of input variables. Initial and final values of input variables as well as number of calculation points are to be specified.
When simulating dynamic behavior, transient responses of the chain system caused by applied disturbances are calculated. Disturbances are considered as changes of input variables of the system (displacements, velocities, pressures, volumetric flows, load forces, load moments, control signals, etc.). Time step length and number of steps are to be specified. For integrations in dynamic calculations the fourth-order classical Runge-Kutta method is used in component models.
Computing processes are organized by corresponding process classes. To follow the system behavior in time, the concept of state is invoked. State variables are introduced for each component to characterize the element behavior at the current simulation step.
The simulation process starts from the initial state and includes calculation of following state (*nextstate*) from previous states (usually from *oldstate* and *state*). Final state (*finalstate*) is computed as a result of simulation.
A special method is used for calculating variables in loop dependences that cannot be calculated in straightforward way.
Such variables are split, initial approximate values are assigned and the variables are iteratively recomputed. Recomputing algorithms are constructed by the CoCoViLa program synthesizer as subtask solving algorithms. Feasibility of splitting

the variable, approximate initial value and request to find recomputing algorithm must be described in the multi-pole model of the technical chain system component.

SUMMARY

Difficulties arising in using existing modeling and simulation tools have been discussed.

Principles of multi-pole modeling have been described for technical chain systems. Modeling of electro-hydraulic servovalve is considered as an example of chain system. An intelligent simulation environment CoCoViLa supporting declarative programming in a high-level language and automatic program synthesis is used as a tool for modeling and simulation.

A special technique has been proposed that allows avoid solving large equation systems during simulations. Therefore, multi-pole models of large systems do not need considerable simplification.

In Part 2 multi-pole mathematical models of functional elements are described. Computing transient responses of the servovalve are considered.

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MULTI-POLE MODELING AND INTELLIGENT SIMULATION OF TECHNICAL CHAIN SYSTEMS (PART 2)

Gunnar Grossschmidt and Mait Harf

Abstract: *Composing of multi-pole models and simulation of dynamic responses of a technical chain system is considered in the paper.*
In Part 1 of the paper difficulties arising in using existing simulation tools have been discussed. A methodology has been proposed that seems to be free of most of these disadvantages. Modeling of electro-hydraulic servovalve has been considered as an example of chain system. An intelligent simulation environment CoCoViLa supporting declarative programming in a high-level language and automatic program synthesis is used as a tool for modeling and simulation.
In Part 2 multi-pole mathematical models of functional elements are described. Computing transient responses of the servovalve are considered.
Key words: *multi-pole model design, electro-hydraulic servovalve, intelligent programming environment, simulation.*

1. INTRODUCTION

Electro-hydraulic servovalve has control function in electro-hydraulic servo-systems that are used in various applications, including military and commercial aircraft flight controls, satellite positioning controls, controls for steering tactical and strategic missiles. They are also used in industrial applications, including injection molding machines for the plastics markets, metal forming, robots and manipulators, synchronized drives, power generating turbines, simulators used to train pilots etc. Computer modeling and simulation is the first step in the design of such systems.

The electro-hydraulic servo-system is controlled by an electro-hydraulic servovalve [1-7]. Sensors are used for feedback, regulator is used for creating and modifying the control signal.

2. MULTI-POLE MATHEMATICAL MODEL OF AN ELECTRO-HYDRAULIC SERVOVALVE

The multi-pole model of an electro-hydraulic servovalve is decomposed into three components – torque motor with flapper **TM**, nozzle-and-flapper valve **NF** and spool in sleeve with elastic feedback to flapper **SP** (Fig.1).

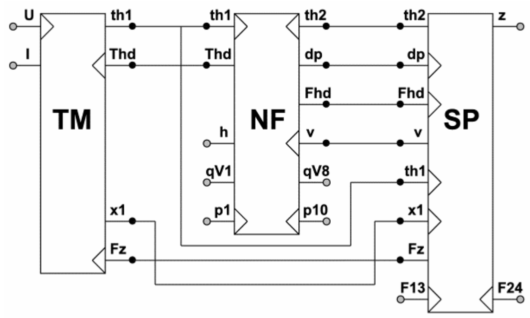

Fig. 1. Multi-pole model of an electro-hydraulic servovalve

2.1 Multi-Pole Mathematical Model of a Torque Motor TM

The input variables of the torque motor **TM** (see Fig. 1) are the input voltage ***U***, hydrodynamic force moment of the fluid jets to the flapper ***Thd*** and force ***Fz***, acting to the sliding spool. The output variables of the torque motor are anchor rotating angle ***th1*** from central position, linear displacement of anchor ***x1*** and current ***I***.

Mathematical dependences of torque motor **TM** for statics:

$I = U/R;$

$Jtu = Pi* (dtu)^4/64*(1 - (ds/dtu)^4);$

$ctu = 2*E*Jtu/ltu;$

$th1=1/(2*ctu-ctm)*(ktm*I-Fz*ltu-Thd)/2;$

$x1 = 1/(3*E*Jtu)*ltu^2* (ktm*I-Fz*ltu-Thd)).$

Additional equation for dynamics:

$Uin = U – koe*om.$

Differences for computing of Runge-Kutta coefficients:

$dI \; = (Uin - R*I)/L*delta;$

$dom = ((ktm*I-ltu*Fz-Thd)/2 - bvr*om – (ctu - ctm)*th1)/(Itm + Imfl)*delta;$

$dth1 = om*delta.$

2.2 Multi-pole mathematical model of a nozzle and flapper valve NF

The input variables of a nozzle-and-flapper valve **NF** (see Fig.1) are torque motor anchor rotating angle ***th1,*** anchor feedback rotating angle ***th2,*** velocity of the sliding spool ***v,*** feeding pressure ***p1*** and output pressure ***p10***. The output variables are the pressure difference of the sliding spool ***dp***, hydrodynamic force moment of the fluid jets to the flapper ***Thd,*** displacement of the flapper ***h,*** volumetric flow rate in inlet ***qV1*** and in outlet ***qV8***.

Detailed multi-pole block scheme of a nozzle-and-flapper valve **NF** is shown in Fig. 2.

Mathematical dependences of nozzle-and-flapper valve **NF** are as follows.

Equations for calculation of the areas:

for spool $A = Pi*dsp^2/4;$

for nozzles $Anoz = Pi*dnoz^2/4;$

for resistors R1...R8 $Ar1...Ar8 = Pi*(dr1...dr8)^2/4.$

The pressure drops in resistors R1...R8 of the nozzle-and-flapper valve are represented in dependence on volumetric flow rates and their values in square. Laminar and turbulent flows through resistors are taken into account.

Square resistance values for resistors R1...R8:

$R1...R8 = (rho1...rho8)/2/(mu1*(Ar1...Ar8))^2.$

Linear resistance values for resistors RL1...RL8:

$RL1...RL8 = AL*(lr1...lr8)*(nue1...nue8)* (rho1...rho8)*Pi/(Ar1...Ar8)^2/8.$

The physical properties of fluid (density **rho** and viscosity **nue**) are determined at constant temperature in dependence on resistor input pressure at each calculation step.

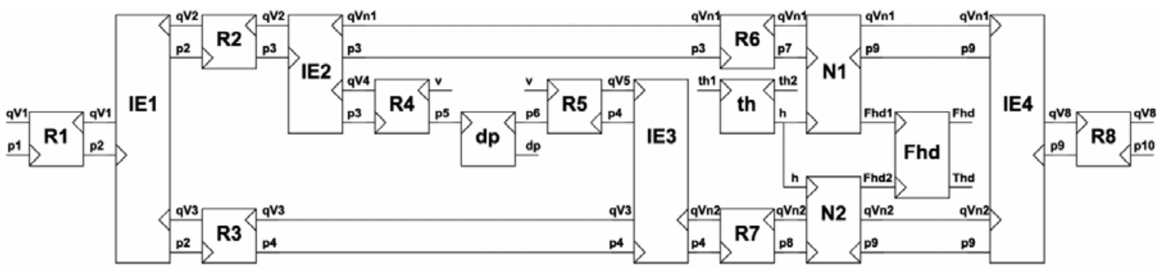

Fig. 2. Multi-pole block scheme of a nozzle-and-flapper valve **NF,** where **N1, N2** - nozzles, **R1...R8** - hydraulic resistors, **IE1...IE4** - interface elements (tee couplings), **dp** - difference of pressures on the ends of sliding spool, **Fhd** - sum of hydrodynamic forces of the fluid jets to the flapper, **th** – difference of inlet and feedback angular displacements of the TM anchor

Mathematical dependences of displacement of the flapper h, hydraulic conductivities Gn1, Gn2 and linear resistances RLn1, RLn2 of nozzle-and-flapper valve:

$h = (l1 - ltu)*(th1 - th2);$

$Gn1 = (munoz*Pi*dnoz*(hsymm - h))^2 * 2/rho9;$

$RLn1 = AL*lrn*nue9*rho9*Pi/(Pi*dnoz*(hsymm - h))^2)/8;$

$Gn2 = (munoz*Pi*dnoz*(hsymm + h))^2*2/rho10;$

$RLn2 = AL*lrn*nue10*rho10*Pi/(Pi*dnoz*(hsymm + h))^2)/8.$

For calculating volumetric flow rates and pressures in the servovalve it is necessary to determinate the approximate initial values of volumetric flow rates through nozzles. This can be done using non-linear oriented graph of the nozzle-and-flapper. To perform calculations more efficiently it is appropriate to transform the oriented graph into linear signal flow graph operating with volumetric flow rate square values (variables identified by prefix “w”). Iterations are used for calculating approximate initial values of volumetric flow rates through nozzles.

The output values are expressed as:

$h = (l1 - ltu)*(th1 - th2);$

$dp = p5 - p6;$

$Fhd = ((p7 - p8)*Anoz + (wqVn1 - wqVn2)*rho/Anoz);$

$Thd = ltu * Fhd;$

$qV1 = (wqV1)^{-2};$

$qV8 = (wqV8)^{-2}.$

2.3 Multi-pole mathematical model of a spool in sleeve with elastic feedback SP

The input values of a multi-pole model SP (see Fig. 1) are ***dp, Fhd, th1, x1, F13*** and ***F24***. The output values are ***th2, v*** and ***z***.

Mathematical dependences of statics of sliding spool with elastic feedback:

$A = Pi*(dz)^2/4;$

$Fz = A*dp;$

$Tz = ltu*Fz;$

$Thd = ltu*Fhd.$

It is necessary to solve the integral to determine bending moment of inertia of the conic feedback spring:

$$I = \frac{1}{l} * \int_0^l (d2 - 2 * x * tg\alpha)^4 * dx,$$

where $l = l2 - l3;$

$tg\alpha = (d_2 - d_1)/(2*l).$

The integral can be expressed as:

$I = l/(5*(d_2 - d_1)*(d_2^5 - d_1^5)),$

where $(d_2^5 - d_1^5) = (d_2 - d_1)*(d1^4 + d1^3*d2 + d1^2*d2^2 + d1*d2^3 + d2^4).$

The bending moment of inertia of the conic feedback spring:

$Jf = Pi*(d1^4 + d1^3*d2 + d1^2*d2^2 + d1*d2^3 + d2^4)/(5*64).$

The bending moment of inertia of the flexure tube:

$Jtu = Pi*(dtu)^4/64*(1 - (ds/dtu)^4).$

The values of x2, x and th2 are:

$x2 = 1/(3*E*Jtu)*(ltu)^2)*(Tz + Thd);$

$x = x1 - x2;$

$th2 = ltu/(2*E*Jtu)*(Tz + Thd)).$

The sliding spool displacement:

$zc = 1/(3*E*Jf)*(l2-l3)^3*Fz - (l1+l2)*(th1-th2) + x.$

The bending rigidity of feedback spring:

$cz = (3*E*Jf)/(l2-l3)^3.$

Differences for computing Runge-Kutta coefficients:

$dv = (Fz - Ffr - hsp*v - cz*(z + l*(th1-th2c) - x)/msp*delta;$

$dz = v*delta.$

3. SIMULATING OF DYNAMICS

The simulation task description of an electro-hydraulic servovalve dynamics in CoCoViLa environment [8] is shown in Fig. 3.

Multi-pole models of functional elements: **TM** – torque motor, **NFD** – nozzle-and-flapper valve, **SP** – sliding spool in sleeve with elastic feedback from spool to flapper.

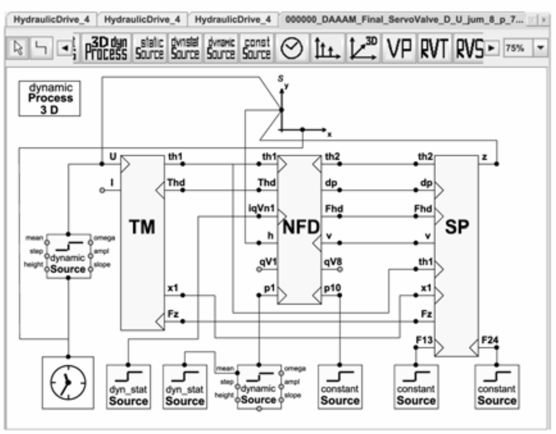

Fig. 3. Simulation task description of an electro-hydraulic servovalve dynamics

Inputs: dynamic Source – input disturbances (voltage ***U,*** feeding pressure ***p1***), dyn_stat Source (***p1*** mean value, initial volumetric flow through nozzle ***iqVn1***); constant Source – constant values (outlet pressure ***p10***, hydrodynamic forces of fluid jets ***F13*** and ***F24*** acting to sliding spool).

Outputs: current ***I***, displacement ***h*** of the flapper, displacement ***z*** of the sliding spool.

Iterated variables: TM.th1, TM.x1, SP.th2, SP.v.

Simulated graphs: input voltage ***U***, displacement ***h*** of the flapper, displacement ***z*** of the sliding spool.

Simulation manager*:* dynamic Process 3D.

Parameters for TM: ctm = 10, ds = 0.003, dtu = 0.0038, E = 2.1E11, Imax = 5e-2, ktm = 3, l1 = 0.0105, l2 = 0.020, ltu = 0.0075, R = 200, bvr = 0.1, Imfl = 3E-7, Itm =2E-7, koe =2.3, L = 0.05.

Parameters for NF: AL = 75, dnoz = 4E-4, dsp = 8E-3, dr1 = 2E-3, dr2 = 0.22E-3, dr3 = 0.22E-3, dr4 = 1E-3, dr5 = 1E-3, dr6 = 0.8E-3, dr7 = 0.8E-3, dr8 = 1.6E-3, hsymm = 4E-5, l1 = 0.0105, lr1 = 5E-4, lr2 = 2E-4, lr3 = 2E-4, lr4 =1E-3, lr5 =1E-3, lr6 = 5E-4, lr7 = 5E-4, lr8 =1E-3, lrn = 5E-4, ltu = 0.0075, mu1 = 0.7, mu2 =0.63, munoz = 0.65.

Parameters for SP: d1 = 0.0005, d2 = 0.00119, ds = 0.003, dtu = 0.0038, dz = 0.008, E = 2.1E11, Ffr = 0.4, l1 = 0.0105, l2 = 0.020, l3= 0.004, ltu = 0.0075, zmax = 6.8E-4, hsp = 15, msp =1E-2.

In the examples dynamic behavior of the servovalve is simulated depending on step and jump disturbances of input voltage.

A special simulation engine has been used for performing simulations and calculating dependences on two different arguments (time and disturbance step in current example). In the examples several dependences can be calculated and presented simultaneously.

Simulation results are shown in Fig. 4…7.

In Fig. 4 the results of the simulation are shown when two different input step disturbances (voltage ***U*** = 2 and 8 V) during tstep = 0.01 s (graphs 1) are applied and ***p1*** = 2.1E7 Pa, ***p1*** = 1.5E6 Pa, ***F13***,***F24*** = 0 N.

Displacements ***h*** of the flapper (graphs 2) in interval of 0...tstep follow the input disturbances. In the interval from tstep to (0.02, 0.04 s) the flapper takes a new position (8E-8, 28E-8 m) due to feedback. Displacements ***z*** of the sliding spool (graphs 3) increase from 0 to (1.5E-4, 5.8E-4 m) during (0.022, 0.039 s). The results are in accordance with catalog characteristics [9].

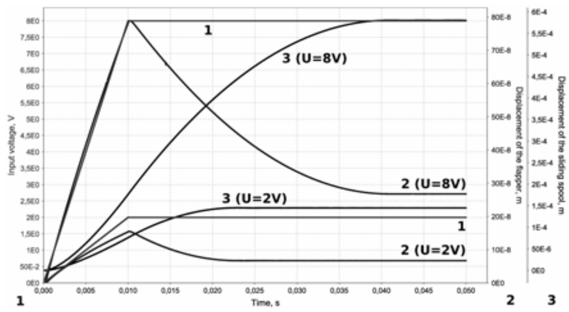

Fig. 4. Simulated graphs of the electro-hydraulic servovalve for step responses (input voltage step ***U*** = 2 and 8 V)

In Fig. 5 the results of the simulation are shown when the input step disturbance (voltage ***U*** = 8 V) during tstep = 0.01 s (graphs 1) is applied and ***p10*** = 1.5E6 Pa, ***F13***, ***F24*** = 0 N. The graphs are calculated for two different values of feeding pressure ***p1*** = 7E6 and 21E6 Pa.

Displacements ***h*** of the flapper (graphs 2) in interval of 0...tstep follow the input disturbances. In the interval from tstep to (0.045, 0.040 s) the flapper takes a new position (59E-8, 28E-8 m) due to feedback. Displacements ***z*** of the sliding spool (graphs 3) increase from 0 to (3.5E-4, 5.8E-4 m) during (0.045, 0.040 s).

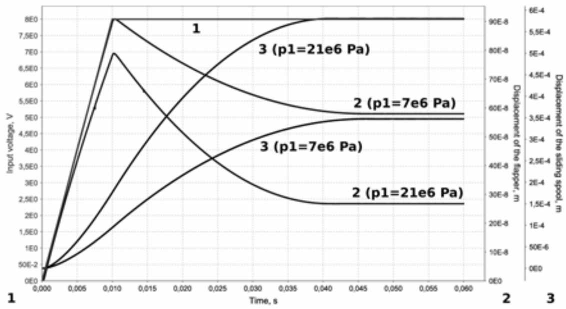

Fig. 5. Simulated graphs of the electro-hydraulic servovalve for step response (pressure ***p1*** = 7E6 and 21E6 Pa)

In Fig. 6 the results of the simulation are shown when two different input jump disturbances (voltage ***U*** = 2 and 8 V, tstep1 = tstep2 = 0.01 s, tjum = 0.02 s)) (graphs 1) are applied and ***p1*** = 2.1E7 Pa, ***p10*** = 1.5E6 Pa, ***F13*** = ***F24*** = 0 N.

In the rising and falling phases of jump disturbance flapper displacement ***h*** (graphs 2) follows the input. When jump disturbance stays on maximum level the flapper tries to take a new position due to feedback. After ending the jump disturbance flapper returns to the initial position.

Displacement ***z*** of the sliding spool (graphs 3) reacts with delay to the rising and falling phases input jump disturbance. When jump disturbance stays on maximum level, ***z*** reaches the maximum (in case of U = 2V).

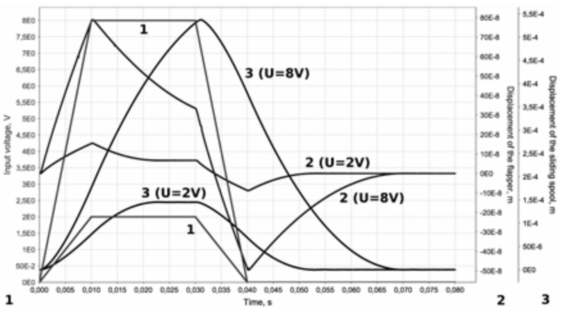

Fig. 6. Simulated graphs of the electro-hydraulic servovalve for jump responses (input voltage step ***U*** = 2 and 8 V)

After ending the jump disturbance sliding spool returns to the initial position due to feedback.

In Fig. 7 the results of the simulation are shown when input jump disturbance (voltage ***U*** = 8 V, tstep1 = tstep2 = 0.01 s, tjum = 0.02 s)) (graphs 1) is applied and ***p1*** = 2.1E7 Pa, ***p10*** = 1.5E6 Pa, ***F13*** = ***F24*** = 0 N. The graphs are calculated for two different values of feeding pressure ***p1*** = 7E6 and 21E6 Pa.

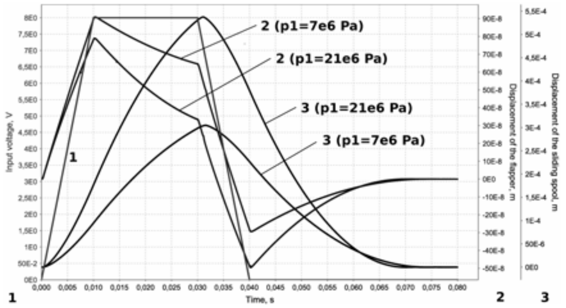

Fig. 7. Simulated graphs of the electro-hydraulic servovalve for jump response (pressure ***p1*** = 7E6 and 21E6 Pa)

A result to be pointed out is that in case of a particular input jump disturbance the displacement of flapper (graphs 2) is less when the feeding pressure is higher. Displacement ***z*** of the sliding spool (graphs 3) is greater when the feeding pressure is higher.

CONCLUSIONS

In the Part 1 of the paper principles of multi-pole modeling of technical chain systems have been described. Modeling and simulation of an electro-hydraulic servovalve has been considered as an example. An intelligent simulation environment CoCoViLa supporting declarative programming in a high-level language and automatic program synthesis is used as a tool for modeling and simulation.

A special technique has been proposed and used that allows to avoid solving large equation systems during simulations. Therefore, multi-pole models of large systems do not need considerable simplification.

In the current paper multi-pole mathematical models are considered in detail. Results of dynamic simulations have been presented and discussed.

The proposed modeling and simulation procedure is an efficient and powerful tool in design of technical chain systems.

ACKNOWLEDGMENTS

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NOMENCLATURE

Nomenclature for torque motor TM with flapper

Input variables (input poles):

Fz Force, acting to the sliding spool, N
Thd Torque evoking through hydrodynamic forces of the fluid jets to the flapper, acting onto anchor of the TM, Nm
U Input voltage of the TM, V

Output variables (output poles):

I Current to the TM, A
th1 TM anchor rotating angle, rad
x1 Horizontal bending displacement of the flexure tube, m

Inner variables:

om TM anchor rotating angle velocity, rad/s
Uin Input voltage to the TM in dynamics, V

Differences for computing of Runge-Kutta coefficients:

dI Difference of current to the TM, A
dom Difference of angular velocity of the TM anchor, rad/s
dth1 Difference of TM anchor rotating angle, rad

Parameters:

bvr Viscous angular resistance coefficient of the anchor of TM, Nms/rad
ctm Angular stiffness of the "magnet spring" of the TM, Nm/rad
ds Flexure tube inner diameter, m
dtu Flexure tube outer diameter, m
E Modulus of elasticity, N/m^2
Imax Max. current in the TM, corresponding to max. displacement of the spool (zmax), A
Itm Moment of inertia of the TM anchor, Nms^2
Imfl Moment of inertia of the flapper, reduced to the axis of the TM, Nms^2
koe Coeff. of the opposite electromotore force, Vs/rad
ktm Coeff. of the moment characteristic of the TM, Nm/A
ltu Flexure tube length, m
l1 Distance between the TM anchor and the nozzle axis, m
l2 Distance between the nozzle axis and feedback spring end on the spool, m
L Inductivity of the circle, H
R Actual resistance of the circle, Ω

Parameters to be calculated:

ctu Angular bending stiffness of the flexure tube, Nm/rad
Jtu Bending moment of inertia of flexure tube, m^4

Nomenclature for nozzle-and-flapper valve NF

Input variables (input poles):

p1 Feeding pressure of servovalve, Pa
p10 Outlet pressure of the servovalve, Pa
th1 Inlet angular displacement of the TM anchor, rad
th2 Feedback angular displacement of the TM anchor, rad
v Velocity of the sliding spool, m/s

Output variables (output poles):

dp Difference of pressures on the ends of sliding spool, Pa
Fhd Sum of hydrodynamic forces of the fluid jets to the flapper, N
h Shift of flapper from symmetric position, m
qV1 Feeding volumetric flow rate, m^3/s
qV8 Outlet volumetric flow rate, m^3/s
Thd Torque evoking through hydrodynamic force of the fluid jets to the flapper, acting onto anchor of the TM, Nm

Inner variables:

Fz Force, acting to sliding spool, N
p2...p9 Pressures, Pa
qV2...qV7 Volumetric flow rates through resistors, m^3/s
qVn1, qVn2 Volumetric flow rates through nozzles, m^3/s
wqV1...wqV8 Volumetric flow rates through resistances in square, m^6/s^2
wqVn1, wqVn2 Volumetric flow rates through nozzles in square, m^6/s^2

Parameters:

AL Hydraulic friction coefficient of laminar flow
dnoz Diameter of nozzles, m
dsp Diameter of sliding spool, m
dr1...dr8 Diameters of hydraulic resistors, m
hsymm Distance between flapper and nozzle in symmetric position of flapper, m
l1 Distance between the TM anchor and the nozzle axis, m
lr1...lr8 Lengths of fluid jets through resistors R1...R8 for computing of linear resistances, m
lrn1, lrn2 Lengths of fluid jets through nozzles N1,N2 for computing of linear resistances, m

ltu Bending length of the flexure tube, m
mu1 Discharge coefficients of resistors R1, R4…R8
mu2 Discharge coefficients of resistors R2, R3
munoz Discharge coefficient of nozzles N1, N2

Parameters to be calculated:
A Active areas of spool at the ends, m^2
Anoz Passage area of the nozzles, m^2
Ar1...Ar8 Passage areas of resistors R1...R8, m^2
Gn1, Gn2 Hydraulic conductivities of nozzle-and-flapper valve, m^7/kg

Nomenclature for spool in sleeve SP with elastic feedback

Input variables (input poles):
dp Difference of pressures on the ends of spool, Pa
F13 Hydrodynamic force of fluid jets through slot 1 and 3, N
F24 Hydrodynamic force of fluid jets through slot 2 and 4, N
Fhd Hydrodynamic force of the fluid jets to the flapper, N
th1 Inlet angular displacement of the TM anchor, rad
x1 Linear displacement of the flexure tube, m

Output variables (output poles):
Fz Force, acting to the sliding spool, N
th2 TM anchor rotating angle evoking through feedback, rad
v Sliding spool velocity, m/s
z Sliding spool displacement, m

Inner variables:
Thd Torque evoking through hydrodynamic force of the fluid jets to the flapper, Nm
Tz Torque evoking through force, acting to sliding spool, N
x2 Horizontal bending displacement of the flexure tube, m

Differences for computing of Runge-Kutta coefficients:
dv Difference of sliding spool velocity, m/s
dz Difference of sliding spool displacement, m

Parameters:
d1 Feedback conic spring litter diameter, m
d2 Feedback conic spring major diameter, m
ds Flexure tube inner diameter, m
dtu Flexure tube outer diameter, m
dz Sliding spool diameter, m
E Modulus of elasticity, N/m^2
Ffr Friction force of sliding spool, N
hmax Maximum displacement of the flapper from symmetric position, m
hsp Damping coefficient of the sliding spool, Ns/m
ltu Flexure tube length, m
l1 Distance between the TM anchor and the nozzle axis, m
l2 Distance between the nozzle axis and feedback force from spool, m
l3 Distance between the nozzle axis and end of rigid part of flapper, m
l Distance between the TM anchor and feedback force from spool, m
msp Mass of sliding spool, kg
zmax Maximum position of sliding spool from initial position, m

Parameters to be calculated:
A Active areas of spool at the ends, m^2
ctu Rotating rigidity of the flexure tube, Nm/rad
cz Feedback spring bending rigidity, N/m
Jf Bending moment of inertia of the feedback spring, m^4
Jtu Bending moment of inertia of the flexure tube, m^4

Calculation parameters:
delta Time step, s
tau Inverse value of the time step, (1/s)

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EMPLOYEE STABILITY IN THE AUTOMOTIVE COMPANY

Holecek, J.; Caganova, D. & Cambal, M.

Abstract: *Market economies are influenced by the fact that employees, both highly and less specialised, change their places of work at increasingly shorter intervals. It often does not depend only on the internal situation in companies but also from the external conditions in the labour market. The staff turnover rate was studied as a possible indicator of instability of employees in the conducted research. The research was carried out in an automotive enterprise, employing more than 3000 people, with a turnover rate reaching from 0.8 to 1.0 % per month and about 10 % per year during the study period. The data was collected over a 9 month period, during which closing interviews were conducted with all job leaving employees and their managers, and the internal study regarding employee satisfaction was assessed. Conclusions can be drawn with regards to the analysis of staff turnover and its causes and a draft of the measures concerned with adaptation, managerial communication at lower levels, reward system and social care, as well as the harmonisation of two directions of managerial behaviour: performance orientation and relationship orientation.*

Key words: employee stability, staff turnover, motive, stimulus, controlled interviews.

1. INTRODUCTION

In our research we looked at turnover as a possible indicator of instability. Research was implemented in the automotive enterprise which employs more than 3 000 employees.

Monthly turnover rate is defined as: Total number of employees who were fluctuated x 100.

The average monthly number of employees was from 0.8 to 1% in the pursued period and about 10% per year. From company view, this turnover was unacceptable relative to character of production and required quality of final product. The company looks for possibilities from this situation.

The aim was to achieve gradually reduce the annual turnover from current 10% to the maximal year turnover rate 3%, what is the monthly turnover rate 0,25%. This was achieved by rigorous analysis based on research and developing measures in the next two years.

2. CHARACTERISTIC OF SELECTED COMPANY AND RESEARCH SAMPLES

Research was realized in automotive enterprise which employs more than 3 000 employees.

In 9 month period the job termination interviews were carried out with all job leaving employees and with their managers. For comparison, we also used the annual survey of staff satisfaction with the work in the company carried out enterprise.

After job termination interviews with job leaving employees the turnover was divided into 6 categories according to Figure 1.

The turnover is divided into this internal categories:

- **adverse turnover:** job leaving employees which are necessary for enterprise

- **acceptable turnover:** reducing the number of employees from side of enterprise
- **avoidable turnover:** job leaving employees which could be affected or who´s leaving could be prevented
- **unavoidable turnover:** job leaving employees which can be avoided (further study, serious illness, moving to leave for better paid jobs to countries Central and Eastern Europe, retirement, transfer within the enterprise).

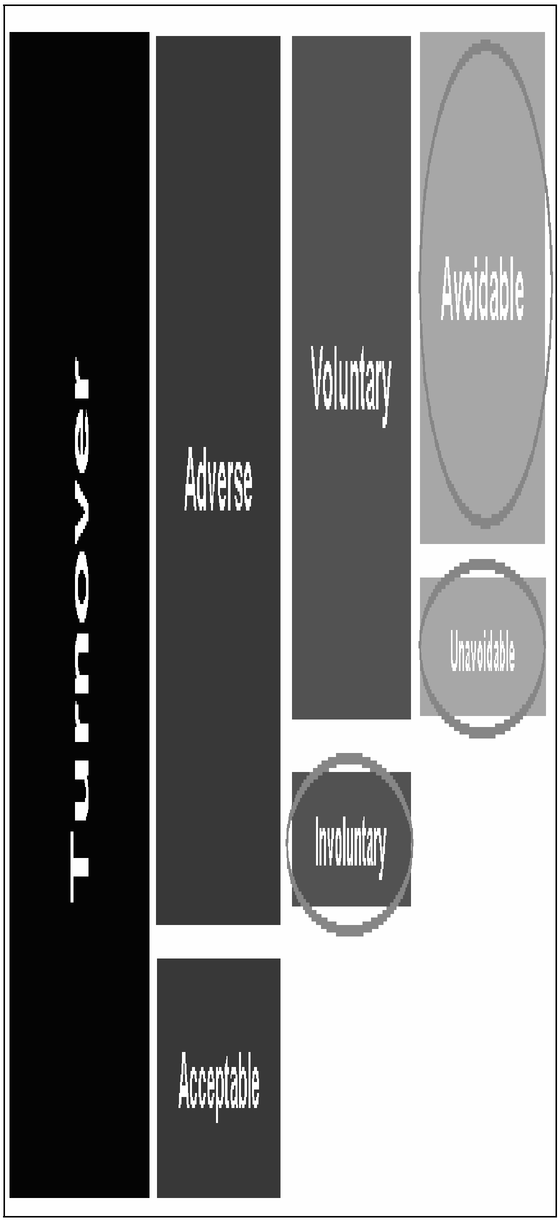

Fig. 1. Internal categories of turnover

In our further research we looked at adverse avoidable turnover. We also define the concept of avoidable monthly turnover rate as:

$$\frac{A-B}{C}\cdot 100 \quad (1),$$

where:
A is number of job leaving emplyees during month,
B is number of unavoidable outcomes and
C is the average monthly number of employees.

The avoidable turnover was 60% from the total monthly turnover. Implementation of 268 interviews with employees who belonged to a group of adverse avoidable turnover, we divided the causes of this turnover into 3 groups:

- **labor market,**
- **work in enterprise,**
- **personal reasons.**

The proportion factors of adverse avoidable turnover is shown in Figure 2.

Based on the findings, we gave in the next examination of avoidable adverse fluctuations (AAF) in individual departments. We found, that most employees leave the assembly department (42%) and the body department (33%), as the main cause the assembly workers reported the type of work and working conditions, working conditions in the body department. In both departments it was lack the financial evaluation, which in this case we have not considered so important, because monthly wages in these plants are 35% higher than in the labor market in a similar sector. Nearly 15% of employees reported as reasons for the termination, relations in team and other reasons, that they did not want to give more. In discussions with them we found out, however, that it was all about relationships between superiors and employees. The most important finding was that more than 90% of employees leaving the group AAF, were employees who worked in business less than 1 year, 80% of employees leaving the company in the first three months of employment and of this number 80% in the first month. This clearly showed, that the expectations of workers regarding working conditions, and also the incorporation of awards (too much work and high work rate did not correspond to award) were not met.

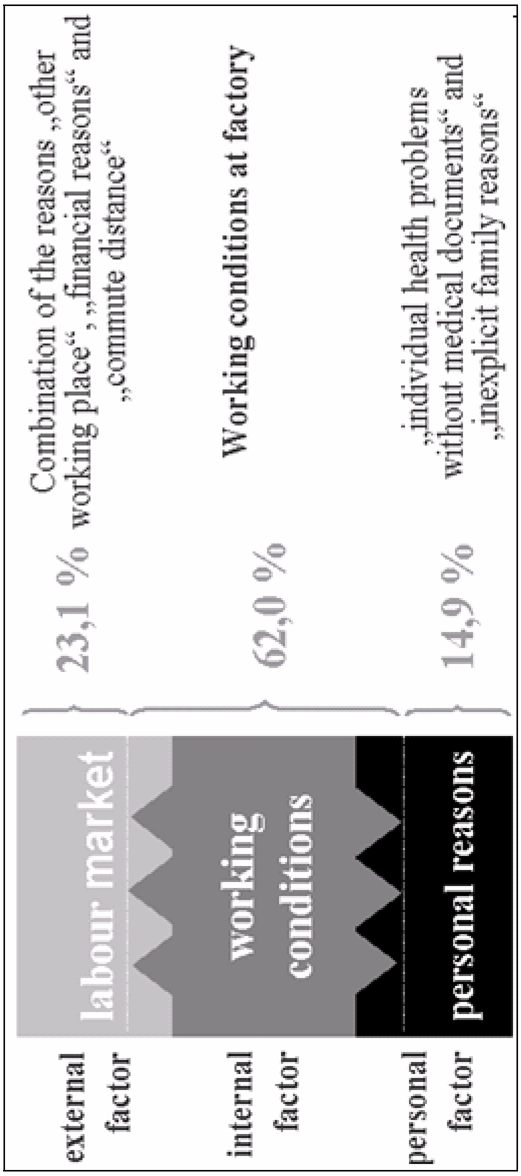

Fig. 2. The proportion factors of adverse avoidable turnover

3. COMPARISON OF THE THEORETICAL BACKGROUND OF JOB SATISFACTION WITH LEARNED KNOWLEDGES

We compared the lessons learned from the theory of motivation and satisfaction with the theory of researching job satisfaction, then we had to identify factors of job satisfaction of preventing a reduction of turnover. We thought about the elements of which an employee can give the importance and we attached them into three dimensions [1].

1. dimension - organizational settings (where man goes),
2. dimension - the status and relationships in the workplace (what man is),
3. dimension - benefits and work requirements (which makes a work for man).

The first dimension involves a lot of factors, that create conditions for work and achieving good performance. This dimension is related to the very basic level of Maslow's pyramid of motivation and reflects primarily a general feeling of safety and comfort in the workplace. These are factors such as work environment, safety at work, physical conditions of the working environment (noise, vibration, lighting, temperature, work equipment) [2]. As a completely new, but for turnover in the enterprise, decisive factors were the requirements for technical skill and control techniques and the associated lack of training of employees and their integration into the enterprise space (large-scale manufacturing facilities, where an employee could "lose", the availability of sanitary facilities, cafeterias). When we were talking we found out, for example, that the employee is required to work at full power after an initial week-training, or employee after the initial program was unable to find their place of work and the next day simply did not come to work.

We considered this dimension as an essential and as a basis we proposed the extension of training new employees from two weeks to one month in specialized training centers of manufacturing facilities outside the production line (professional rooms) and within of this program emphasise, except of qualifications required for performance of work, also to familiarize employee with full production in the hall to prepare for the gradual pace of work on the line and shift working regime. Up to 72% of new recruits were graduates of secondary schools and colleges who have not had any work habits. This measure a year after introduction mean the 48% reduction in turnover, because employees come to work and trained acclimatized and their superiors just had to properly stimulated them. They were sufficiently motivated.

The second dimension incorporates two hygiene factors, that although have not strong motivational in nature, but if absent, can cause considerable dissatisfaction at work. Man is perceived not only as an individual, but also as part of the social environment. Important factors are the human condition in interpersonal relationships, their job title and also the quality of interpersonal relationships, of which the most important relationship is superior to a subordinate. Method of negotiation of the principal with employees is one of the sources of their satisfaction. [3], [4]. This is reflected particularly in the evaluation of the employee (whether formal or informal), understanding the needs of employees, respecting promises and resolve conflicts [8]. As mentioned earlier, only 15% of employees have left the company due to bad relations with others and their satisfaction by the supervisor (eg failure to insensitive failure to give holidays, "punishment" for lack of overtime work on Saturdays, etc..). As a measure we proposed to introduce the project "high-high manger," which focused on a targeted selection and training of managers in the field of motivation and coping with two-way communication. The aim was to strengthen the behavior of managers, oriented in interpersonal relationships and strengthen their behavior in orientation to achieve the performance of employees. We also suggested to introduce the audit team in teams, where XX turnover exceeded 1% per month.

The third dimension incorporates the expectations of employees „what work gives to the man“. In this direction, the employee is comparing, if power, which he is maked, is proportional to the appreciation, that is in the form of wages and non-formal awards and benefits received. Like a lack of appreciation and qualitative and quantitative overload can lead to stress, job dissatisfaction to the subsequent departure [5]. Important factors in this dimension are therefore effective rewarding based on performance, fair rewarding based on an objective evaluation of the job, transparency and awareness of the rewarding system and currently there are employee benefits, which are playing an increasingly important role [6]. In personal development of employees it is a professional (horizontal) and career (vertical) growth and self-fulfillment [7]. In this area we proposed to do an analyze of trends and implement variable pay component of remuneration performance since the second month after the initial training (previously it was only after 6 months). The reason was that even 80% of fluctuated employees from company were employeed less than three months. We also proposed to increase the weight of social benefits and attractive drawing from Social Fund. As total system suggestion we measured to implement the project of modernization of personal service, where personal service just has to be a catalyst for improvment the communication between the leader and subordinates.

4. RESUME

By analysing of fluctuations in a particular automotive business through nine months of research and the causes of fluctuations compared to specific theoretical basis, we proposed the following measures to reduce turnover:

1. provide initial training of employees in special training centers of manufacturing facilities outside the production line of at least 4 weeks. The training must also acquire the necessary skills to perform work (training) include the familiarization of staff with the hall, the bathrooms, work organization and preparatory process

for the pace of work and in exchange of modes of line.
2. establish a project for training of line managers "high-high manager" to strengthen the manager's behavior in interpersonal relationships.
3. in case of high turnover make an audit in a team relationships.
4. implement the project of modernization of personnel work focused on identifying problems of employees and preparation of personnel issues for managers to propose solutions.
5. introduce a variable performance component of awards since the second month of employment (after initial training).
6. increase the weight of social benefits to employees and attractive drawing from Social Fund and inform the employees of its existence.
7. continue in the established system of job termination interviews with departing employees according to a prepared questionnaire and regularly evaluate the fluctuation analysis.

Fourteen months after the introduction of these measures, the monthly turnover rate gradually decreased from the original 0.93% to 0.28%, which represent an annual turnover of 3.64%.

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INNOVATION, PRODUCT DEVELOPMENT AND PATENTS AT UNIVERSITIES

Kartus, R. & Kukrus, A.

Abstract:
In the present article actual matters of technological innovations are dealt with in the context of research universities, mainly taking into account the circumstances in Estonia. One of the cognitive models of the process of technological innovation has been presented. Patents are an integral part of technological innovation, notably in the case of development of new products. The patent statistics given in the article shows that despite wishes the business sector and universities not enough oriented internationally. Key words: knowledge-based economy, license of rights, patents statistics, product development, technological innovation, university, utility model.

1. INTRODUCTION

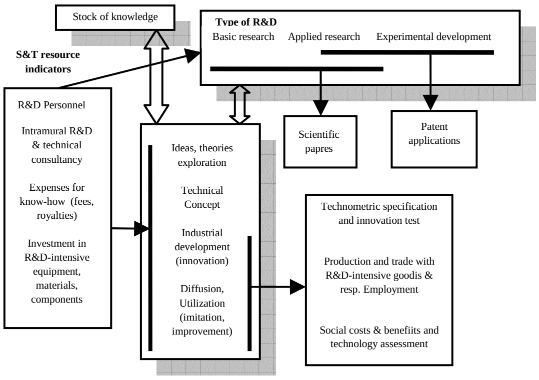
Explosive development of information technology during in the recent decades has significantly influenced the development of innovative products and their use in practice. Bringing innovations to market has not been the main historical role of university based researchers. Instead, university researchers quite appropriately concentrate on basic science. There is an eternal dilemma whether it is more important to publish the scientific papers or to file patent applications. As technologies have grown more sophisticated and emerging industries have become more high-tech, universities have become more important players in the processes of invention, innovation, and commercialization [1]. Undoubtedly patents are an indicator showing the competitiveness of the products and technological processes created as a result of R&D activities in the universities. National research and development programmes were launched on the basis of the strategy for developing these key technologies [2].

2. MEANING AND MODELS OF THE INNOVATION

Innovation means different things to different people. Generally innovations are divided into technological innovations and non-technological innovations.

Technological innovations comprise new products and processes and significant technological changes of products and processes.

In order to harmonize the understandings of the nature of the innovation and to compare the countries on the macro level as well as the enterprises and other institutions on micro level nowadays OECD methodology based on three manuals is used. The Frascati Manual contains standard practice for surveys on research and experimental development (R&D). The Oslo Manual gives guidelines for collecting and interpreting technological innovation data and Patent Manual is intended to give guidance on the measurement of scientific and technological activities using patent data as science and technology indicators. According to the Oslo Manual (point 59) the knowledge-based economy is an expression coined to describe trends in the most advanced economies towards greater dependence on knowledge, information and high skill levels, and an increasing need for ready access to all of these. R&D and innovation are key elements in the knowledge-based economy.



Source: Schmoch et al, OECD

Fig. 1. Models of the process of technological innovation

In Figure 1 one of the cognitive models of the process of technological innovation has been given for better understanding of the nature of the innovation.

3. TECHNOLOGICAL INNOVATION AND PATENTS

Nowadays development of technological innovations is based mainly on the system of intellectual property, especially on industrial property. However, legal protection of the subjects of industrial property, first of all inventions plays an important role in the industrial and innovation policy of industrially developed countries.

Patent is a good measure of accumulation of national intellectual capital. It represents one aspect of country's R&D effort. It is a good approximation for technological sophistication [3].

Disadvantages of the patents as indicators are that patents measure inventions rather than innovations. Not all inventions are patentable. This is the case of software, which is protected only by copyright, except in the USA. Firms prefer to in many cases protect their innovations with other methods, such as technological complexity (know-how) or other industrial secrecy.

Despite the fact that, taking into account the afore given, patents can be treated as an indication of the efficiency of innovation process in different ways, their existence and number of patents is extremely important nowadays let alone because a patent portfolio of sufficient size is required for a successful “patent arms race”.

4. PRODACT DEVELOPMENT AND UNIVERSITY INVENTIONS

In case of university research there is an eternal dilemma whether it is more important to publish the scientific papers or to file patent applications in the innovation process from basic research until experimental development. International publications are without doubt essential for the universities, because these are the main indicators at accreditation of the universities. But large number of references and interest in scientific articles do not mean that the results of the scientific researches have novelty to the extent that they can be protectable. Undoubtedly patents are an indicator showing the competitiveness of the products and technological processes created as a result of R&D activities in the universities. Neither development of new products nor sustainable cooperation with industry is possible without patents. Moreover, competitive products have to be protected as a basis for the establishment of start-up and spin-off firms. Although patenting activity of the universities of the EU has increased, the universities of the USA and Japan are still on the leading position. According to the WIPO top ten university applicants by number of published PCT international applications in 2010 had between 306 and 80 applications [4].

5. PATENTING ACTIVITIES IN ESTONIA

As it was mentioned before information and communication technologies, biotechnologies and material technologies are technologies considered key technologies for the economy of Estonia to which much attention has been paid. These fields of technologies have been one of the most important fields of technologies in the world for a long time from the standpoint of innovation. In 2010 according to the WIPO number of PCT international applications published in the field of digital communication saw the fastest growth 17.3%, (10,581 published applications). This technical field accounted for the largest share of total PCT applications published in 2010. Almost every other field of technology experienced declines or modest growth. The sharpest decline in patenting was seen in the field of telecommunications [5]. Scientific research has been carried out in the aforementioned key areas in Estonia for the last 30-40 years. Therefore there are highly qualified scientists in these areas and nowadays they have assembled into two main research universities – Tallinn University of Technology (TUT) and the University of Tartu (UT). Before the 1990-ies the universities had for their basic research and applied research an output as an experimental development either in Estonia or former Soviet Union. It should be mentioned that unfortunately in Estonia there is no industry for implementing key technologies to the extent to have an essential impact in the economy, incl. as an employer. However, especially biotechnology and material technology are areas which require big investments for the implementation of production and highly qualified work force, which are nowadays clearly too demanding for the economy of Estonia. Taking that into account it can be understood that the universities wish to prefer international cooperation to internal in Estonia in the field of high technology.

Proceeding from the evaluation on the basis of the research on innovation in the Baltic region made by Technopolis Group to the EU Commission, DG Regional Policy in April 2011 the small absolute number of patents and the absence of patents in some fields suggests, firstly, that the business sector in all three Baltic States is not internationally oriented and secondly there is an absence of industries, or of R&D performing firms, in some key fields. The low number of patents makes it not possible to identify a technological specialization for these three countries [6].

In Fig. 2 the number of Estonian patent applications and granted patents filed with the Estonian Patent Office in the years 2005-2011 and in fig. 3 the number of utility model applications and registrations has been given.

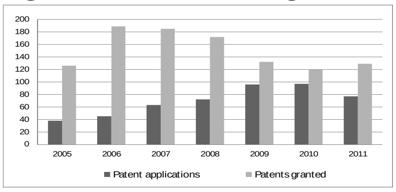


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Fig. 2. Patent applications and granted patents

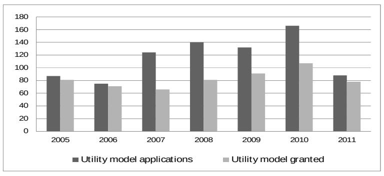

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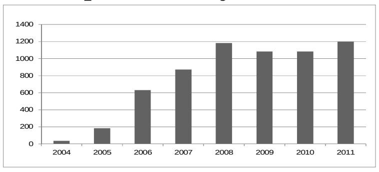
Fig. 3. Utility model applications and registrations

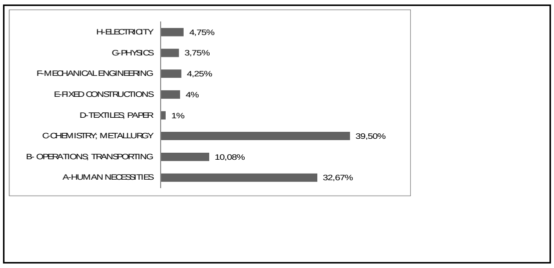
In fig. 4 European patents enforced in Estonia have been shown. It should be mentioned that the numbers seen are too low to call Estonia a technologically developed country.



Source: EPA

Fig. 4. European patents enforced in Estonia

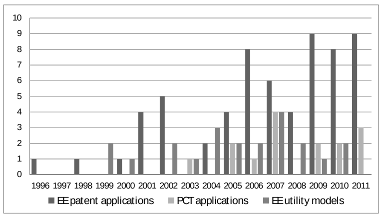
In Figure 5 it can be seen which fields of technology the patents enforced in Estonia in 2011 belong. It should be mentioned that in class C enforced patents concern mainly pharmaceutical industry. The rate of the enforced patents belonging into the areas of key technologies is small, which may mean that there is little interest in making investments in these fields.



Source: EPA

Fig. 5. European patents by IPC inforced in 2011

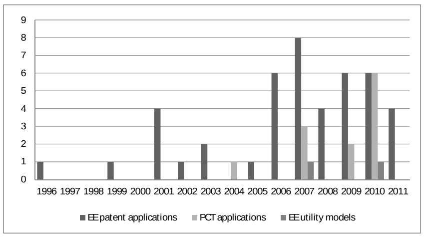
In fig. 6 and fig. 7 the number of patent applications, utility model applications and PCT international applications filed with the Estonian Patent Office by the TTU and the UT during the period from 1996 until 2011 has been given. It can be seen that the absolute number of applications for legal protection of inventions has been very low in case of both universities during the whole period. On the whole from the patents granted on the bases of the total number of 44 patent applications filed with the Estonian Patent Office by the TTU 17 patents were still in force at the end of 2011. In case of the UT 12 patents were in force from the 36 filed patent applications. The small



Source: EPA

Fig.6. Patent and utility model applications of the Tallinn University of Technology

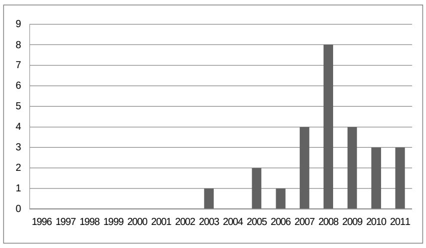
On the whole from the patents granted on the bases of the total number of 44 patent applications filed with the Estonian Patent Office by the TTU 17 patents were still in force at the end of 2011. In case of the UT 12 patents were in force from the 36 filed patent applications. The small number of patents in force reveals that it is impossible to make use of the inventions or their long-term legal protection in Estonia has not been required.



Source: EPA

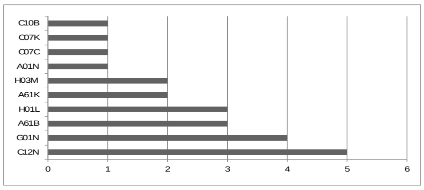
Fig.7. Patent and utility model applications of the University of Tartu

In fig. 8 the number of published PCT applications of Tallinn University of Technology and in fig. 10 the number of published PCT applications of the UT have been shown. The data of the WIPO contain also the patent applications that were not filed via the Estonian Patent Office or were filed with a patent applicant from some other country via another country. In fig. 9 and fig. 12 it can be seen that in case of both universities the largest number of patent applications have been filed in the fields of microbiology and gene technology (int. Cl. C12N and C12Q).

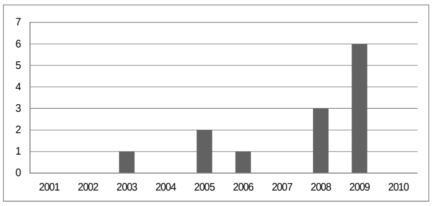


Source: WIPO
Fig.8. PCT applications of the Tallinn University of Technology

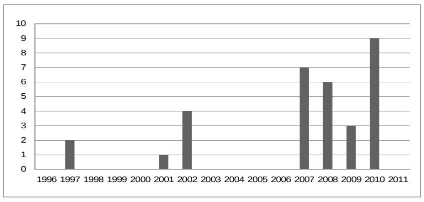
The number of European patents filed by Tallinn University of Technology has been provided in fig. 10 and the number of patents filed by the University of Tartu has been shown in fig. 13. It can be noticed that the number of the European patent applications is low.



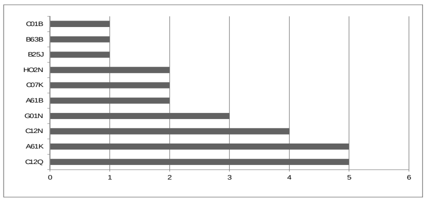
Source: WIPO
Fig. 9. PCT applications of the Tallinn University of Technology by IPC



Source: EPO
Fig.10. EP applications of the Tallinn University of Technology

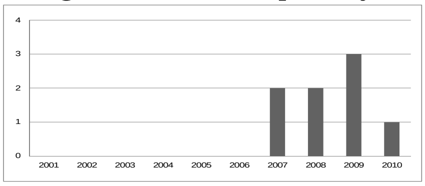


Source: WIPO
Fig. 11. PCT applications of the Tartu University



Source: WIPO
Fig.12. PCT applications of the Unuversity of Tartu by IPC

In case of the afore-given data it should be stated that these are public data. Therefore it should be taken account that due to long backlogs especially in the EPO and the USPTO it is impossible to evaluate whether the activity of patenting of the universities has remarkably changed in recent couple of years.



Source: EPO
Fig.13. EP applications of the University of Tartu

Neither has the present research brought out the impact of the inventions, the authors of which are the scientists of the universities, but in which the universities have not been mentioned as applicants or co-applicants. The main inventions made by the employees of the universities outside the university are created in the

framework of international cooperation or in start-ups.
Possible expenditures on court disputes in case of infringement of the patent or in case of making an opposition should be taken into account. Despite that the high indicators planned by the research and development (R&D) strategy of Tallinn University of Technology for the years 2005-2015 exceed significantly the actual achievements. Besides evident overestimation of possibilities one of the reasons for the low number of patenting of the universities of Estonia is the lack of Patenting Strategy, which is mandatory in the universities of the UK and the USA.

CONCLUSIONS

In knowledge-based economy innovation is predominantly based on legal protection system of intellectual property. Innovation is successful production, research and use of new products in social as well as economic spheres. Patents as indicators of technological innovation enable *inter alia* to find out the directions of development, the leading firms and institutions of scientific research in a particular field. In Estonia the key technologies are information and telecommunication technologies, bio-technologies and material technologies, research of which is concentrated mainly in Tallinn University of Technology and the University of Tartu. Arrangement of production on the basis of these fields requires large investments. Therefore International cooperation has to be preferred in the field of high technology. The analysis shows that the number of filed patent applications and the ratio of the enforced patents belonging to the fields of key technologies is low, which means little interest in investing in these fields. The number of patents issued to the Tallinn University of Technology and the University of Tartu is also low, because publication of scientific achievements is preferred to patenting and patenting strategy does not exist.

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8th International DAAAM Baltic Conference
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19-21 April 2012, Tallinn, Estonia

HYBRID CONTROL STRUCTURE AND SCHEDULING OF BIONIC ASSEMBLY SYSTEM

Katalinic, B.; Kukushkin, I. K., Cesarec, P & Kettler, R.

Abstract: *This paper describes hybrid control structure, working scenarios and logic of working cycles during the assembly of one unlimited sequence of assembly orders in Bionic Assembly System (BAS). BAS is a new concept of advanced assembling system, which combines two basic control structures and principles: centralized control system, based on the hierarchy and self-organizing control system, based on the heterarchy.*

Key words: hybrid control structure, scheduling, bionic assembly system, self-organization, assembling.

1. INTRODUCTION

Actual design results of continuous research focused on the development and implementation of the next generation of assembling systems are presented in this paper. The next generation of assembling systems is hybrid type, which combines two basic control structures and principles: centralized control system, based on the hierarchy and self-organizing control system, based on the heterarchy.

The first one concept is well-known and it is the most used control concept in the industry up till now. The other one is very present in the nature, but almost not used in the industry.

There are many definitions of self-organization, [1], [2] and [3]. As told in [4] "*The self-organization is one of the main patterns of the organization of material, energy and information in the nature. It is a present in inanimate and in the biological systems. The self-organization phenomena is a present in the whole range of the size from less than atom till the whole universe. The self-organizing is a very complex phenomenon with many different phases. At the moment there is no one unique definition of self-organizing. But there are many definitions which are describing particular characteristics, affects and forms of self-organizing.*"

Combination of those two concepts brings out the hybrid system. As shown at Fig. 1. Basic control structures: hierarchy, heterarchy and hybrid. This system is known as "Bionic Assembly System (BAS)". The structure, functions and characteristics of this system described at [4], [5] and [6].

2. PLANNING

The main aim of planning BAS work is to achieve the highest possible productivity of BAS during the assembly of one unlimited sequence of orders. Maximal productivity means maximal number of assembled product during one particular period of time, taking into consideration the external priority of BAS orders, system's bottle-necks, limitations in the number of production facilities, and the limited capacity of each essential production unit. It is only possible to achieve the above-mentioned aim through the carrying out of all activities which are placed on the critical path in as short a time as possible. The work of assembly stations, mobile robots and operators has to be simultaneous and synchronized, based on the chosen BAS working scenario.

The interface between factory planning system and BAS is a pool of BAS orders as shown at Fig. 2. Hybrid control structure of bionic assembly system. Each BAS order has an external priority as a measure

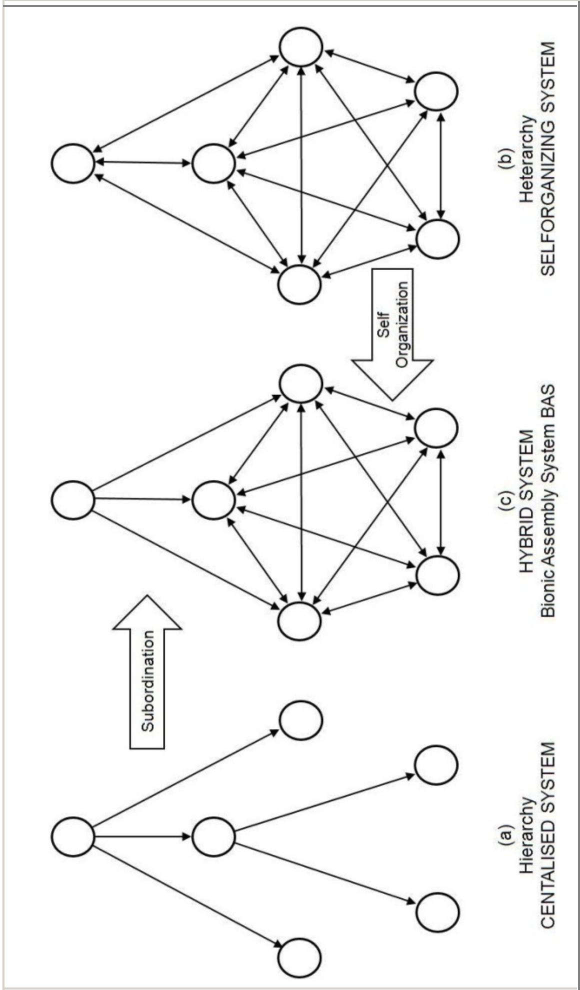

Fig. 1. Basic control structures: hierarchy, heterarchy and hybrid

of order urgency. Normal urgency is priority 2; urgent order is priority 1; and low priority order is 3. Locked orders have priority 0.

Scheduling optimization module has to find out the most suitable BAS order from the pool of BAS orders taking in to the consideration: target scenario, criterion of planning, actual state of BAS, free and reserved resources of system during the time planed.

The result of optimization is (sub)optimal order. This order will be built in virtual scenario of BAS in the case of simulation or in working scenario of BAS in the case scheduling planning. The results obtained from scheduling planning give data which build the queues. The queues determine the order and sequence of pieces, in which different products will be assembled.

3. COMMUNICATION

Each single assembly module or assembly station has two-communication channels one vertical to BAS central computer and other horizontal to the mobile robots. Main tasks of central computer of BAS are to plane the global production of BAS, synchronize the part supply and setups, bring the demands from factory level, and organize the BAS as an integral part of factory. The horizontal communication between assembly station and mobile robot with the assembly pallet which carry one particular product from one to other assembly station in the search for the assembly station which can complete the next assembly operation is kernel part of self-organization of systems.

The assembly pallets are transported through the assembly system by lineless mobile robots. After each assembly operation the assembly station makes the quality check to find out, was the assembly operation completed successfully if yes the assembly station give this information to the mobile robot which carry the product on the assembly pallet during the process of assembly. This information has key role in the search for the station that can carry out the next assembly operation on the product of this type.

The horizontal communication between the control system of one assembly unit and the mobile robot includes following information: pallets type, palettes status, product type, assembly stage of product - which is next assembly operation on that product which has to be done, quality status of product - was the last assembly operation completed successfully. If the last assembly operation was not successful the quality status of product will be negative, and all assembly units will tell that they are not responsible for next operation. For such cases is in the system organized special repairing station. At this place the robots/pallets are waiting on the shop operators which will try to correct the part. If he cannot correct the mistake,

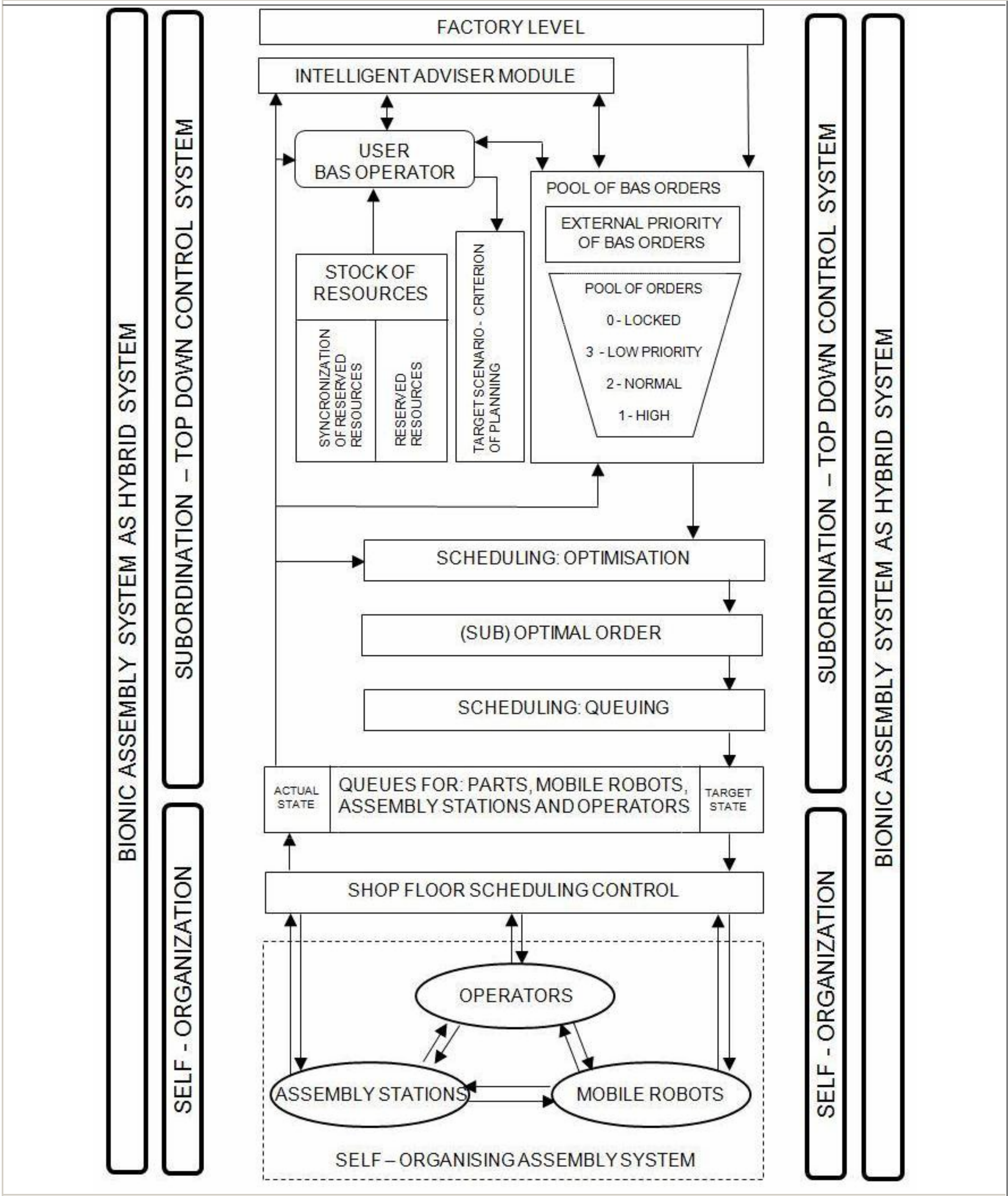

Fig. 2. Hybrid Control Structure of Bionic Assembly System

he will move the product from the pallet and reset the pallet and send it to the system as new pallet free to take the first part of next product. After the product successfully completed all assembly operations and tests he will be removed from the pallet and packed for transport. The robot/pallet will be reset and send as the free robot/pallet back to the system.

4. SCHEDULING STRATEGIES

Scheduling strategies are designed to fulfill the key aim: Just-in-Time delivery of products according to the specification of customer order. The scheduling strategies are task oriented to fulfill the order for one particular customer in good time. That means one customer has ordered different quantities of different types of products, and all his products have to be assembled, packaged and prepared for the delivery and transportation at predefined day and time (yyyy-mm-dd hh:mm).

The first step in the production planning at the factory level is to combine orders from different customers to find out the best way to fulfill wishes of all customers. The result of this planning is called system order. It tells what and how many (product types and their runs) and how urgent (priority) has to be assembled during the next period of time. All unlocked orders in the pool of the orders are making the system order (Fig. 2.) Assembling a run of one product type here is called as assembly order. The logic and hierarchy of working cycles during the completition of one system order are shown at Fig. 5.

These activities are happening in following way.

1. The group of assembly orders with the highest priority is selected from the system order.
2. From these group the first product type is selected
3. The first piece in the run of that product type will be assembled.
4. Mobile robot is getting order to assemble that piece. It takes suitable assembly pallet and goes from the assembly station for the assembling of the first part till the assembly station for the assembling of the last part of that piece and finally to the unloading and packaging station. During the assembling procedure mobile robot can have alternative ways. This is happening when one assembly operation can be completed by the different assembly stations or workers. During the selection of the most suitable station for the next assembly operation robot follows the criteria of "the shortest completition time" of the next assembly operation. The time for the completition of the next operation is the sum of the waiting time and operation time. During the assembling procedure of one piece of product mobile robot is coming to the different situations as shown at Fig. 4. What to do in the particular situations can be determined with following "if-then" rules, shown in Fig. 3.

This assembly process is happening in the shop-floor and follows basic principles of self-organization. Participants in self-organizing process are mobile robots, assembly stations and shop-floor operators. This part is shown at the bottom of the Fig. 2. Hybrid control structure of bionic assembly system.

a) rule
if {the next step of assembly is packing}
then {the new assembly order, a robot has to go to the loading/unloading station}

b) rule
if {the quality state of product is negative}
then {the robot has to go the repair station. wait to the shop floor operator. the shop floor operator will try to repair the product. if this is not possible, he will remove it from the system, and will prepare the pallet and the mobile robot for assembling of the next (new) product. the results of repair operation: the state of assembly and the quality state}

c) rule
if {a assembly station becomes active or passive}
then {the rearrangement of the queues of alternative assembly stations}

d) rule
if {the quality state of product is positive and the next operation is assembly operation}
then {find out which assembly station(s) can perform the next assembly operation; if there are more than one, find out which is better, taking into consideration existing queues and priorities}

e) rule
if {the mobile robot is present and the assembly station is busy or there are waiting robot(s) with equal or higher priority or there are robot(s) of equal priority which are waiting for longer time}
then {the mobile robot has to wait in the queue of the assembly station for the next operation}

f) rule
if { the assembly station is free and there are no robot(s) with higher priority in the queue}

then {docking, execute assembly operation, check the quality of results of the assembly operation, write the new state of assembly and the quality state of product, undocking}

Fig. 3. Mobile robots' acting rules

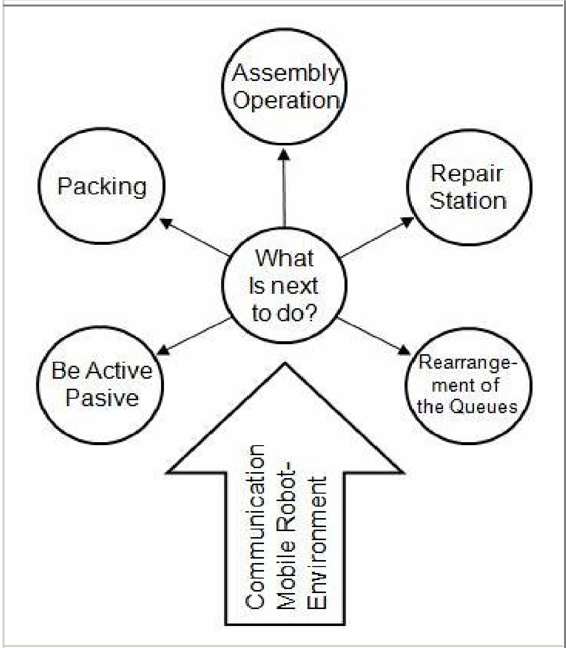

Fig. 4. Five Basic Tasks for Mobile Robots

5. The procedures 3, 4 are repeating since the very last piece of the run is assembled.
6. The procedure is repeating for the next product type in the priority group.
7. When the last product type in the priority group is assembled the whole procedure from step 2 till 6 is repeating for the next priority group.
8. End of system order: when the last piece in the run of the last product type in the lowest priority group is finished, the system order is completed.
9. It is a time to prepare the next system order for the time coming. Generation of system orders can be made also more continuously.

5. BAS BASIC CHARACTERISTICS

The main characteristics of proposed BAS are: (1) The variable structure of system, the number of stations can vary from min 1 of each type to unlimited; (2) This system is possible to organise as workers friendly system, which has the possibility to be high, automated from one side and has ability to integrate of workers from other side; (3) Product mix and size of run can vary in extremely wide range; (4) Self-organizing behavior of system make it robust against external and internal disturbances; (5) Variable dynamic layout of system can be used for optimization of working scenario and system parameters; (6) The BAS can very quickly respond on the demands of master scheduling system.

```
Start
{
    For (i=1;i=iSYSTEM ORDER;i=i+1)
    {
    Completition of System Order in BAS according to the priorities starts with the highest priority (j=1) and
    finishes with the lowest priority (j=3)
            For (j=1;j=3;j=j+1)
            {
                    For (k=1;k=last;k=k+1)
                    {
                            For (l=1;l=lRUN;l=l+1)
                            {
                                    For (m=1;m=mLAST;m=m+1)
                                    {
                                            Find and go to the most sutable assembly station and
make
                                            ijklm_ASSSEMBLY_OPERATION ( )
                                    }
                                    l-th example of k-th product type is finished
                            }
                            Run of k-th product type is finished
                    }
                    Runs of all product types with j-th priority are finished
            }
            i-th system order for all priorities is finished
    }
```

```
        All system orders are finished
    }
    End
```

Fig. 5. Logic of working cycles during the completition of BAS system orders

6. CONCLUSION

The proposed concept of Biologic Assembly System (BAS) is logical result of the further development of flexible assembly systems. The BAS has stronger characteristics of self-organizing, robustness, and adaptation. The main problem is the conflict between hierarchy and heterarchy. The concept is suitable for application by most complex flexible assembly systems. The concept accepts the variations in the structure of assembly system. Introducing of additional assembly stations without change scheduling strategies and scenarios can increase the capacity of system. This system is possible to organize as workers friendly system, which has the possibility to be high, automated from one side and has ability to integrate workers from other side. This characteristics of system open basically new trend in the development of automation, and that is the (re)integration of workers in high automated industrial environment. This development can be highly interested for the solving of present situation in development countries which have high rate of unemployed skilled people which cannot be integrated in classical automated systems. Variable layout of system can be used for optimization of working scenario and system parameters. The future research will be focused on system reconfiguration, system starting procedures and solution of conflict situations between centralized and self-organizing parts of the system.

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NOVEL TRENDS IN THE INTELLIGENT MANUFACTURING SYSTEMS

Kerak, P.; Holubek, R.; Košťál, P.

Abstract: *The current trend of increasing quality and demands of the final product is affected by time analysis of the entire manufacturing process. The primary requirement of manufacturing is to produce as many products as soon as possible, at the lowest possible cost, but of course with the highest quality. Such requirements may be satisfied only if all the elements entering and affecting the production cycle are in a fully functional condition. These elements consist of sensory equipment and intelligent control elements that are essential for building intelligent manufacturing systems. Intelligent manufacturing system itself should be a system that can flexibly respond to changes in entering and exiting the process in interaction with the surroundings.*
Key words: sensory equipment, intelligent manufacturing systems, manufacturing process, control system.

1. INTRODUCTION

The industrial intelligence is still forwarding. Today we are not talking only about using of IT, classical automated instruments. But when we are talking about flexible intelligent manufacturing systems it is effective to talk also about possible using of new generation intelligent manufacturing systems. This new generation of manufacturing systems are also called intelligent manufacturing systems. All IMS subsystems are including parts of so called machine intelligence (sensor equipment). Using of given systems with combination of machine intelligence will lead to the complete labor remove from the manufacturing system.

2. USE OF CA SYSTEMS IN FLEXIBLE MANUFACTURING

CA systems are computer systems that are intended to support of activities at all stages of manufacturing – from development and design of component, production planning to production and assembly, storage and expedition.
Use of CA systems in manufacturing and execution time of the components is shown in Fig. 1 [1]

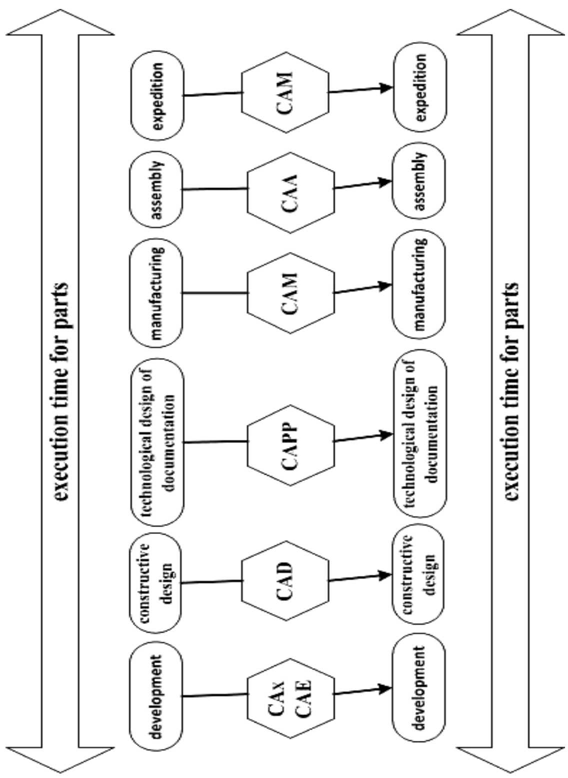

Fig. 1. CA systems and execution time of components [1]

Realization of components consist of:

- stage of *development - design and planning*
- stege of *technological – implementation*

In the design and planning stage is made after modeling, simulation and analysis activities the complete design and technological documentation, respectively, are generated by CAD and CAPP data - *Computer Aided Engineering works CAE.* Second stage is characterized by different automated systems with computer support (manufacturing, assembly, storage) - *Computer Aided Production Engineering CAPE.* [4]

Central production planning/manufacturing systems rely on centralized communication, are rigid, lack scalability and robustness, and have a high cost of integration. Mass Production Systems place emphasis on the reduction of products' costs and full utilization of plant capacity.

This manufacturing approach resulted in inflexible plants, associated with work-in-process and finished goods inventories.

Computer-Aided Design (CAD)/ Computer Aided Manufacturing (CAM) systems integrate different tools (e.g., e-mail, multimedia, 3-dimensional CAD geometry viewer) in a distributed multimedia-designing environment through the Internet (e.g.). In CAD, the computers are used in the design and analysis of products and processes. In CAM, the computers are used directly to control and monitor the machines/ processes in real-time or offline to support manufacturing operations (e.g., process planning). [3]

Computer integrated manufacturing (CIM) systems have been used to integrate different areas within manufacturing enterprises. They use a graphical user interface within a programming environment and incorporate multimedia packages to facilitate the dissemination of product information (e.g.) [3].

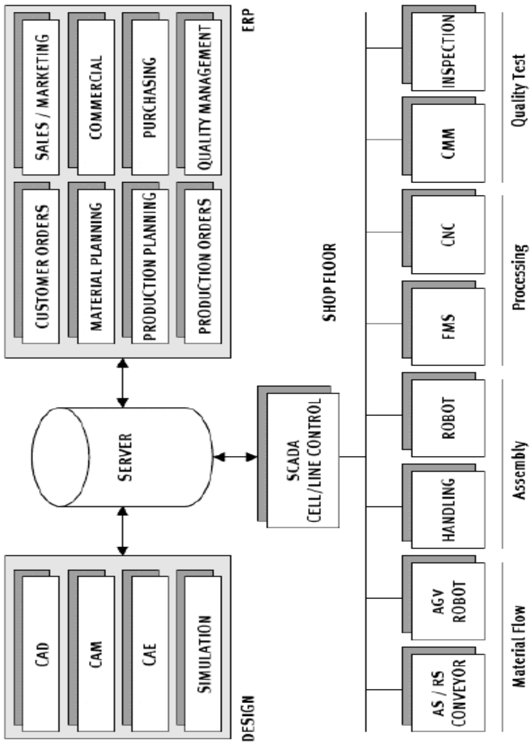

Fig. 2 Connection of CA systems with the manufacturing

Connection of CA systems with the manufacturing is showed on Fig. 2. Main paradigms of manufacturing engineering, and their underlying technologies are presented in Table 1.

Nr. Crt.	Manufacturing System/ Paradigm	Focus	Main Strengths	Main limitations	Technologies/ Approach
1.	Mass production	[illegible]	[illegible]	[illegible]	
2.	CIM	[illegible]	[illegible]	[illegible]	
3.	Flexible	[illegible]	[illegible]	[illegible]	
4.	Reconfigurable	[illegible]	[illegible]	[illegible]	
5.	Intelligent	[illegible]	[illegible]	[illegible]	Agents
6.	Holonic	[illegible]	[illegible]	[illegible]	Agents, [illegible]
7.	Balanced automation	[illegible]	[illegible]		Agents
8.	Bio-inspired	[illegible]	[illegible]	[illegible]	[illegible]
9.	Wise	[illegible]	[illegible]	[illegible]	[illegible]

Table 1. Main paradigms of manufacturing engineering systems [3]

3. AUTOMATIC MANUFACTURING SYSTEM

For better understanding of “intelligent manufacturing systems” term, is the most suitable to compare its behavior with behavior of flexible manufacturing system.
Automation manufacturing system is today known as manufacturing device with various levels of automation of operating and non-operating activities and with various levels of subsystems integration (technological, supervisory, transportation, manipulating, controlling):

- technological (set of technological workstations)
- transportation and manipulating (is realized by industrial robots, manipulators and transporters)
- supervisory (is included to system if machines in system do not have own supervisory devices)
- controlling (there are dominating own controlling systems of all devices) [2]

Using of intelligent production systems is conditioned by efficiency of all subsystems, which are contain in given system. Subsystems are developed with automatic manufacturing systems, in order to save the system parameters.
Automatic manufacturing systems in repetitive production, where is demanded big rate of flexibility, are called flexible manufacturing systems. [2]
To category of automated manufacturing systems (flexible manufacturing systems) are included one or more technological workstations, at which are all inputs, material and immaterial, automated. Basic classification of automated manufacturing systems takes into the account also the number of the machines in the system as well as flexibility of the production.
According to this classification we distinguish three basic types of automated manufacturing systems:

- Flexible manufacturing cell – up to maximum three of the machine tools; it’s characterized by highest level of flexibility.
- Flexible manufacturing line – is characterized by the lowest level of flexibility; range of goods is narrow and being produced in large batches.
- Flexible manufacturing system – minimum three machines and more; is characterized by lower level of flexibility.

4. INTELLIGENT MANUFACTURING SYSTEM

Intelligent manufacturing system presents system with self-contained capability of adaptation to unexpected changes, i.e. assortment changes, market requirements, technology changes, social needs etc. However, intelligence of these systems is frequently understood as control of the software product, and not as implementation of modern technologies of machine artificial intelligence.
Intelligent production systems consist of subsystems like automatic production systems (technological, supervisory, transportation, manipulating). Subsystems have to be equipped with aids, which give to subsystems specific level of intelligence. It is possible to consider it as higher phase of flexible production systems. [2]
Components of an intelligent manufacturing systems consist of (Fig.3):

- intelligent design,
- intelligent operation,
- intelligent control,
- intelligent planning
- intelligentmaintenance.

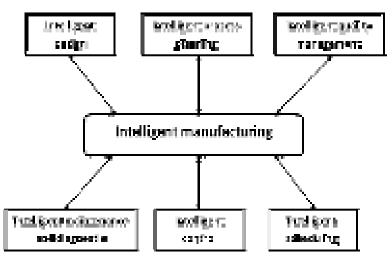

Fig. 3 Components of an intelligent manufacturing systems [3]

Manufacturing engineering systems evolved in order to meet several objectives, such as:

- reduction of cost;
- reduction of lead times;
- easy integration of new processes, sub-systems,technology and/ or upgrades; interoperability;
- reduction of production waste, production process and product environmental impact to 'near zero';
- fast reconfiguration; fast adaptation to expected and unexpected events.

5. MECHANICAL PERIPHERY INTELIGENCE ENHANCEMENT POTENTIAL AND LIMITATIONS IN PRODUCTION

Monitoring of all actions inside the production process but also in its environment is aimed at increase of this system reliability and failure prevention of the system itself or avoidance of defective products. There are several possibilities how to enhance production system intelligence.

In term of automation assembly is the most complicated operation. Sequences like correct grip, orientation and positioning of the component entering the assembly system in disordered condition (e.g. loose in a container) are very easy to realize by a human. In term of automation however these seemingly simple acts represent one of the most complicated problems. Usually we try to keep aloof from such acts in the automated assembly process so that individual components enter the assembly system already oriented and in a defined place by means of various feeders, tanks or pallets.

In case the automated assembly system is entered by individual components which are unpositioned and non-oriented an intense cooperation between the sensor subsystem and various intelligent mechanical peripheries is necessary. Various types of sensors (contact, contactless, pressure, sensors of strength and moments, CCD cameras and others) are used dependent on specific demands of the specific application. Simultaneous combined use of various sensor types affords solution opportunities also of very complicated monitoring tasks. Individual sensor types can differ also in their output signals. Some sensors have only simple binary output signals, others can have a more complicated output signal consisting of several simple binary signals (e.g. sensor differentiating colours) and others can provide an analogue signal (e.g. rheostatic thermometer). All these signals must be processed and correctly evaluated by the control system because only on the basis of this information it can correctly respond to the actual state of the production system en bloc, of its individual subsystems as well as the actual state of the technological process.

One of the application areas of monitoring systems is the area of robotized assembly. Equipping of assembly systems by sensors is one of the basic levels of increasing of automation and machine intelligence. Sensorial systems provide scanning and monitoring of various functions of assembly process, assembly technology, properties of assembly objects, mounted parts and properties of environment. Realization of monitoring functions provides suitable sensor sorts, whereupon the supervisory systems provide the control interventions. Sensors are the basic devices for capturing of information and their transformation. The present monitoring systems have reserved structures which are realized according to application or purpose.

Selected sensor or sensorial systems (monitoring systems) must meet technical, economic and operative indices. Factors, which affect their selection are multiple and multilevel. Center of the sensors application is mostly in robotized assembly, where the sensorial systems enable to assembly (so-called intelligent robots) and others technical elements to identify and monitor workspace and system environment with building elements.In robotized assembly the ideal event occurs when PR can recognize, place and grab random oriented object.

Sensorial equipment applied in assembly systems use three basic groups:

- tactile sensors
- proximity sensors
- visual sensors

Development of the new kinds of sensors takes place in all three groups. Classification of the most frequently used kinds of sensors is on figure 4.

Tactile sensors are used in case, that technical, realization instruments, mostly assembly robots, are in direct contact with object of assembly.Important are especially sensors which enable control of the object presence, identification of grasp force, monitoring of the starting position of assembly tools, let us say other functions. With tactile sensors are equipped tentacles, position table, transporting units, other units and devices. For recognizing of the orientation, kind of objects, detection of edges are used visual sensors of various kinds.

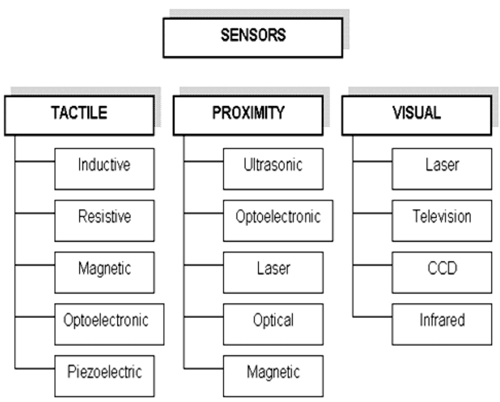

Fig.4 Classification of the most frequently used kinds of sensors

These sensors are generally in cylindrical or angular cases with digital, analog inputs, with connectors, or fixed with cable, e.g. for machining, packing and transporting devices. Present tactile sensors are conceived primarily on the basis of pressure and force measuring. Output signals are treated to signals suitable for proper level of control.

Among main advantages of ultrasound sensors belong:

- contactless detection of object presence and position measuring
- high precision of measuring
- high measuring distances
- measuring is not affected by particles in the air etc.

Other tactile and proximity sensors are also the magnetic sensor. These types of sensors proved thanks to their high switching distance.

6. CHALLENGES AND TRENDS

An extensive survey on manufacturing systems allowed the identification of the main *current trends* for manufacturing systems, which can be summarized as follows:

- specialization, characterized by an extensive focus on core competences;
- outsourcing;
- transition from vertical to horizontal structures (e.g., concerning management systems), from highly centralized to decentralized structures (e.g., where an individual element, unit or sub-unit is enhanced with decision making/ intelligence capabilities);
- evolution towards self-properties or self-sufficiency (e.g., self-adaptation) which generally occur at low levels. Manufacturing systems with these characteristics have a high level of integration, are easy upgradable, evolvable and adaptable (e.g., to new market conditions);
- the development of technologies and applications to support all the

requirements of current distributed manufacturing systems;

- competitiveness: the enterprises should remain competitive, e.g., in terms of costs (e.g., lifecycle costs, investments) vs. payoffs; adequate equipments and machines (e.g., sensors) adequate to new manufacturing paradigms; sustainability (e.g., to consider environmental concerns into design);
- technology, equipment and manufacturing systems' selection (e.g., to evaluate various systems configurations based on life-cycle economics, quality, system reliability);
- integration of humans with software and machines; non-functional properties, e.g., fault tolerance;
- openness, self-adaptability; each unit/sub-unit/ element of the manufacturing system should independently take optimal *wise* decisions (e.g., concerning resource utilization, incorporating scheduling algorithms, planning and control execution techniques), having a goal-driven and cooperative behave;
- performance assessment. [4]

Concerning *future trends*: it is rather difficult to forecast long term trends for manufacturing engineering systems.

7. CONCLUSION

Despite the developments in the area of engineering systems and advancements of information and communication technologies, current (manufacturing) engineering systems fail to address all the needs of today's manufacturing enterprises. Current trends of manufacturing engineering system are towards enhancing machines with bioinspired and human abilities (e.g., intelligence, wisdom, cognitive functions), and in hiring (fewer) highly skilled employees. However, this trend has to be closely accompanied with (positive and negative) human, social and environmental consequences.

Currently, due to shortened product life cycle, market liberalization, a great competitive pressures and constantly dynamically changing demands of customers, enterprises are forced to gradually rebuilding the nature of its production to mass production and small series with a wide range of products.[4]

8. ACKNOWLEDGMENTS

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MODELLING OF SYMMETRY MEASUREMENT UNCERTAINTY USING MONTE-CARLO METHOD

Kulderknup, E

Abstract: *Symmetry deviation has importance for details which operating jointly as the moving parts of exact devices. The measurement of symmetry deviation has difficulties by main reason that there exist problems to present the datum surfaces for measurement. This paper presents measurement uncertainty estimation model for symmetry measurement. Novelty is, that the model takes account also production operation and simulation of uncertainty estimation is achieved using Monte-Carlo method.*

Key words: symmetry deviation, measurement, Monte-Carlo method

1. INTRODUCTION

Symmetry deviation has importance for details which operating jointly as the moving parts of exact devices. The measurement of symmetry deviation has difficulties by main reason that there exist problems to present the datum surfaces for measurement. The real datum surfaces itself have geometrical deviation. Second problem is caused by circumstances that symmetry deviation depends on greatly from concrete production process.

This paper presents measurement uncertainty estimation model for symmetry measurement. Novelty is, that model takes account also production operation and simulation of uncertainty estimation is achieved using Monte-Carlo method.

For Monte-Carlo method is important to have exact model of combined measurement and production process as cumulative probability function $F(x)$. Probability function $F(x)$ is easy to bind to the measurement uncertainty, which can be found on the basis of uncertainty estimation model. Each correction in the model has its uncertainty and those shall to be estimated. Some of them can be found through practical experiments and some of them through calculation. Giving various values for those components depending on concrete operations can be found model Δ_{sym} for various situations.

Main tasks of this work were to have model suitable for use in practise This model allows to choose optimal production operation, to have higher accuracy of assemblies, to take account mate detail in use and to give some opinion which uncertainty components are representative and how they acting in practice.

Above allows to have higher production and measurement capability.

2. MODEL OF SYMMETRY MEASUREMENT

Symmetry deviation zone is limited by two parallel planes, a distance Δ_{sym} apart, symmetrically disposed about median plane with respect to the datum [1]. Measurement scheme is shown in Fig 1.

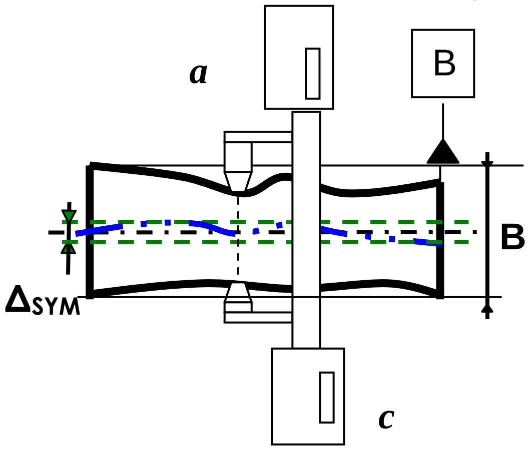

Fig. 1. Symmetry measurement schema

On Fig. 1 line ▬ · ▬ ·presents real details symmetry axes, the datum is symmetry axes for measure *B* and *a* and *c* are measuring instruments for plane *A* and *C*. Main problem is to find the ideal symmetry axes for the measure *B* by measurement procedure. This means that symmetry of the measuring instrument for plane *a* and *c* (Fig 1) shall be the same that symmetry axes for measure B during movement across the detail.

Symmetry deviation Δ_{SYM} can be calculated initially through measuring instruments *a* and *c* indication by Equation:

$$\Delta_{SYM} = \max\ \{B + a_i + c_i\} \qquad (1)$$

where a_i and c_i are the measuring instrument indications and *B* is the reference value.

The symmetry measurement model can be expressed exactly taking account influence factors as follows:

$$y = x + K_{MI} + K_{SR} + K_{MF} + K_{SC} + \\ + K_{SCO} + + K_{SA} + K_{ENV} \qquad (2)$$

where *x* is the measurement value of measure Δ_{SYM}, K_{MI} is the correction from the measuring instruments calibrations, K_{RE} is the correction from the reading of indication, K_{DA} is the correction from the datum deviations, K_{MF} is the correction from measurement force, K_{SC} is the ideal symmetry axes deviation for measuring instrument and K_{ENV} is the correction from the measuring environment.

For obtaining the real detail symmetry value huge importance has the production process which shall be added to the Equation 2 as separate correction K_{PROD}.

3. UNCERTAINTY OF SYMMETRY MEASUREMENT

3.1 Uncertainty components

The designer gives often high accuracy values for the tolerances for measures including for the symmetry deviation. To obtain realistic values in practice, tolerances should be optimised and uncertainty estimation would facilitate it. Uncertainty estimation allows prioritising the factors including producing, measurements and testing possibilities and measurement chain optimisation. During measurement of parameters, components having importance for uncertainty estimation are involved with various sub-parameters.

Uncertainty of symmetry deviation Δ_{sym} can be expressed through measurement model (2) giving concrete values for the influence components. For the batch of detail Δ_{sym} shall be included summary uncertainty of production process.

Combined uncertainty model $u(\Delta_{sym})$ for batch of details can be expressed as:

$$u(\Delta_{sym}) = g(L_{meas}, \Delta_{meas}, \Delta_{prod}, \Delta_{meth}, \Delta_{bsurf}, \Delta_{var}), \qquad (3)$$

where L_{meas} is the measuring instrument indication, Δ_{meas} is the measuring instrument indication correction on base of calibration, Δ_{prod} is the correction from the production operations, Δ_{meth} is the correction taking account measurement method, Δ_{bsurf} is the correction from datum surface determination and Δ_{var} is correction from other various influence factors.

3.2 Uncertainty components values

Uncertainty components presented in the general model (3) have next sub-components from influence factors F_i:

- caused by measuring instrument: measuring instrument dimensional parameters; environment and its variation during the use of measuring instrument; calibration procedure of measuring instrument; measuring instrument specificity and its behaviour during measurement especially sensitivity and stability;
- caused by production process: quality of the production and technological process, machining accuracy;
- caused by measurement method: tolerances, object versus measuring instrument, measurement force, symmetry axes locating;
- caused by measurement object: design, size, materials and chemical quantities and tolerances, surface roughness;
- environment: humidity, temperature, vibrations, noise, altitude, interference fields, barometric pressure, pureness;
- human factor, operator: sensitivity, competence, experience, commitment.

Above factors that influence to the measurement can be shown as a structural scheme in Figure 2. This is fundamental for the further uncertainty estimation and has great similarity with circuit boards measurements handled in [2].

Parameters presented in Fig. 2 give components, which have influence to the uncertainty budget. The effect of some of these components may be little as long as they remain constant, but could affect measurement results when they start changing. For example, the variation of datum can be particularly important.

3.3 Uncertainty components values

Combined uncertainty u_B is found through the estimation of standard uncertainties caused by individual factors F_i. shown in art. 3.2.

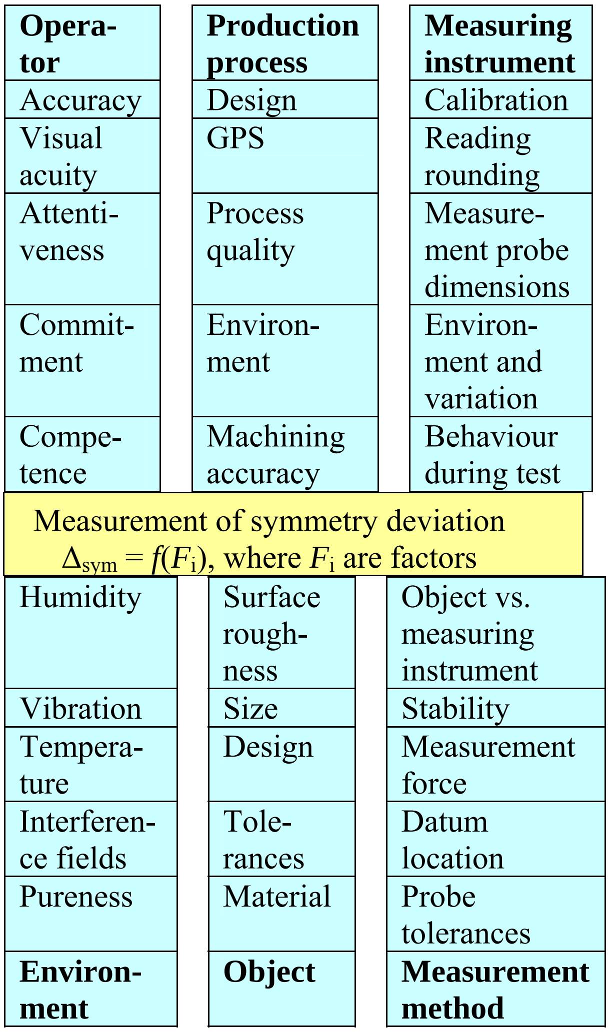

Fig. 2. Symmetry deviation influence factors scheme. Uncertainty tree

Combined uncertainty u_B is calculated by next equation:

$$u_B = \sqrt{u_{PROD}^2 + u_{HF}^2 + u_{MI}^2 + u_{MET}^2 + u_{EC}^2 + u_{OBJ}^2} \quad (4)$$

In the Equation (4) are given the main grouped factors accordingly to the model (2). Each uncertainty component has a concrete sensitivity coefficient. In equation (4) sensitivity coefficients are shown as 1, i.e. uncertainty components are estimated on the same influence level. In Table 1 is an example of uncertainty components values given in structural scheme in Fig.2 for one measure value of object. The values are estimations collected during experience and measurements in the production process.

Factor F	Sub-uncertainty	Uncertainty value u, µm
u_{PROD}	Design	1
	Process quality	1,5
	Prod. accuracy	2
u_{HF}	Competence	1
	Experience	1
u_{MI}	Dimensions of probe	1
	Calibration	2
	Stability/behaviour	1
u_{MET}	Datum locating	2
	Measurement force	1
	Stability	1
u_{ENV}	Vibration	0,5
	Temperature	0,2
u_{OBJ}	Material	0,5
	Surface roughness	0,5

Table 1. Uncertainty components values by Δ_{sym} = 0,020 mm, $u(\Delta_{sym})$= 0,005 mm

4. SIMULATION USING MONTE-CARLO METHOD

4.1 Cumulative probability function for symmetry measurement

Symmetry deviation simulation can be presented using Monte-Carlo model as $F(x) = P(x)$, where $F(x)$ is cumulative probability function and $P(x)$ is probability of symmetry deviation various values. Probability can be linked to the expanded uncertainty U, as $P(x) = U(\Delta_{sym})$ and present as shown in Fig. 3.

Dependence from some uncertainty components as $P(x) = U(\Delta_{sym})$ can be shown presenting various curves 1, 2, 3 up to i as $P(x) = U(\Delta_{sym};\ \Delta_{i,factor})$, where $\Delta_{i,factor}$ is symmetry deviation individual component. Simulation of symmetry deviation measurement using Monte-Carlo method allows interpretation and optimisation of the production process and measurement method. This is important to achieve required statistical tolerances and process capability indices C_p and C_{pk} for batch of details.

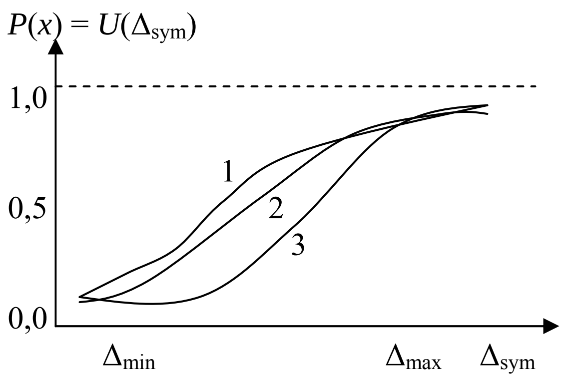

Fig. 3. Graph of dependence $P(x)$=Δ_{sym}

5. CONCLUSION

Symmetry deviation has problems by measurement caused by various influence factors. Measurement result can be exacted through uncertainty estimation.
Simulation of symmetry deviation measurement is useful to carry out using Monte-Carlo method which allows interpretation and optimisation of the production process and measurement method.

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Ways of Increasing Synergy in Engineering Design Teamwork

Rommi Källo, Martin Eerme and Vello Reedik

Abstract: *The proposed paper is focused on the problems of reducing losses of resources at the start-up of new automated factories caused by human shortcomings in teamwork activities. The basis for research is a unique database of empirical studies of human faults and mistakes at the design of factory automation systems collected since 2006. It is shown that the most suitable tool for teamwork analysis is the Dependencies Structural Matrixes (DSM) system that allows visualizing of the complexity of the synergy relations between all team members on the basis of the frequency and amount of information interchange. The mathematical treatment of DSM matrixes enables us to form the most capable teams and to schedule their activities. The proposed approach may be easily connected to the previous research on the development of adaptive tools for engineering design and quality management.*

Key words: factory automation, engineering design, teamwork management, synergy deployment, quality assurance

1. INTRODUCTION

The losses of resources at the start-up of new automated factories caused by human shortcomings reach up to 5-10% of whole investment costs and tend to increase with the growing complexity of the control systems. The key to reducing these losses is the profound analysis of human shortcomings in the automation systems design teamwork.

Nowadays the production process is changing towards higher degrees of automation and new solutions in control systems technology. Automation systems have been developed to be more universal, being capable of controlling different types of equipment; the requirements including also reconfigurability, responsiveness and flexibility [1]. In addition to that, advanced functions such as optimization, scheduling and planning are becoming an important part of the process control system [2]. At the same time the traditional barriers between information, communication and automation technologies are, in the operational context, gradually disappearing. The latest technologies, including wireless networks, fieldbus systems and asset management systems, boost the efficiency of automation systems [3]. On the other hand, a time specific factory needs a peculiar automation system configured from universal systems.
Manufacturing companies in their turn are changing their production philosophies shifting the focus from the manufacturing of the physical product towards its life cycle [4]. At the same time the need for systems engineering is growing owing to a steady increase in systems complexity. A system can become more complex not only from the engineering side but also due to an increase in the amount of data, variables, or the number of fields that are involved in the design [5].
Despite everything, the key figures in this overall change process are still human beings with their personality's cultural, educational and technical backgrounds and working habits. The research in the field of

socio-technical teamwork inefficiency due to human shortcomings is a real possibility to reduce the above-mentioned losses in factory automation development costs. Experience has shown that human shortcomings can be treated as a result of negative synergy in mutual or inner communication of team members and also due to the lack of competence [6]. The synergy-based approach to factory automation systems start-up difficulties is comparatively new, providing an opportunity to analyze the real reasons of human-based start-up problems and to plan the measures to avoid them.

From the purely technical side, the reliability of a whole factory automation system depends on the reliability of the individual components, component interactions and execution environment. Reliability can also be viewed as quality over time [7], where the lifetime of a product or a system is divided into three cycles: running-in, normal work and build-up depreciation. In addition, the impact of faults on reliability differs, depending on how the system is used [8]. So, in reality we meet a complex mix of technical and human factors.

Due to the fact that in the development of a multi-agent system the human being is still the key figure, human-related problems must be approached through psychology and teamwork organization. Thus, the management and development of skills and competences in a decentralized organization is becoming increasingly important [3].

For the better integration of all these matters the synergy-based approach is used in the present research, which aims to decrease the weaknesses and to boost the beneficial features at joining technologies and human activities.

2. EMPIRICAL STUDIES OF TEAMWORK QUALITY

The firm basis of any research in the field of effectiveness of human cooperation is its reality database concerning empirical studies of human shortcomings. The existence of such a unique database gives confidence in the reality and authenticity of the results attained by theoretical research, developed on this basis. The human shortcomings database at the design of factory automation systems has been collected since 1999. This database covers over 25 automated factories on three continents, containing pulp and paper mills, chemical and petrochemical plants and power stations. In the calendar plan the process of automated factory engineering design covers the drafting of the general description of the system, detailed task description for system configuration and a factory acceptance test. The human shortcomings in the described above procedures at the beginning of the research up to year 2006 were classified as human faults (misunderstanding each other and negligence) and as mistakes (due to lack of competence and absence of special knowledge that can be found only in the process of commissioning) [6]. For the present research, considering the higher level of control systems development a new and more detailed database for the years 2006-2011 was compiled. The introduced advanced classification of human shortcomings is shown in Fig. 1.

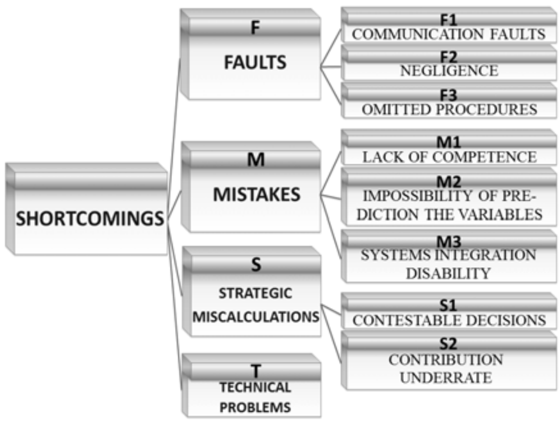

Fig. 1. Advanced classification of human shortcomings

Human shortcomings in this new database are divided into three main categories –

faults, mistakes and strategic miscalculations. Technical problems form a separate category. Faults are wrong decisions that have no justification. The faults class **F1** includes all misunderstandings in communication between the client, consultant and the design teams or between design team members. **F2** joins together all shortcomings connected with negligence. All transfers of unsuitable or late information and documentation in the design process are assorted into the faults class **F3**.
Mistakes have a far more complicated nature. To this category belong wrong decisions **M1**, caused by lack of core competence. Mistakes **M2** are conditional and are caused by the impossibility of predicting the production process variables at the moment of design and they may be resolved in the course of further projects activities. To the third class **M3** belong mistakes caused by system integration disability that leads to the situation where technologies cannot be integrated due to their different level of development. A new differentiated category of human shortcomings is strategic miscalculations **S.** Contestable decisions **S1** may be taken due to temptation to use cheaper or simple technical solutions that are not able to grant the necessary operating ability and quality. Contribution underrate **S2** is a very spread phenomenon in a highly competitive society when under market pressure unreal obligations are accepted. A special category here is that of technical problems **T** which involve classical reliability problems.
The real database consists of the information about how the shortcomings were discovered and it may not always describe the real nature of the shortcoming but only its symptoms. Therefore, a thorough analysis of the current situation is often required when a shortcoming has occurred in order to reveal its real reason.

In Fig. 2 the statistics of shortcomings for factory automation systems design and application on the Factory Acceptance Test (**FAT)** level for one of the latest factory automation projects is presented. For obvious reasons the factory is confidential. However, it is necessary to say that the statistics for different automation projects are quite similar and naturally depend on the competence of the team.

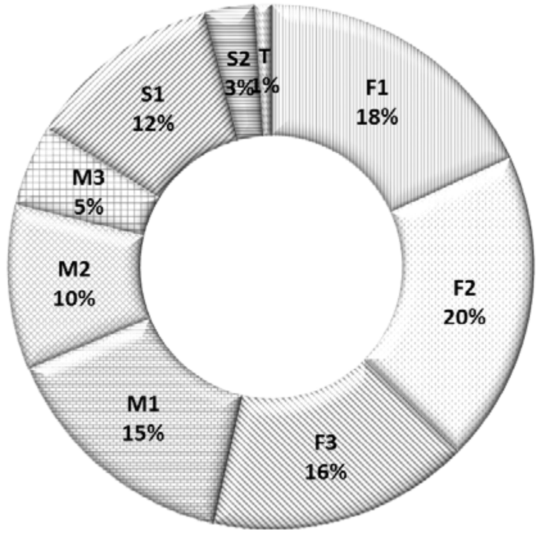

Fig.2. Statistics of shortcomings for the design of factory automation systems

Misunderstandings in communication **F1**, negligence faults **F2**, and documentation transfer failures **F3** constitute more than 50% of all shortcomings. These faults are usually clarified during the **FAT**, but it takes a lot of time and resources. **F1** type of faults arises due to lack of communication, where all necessary information is not handed over from one group to another and the latter works out a solution without exact knowledge. This group also includes the not discussed items, when different persons or working groups understand the solutions in different ways. Negligence faults **F2** usually comprise mistakes in copying the documents, graphic configurations or application items and also faults due to not reading the documents carefully. Faults **F3** cause the biggest resource and time losses as unsuitable information leads to extra work, which easily compromises the time schedule and budget issues. The usual fault in category **F3** is missing information in documents or not meeting the document delivery deadlines, which leads to problems with the deployment of manpower and being late.

Mistakes due to lack of necessary competence **M1**, the failures of presaging the variables **M2** and the system integration disability **M3** make up 30 % of total shortcomings. Mistakes are more difficult to avoid as individual and overall competence levels have to be identified before the start of the project. Mistakes **M1** are caused by lack of team members' personal competence and sometimes they may become evident only during the virtual testing of systems. However, the missing competence can be usually found inside the team and the problems can be solved. The **M2** types of mistakes are more difficult to discover and fix due to unavailable competence in the specific area. The need for possible modifications may arise not before the design of sub-processes or testing of the configured software. Some variables of processes can be evaluated only during the process of commissioning the new automated factory. The solving of this kind of problems requires a high level of overall competence and flexibility from all the working groups involved and depending on the level of complexity it can be very time-consuming. The system integration problems **M3** are mainly related to system hard- and software, where the stage of development of different systems varies and does not always consider all the requirements from the subsystems involved. Incomplete testing of different subsystem integration can lead to significant losses in time and resources as new solutions have to be contrived in a very short time.

Even the quantity of strategic miscalculations **S** is smaller than faults **F** and mistakes **M**, their impact on the whole project can be significantly bigger as a considerable number of process areas might be involved. Contestable decisions **S1** usually occur, when the work packages for certain groups are relatively big and a temptation may arise to increase the profit at the expense of small sub-items. The **S2** types of problems are caused by market pressure, when the project-oriented companies are unable to schedule their work effectively. Trying to survive on the market, they need to accept all the orders and hope that somebody else's delay will open up an opportunity for them. The ratio of technical problems is trivial and consists mainly of system hardware failures.

3. DEPLOYMENT OF SYNERGY DEPENDENCIES IN TEAMWORK

The main goal of the synergy-based analysis of multi-agent systems is to find a design methodology that would be able to highlight and amplify positive synergy and prevent mismatches caused by the negative synergy of technologies and in teamwork. The growth of positive synergy does not work by itself, but only by a systematic synergy-based approach to systems design. The search for a powerful tool for describing human relations and grouping them on the basis of their cooperation capabilities has proved that the most suitable tool for that is the Dependencies Structural Matrix (DSM) system that allows visualizing all the complexity of the relations between all team members [9].

Fig. 3 presents a matrix of personal activities during the design of a typical factory automation system project ending with **FAT**. First of all, the owner names responsible persons in his team to keep watch on the progress of building a new production plant and to transfer his own requirements and necessary competence from the already existing production. Next, to run the project a consultant company is hired to integrate all efforts of project groups. The task of the consultancy group is to forward the owner's requirements to the process supplier(s). After that, it is necessary to collect the resound data from the process supplier(s), convert them to the required format, get approval from the owner and give this input information to the automation supplier. Then the automation supplier starts system configuration, including application software programming, human-machine interface and process interfaces configuration.

At compiling the matrix, all inputs/persons must be preliminarily numbered in order to involve synergy relations between persons in the matrix. Therefore, the numbers of inputs must be the same on vertical and horizontal axes. The number of inputs is practically not limited and depends only on the complexity of the project. It is comparatively easy to introduce the synergy dimension into the matrixes to empower teamwork capability through the evaluation of synergy interactions between persons involved. The interactions strength is characterised on a 3-step scale: 0 - indifferent (left blank), 1- interaction is moderate and 2 - interaction is strong. Here, the direction of interaction is very important and in case the results of the previously completed task are used in the following one, only the first should be written into the matrix. The treatment of matrixes by hand or mathematically enables to form the most capable teams and to schedule their activities [10], [11].

The practical use of matrix for growing the The practical use of the matrix for growing synergy in teamwork depends on the selected scope of the matrix information. If to take the whole matrix, then there dominate recommendations of a general nature. For example, it is possible to prevent the faults **F** by setting the communication procedures and sharing the responsibilities. Also, personal motivation is important. Although more difficult, it is possible to obviate the mistakes **M** by training and upgrading the personnel and involving qualified consultants into the teams. The strategic miscalculations **S** can only be minimised during business negotiations specifying the needs very precisely and stipulating the project plan on a detailed level.

If the scope is addressed to the concrete working group, teamwork interactions dominate. Synergy building inside the team starts with the hierarchy structure and clear tasks on every level. The structure of communication inside the teams is highly interdependent as it is shown in Fig. 3. Financial and technical tasks and rules must be very clearly defined. The result is affected by personal relationships between team members. The overall scheduling of the work is important as the next group

Task Name	Level		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Project manager	1	1		2			Owner																1
Technical leader	1	2	2		2	2																	2
Automation and instrumentation specialist	1	3	1	2		2																	3
Process specialist	1	4	1	2	2																		4
Project manager	2	5	2	1				2			Consultant												5
Automation leader	2	6	1	2	2	2	2		2	2													6
Automation Designer 1	2	7		1	1	1	1	2		2													7
Automation Designer 2	2	8		1	1	1	1	2	2														8
Project manager	3	9	2	1			2	1				2	2	1			Process Suppliers						9
Process Designer	3	10		2	2	2		2	2		2		2		1								10
Instrumentation Designer	3	11		2	2	1		2	2		2	2				1							11
Project manager	3	12	2	1			2	1			1				2	2							12
Process Designer	3	13		2	2	2		2		2		1		2		2							13
Instrumentation Designer	3	14		2	2	1		2		2			1	2	2		Automation Supplier						14
Project Manager	4	15	2	1			2	1			1			1				2	1	1	2	1	15
Lead Engineer	4	16	1	2	2	2	1	2	1	1	1	2	2	1	2	2	2		2	2	1	2	16
Graphics Designer	4	17		1	1	1		1	2	2		1			1		1	2		2	1	1	17
Configuration Engineer 1	4	18		1	1	1		1	2			2	1				1	2	2		1	1	18
Configuration Engineer 2	4	19		1	1	1		1		2					2	1	1	2	2	2		1	19
System and Hardware Engineer	4	20		1	1	1		2	1	1		1	2		1	2	1	2	1	1	1		20
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	

Fig. 3. The DSM of personal relations in teamwork

can start their work after the previous has finished their task. However, scheduling does not exclude later clarification of the task or even modifications caused by new knowledge obtained during the project, but these activities cannot be fixed in the matrix.

The last scope is personal relations. In this sphere competence, psychological and cognitive dimensions dominate in parallel. On this level soft computing tools are useful for marking ways to better synergy.

4. CONCLUSIONS

The Dependencies Structural Matrix System is a capable tool for visualizing synergy relations between development project groups, in information interchange during group teamwork and in group member's personal relations. The proposed approach may be easily connected to the previous research into the development of adaptive methods for engineering design and quality management. As a result, it is possible to form a total quality assurance system where the competence of the teams and their members can be fully exploited.

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MULTISTAGE MANUFACRURING PLANNING

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Abstract: *A firm must plan its manufacturing activities at a variety of levels and operate these as a system. Manufacturing planning and scheduling has attracted an increasing amount of attention from both the academia and the industry in the past decade. This study aims to develop a better understanding of the production planning problems for low-volume and make-to-order production for engineering industry. The proposed models based on mathematical programming. The time horizon splitting approach is proposed, where the whole planning task is decomposed into hierarchy of sub-problems*

Key words: manufacturing planning, multi- step and multilevel planning

1. INTRODUCTION

The ability to model a manufacture planning process adequately is a critical success factor for an enterprise. The reason for this is twofold. First, it reflects the pressure faced by enterprises to improve effectiveness. Second, it is driven by the advances of related modelling and solution techniques, as well as the growing computational power. It is typical that manufacturing planning ([3,4,5]) models are based on mathematical programming approach.

This study aims to develop a better understanding of the production planning problems for engineering industry.

2. A MASTER PRODUCTION SCHEDULE (MPS)

In practice manufacturing planning involves a sequence of decisions that are made over time and results of planning are generally called the Master Production Schedule (MPS) [1, 2] ,The accuracy of MPS affects the effectiveness of enterprise. Due to software limitations, MPS do not include every aspect of production, the choice of what to model varies among used planning systems and companies.

MPS sets the quantity of each end item to be completed in each time period of a planning horizon. The simple example (Figure 1) illustrate the MPS.

			Period 1	Period 2	Period 3	Period 4
Product A						
Inventory I_i	I_0	5	8	5	10	5
Safety stock s_i			5	5	5	5
Lot size Q_i			16	23	27	12
Demand d_i			25	35	35	25
Amount sold S_i			30	50	50	30
Backorder b_i						
Amount produced X_i			33	47	55	25
Product B						
Inventory I_i	I_0	10	10	10	10	10
Safety stock s_i			10	10	10	10
Lot size Q_i			15	15	15	15
Demand d_i			20	20	20	20
Amount sold S_i			30	30	30	30
Backorder b_i						
Amount produced X_i			30	30	30	30

Figure 1. An example of MPS

For each product and each time period in MPS the following system on constraints must be satisfied:

$$\begin{cases} I_{i-1} + X_i - S_i = I_i \\ S_i \le d_i - b_i \end{cases} \quad (1)$$

Regarding enterprise resource planning (ERP) systems the MPS is usually used as information basis to integrate different planning tasks.

To formulate a MPS, the major issue is how to represent the planning time. The basic idea is to take manufacturing planning problem for given time horizon and somehow break it down into time intervals.

The key is the selection of the time interval duration, which presents a trade-off between the solution quality and the computational requirement.

The entire process of planning is interconnected. We cannot make optimum plan by considering each decision in isolation. The main point is that the various levels could be addressed with different tools and assumption, but must be linked.

The most widely employed strategy to overcome the computational difficulty for the large models is the multilevel-planning, based on idea of decomposition. Several decision levels are distinguished. The upper-level planning horizon is relatively long, and the number of time intervals is large. On lower level smaller sub-problems, can be solved, and they reduce the problem complexity and the solution time.

For multilevel planning the time **horizon splitting approach** is proposed, where the whole planning task is decomposed into hierarchy of sub-problems with shorter time horizons and correspondingly also with shorter time intervals (periods).

3. AGGREGATE PLANNING

Aggregate planning is concerned with the determination of production, inventory, and work force levels to meet demands over a planning horizon. In the broad sense, the aggregate-planning (AP) [1,3] has the following characteristics:

- a time horizon of about 12 months, with updating of the plan on a periodic basis;

● a variety of management objectives are used: low inventories, high profit, low costs, good customer service etc;

● resources are considered fixed, limited and shared.

Since it is usually impossible to consider every detail associated with the production planning for a long planning horizon, it is mandatory to aggregate the information being processed. The aggregation leads to mathematical models of smaller size and requires less computational effort for solution. For aggregation for example the units in the plant are grouped into departments and the products into families of products, etc.
Once the aggregate production plan is generated, the next level planning models are used for shorter time horizons and intervals.

On the lower levels additionally the scheduling models could be used for preparation of production recipes, which specify the sequences of tasks to be performed in each equipment for products given, and the timing of each task.
The most common techniques being used for solution of manufacturing planning problems are linear programming, nonlinear programming and genetic algorithms [1 , 3]. Especially Linear Programming and Mixed Integer programming approaches have become widely used methods to a variety of real-world planning problems, because their extensive modelling capabilities.
We introduce the following notations for model of AP:

i = An index of product, $i=1,\ldots,m$, where m the total number of products

j = An index of workstation, $j=1,\ldots,n$, where n total number of workstations

t = An index of time period, where $t=1,2,\ldots,tl$, where tl is the planning horizon

$d_{it}^{\max}$, $d_{it}^{\min}$ = Maximum and minimum demand for product i in period t

a_{ij} = Time required on workstation j to produce one unit of product i

c_{jt} = Capacity of workstation j in period t in units consistent with those used to define a_{ij}

h_i = Holding cost to carry a unit of inventory for one period

C_i = Unit production cost product

s_i = Selling price of product i

X_{it} = Quantity of product i produced during period t

S_{it} = Quantity of product i sold during period t

I_{it} = Inventory of product i at the end of period t .

For protection from disturbances the constraints for a safety stock are recommended to use:

$$I_{it} \geq s_{it}, i = 1, m, t = 0.tl \text{ .}$$

X_{it}, S_{it}, I_{it} are decision variables, (data of MPS), other symbols are representing input data.

We can give a linear programming formulation of the problem to maximize net profit subject to upper and lower bounds on sales and capacity constraints:

$$\textbf{Max} \quad P(\sum_{t=1}^{tl} \sum_{i=1}^{m} s_i * S_{it} - C_i * X_{it} - h_i * (I_{it} + X_{it} / 2) \qquad (2)$$

subject to:

$d_{it}^{\min} \le S_{it} \le d_{it}^{\max}$ *for all i,t*

$\sum_{i=1}^{m} a_{ij} * X_{it} \le c_{jt}$ *for all j,t*

$I_{it} = I_{it-1} + X_{it} - S_{it}$ *for all i,t*

$I_{it} \ge s_{it}$, for all $i = 1,...,m; t = 0....tl$

X_{it}, S_{it}, $I_{it} \ge 0$ *for all i,t.*

X_{it}, S_{it}, I_{it} *are integer*

Basic formulation contains only capacity constraints for the workstations. In some situations the other resources, such as people, raw materials, transport device, allowed maximum for inventory, etc may be important determinants.

Additionally to basic model the economic order quantity and corresponding lot size Q_i (table fig 1) could be determined using well-known formula EOQ [1]. The determination of optimal Q_i could be included into model (2) as decision variables. The objective function for this case must include the costs for set up and holding. Additionally in the constraints $\sum_{i=1}^{m} a_{ij} * X_{it} \le c_{jt}$ the times for setup must be included.

For improved model the non linear planning methods must be used. For small series batch production the genetic algorithms are recommended to use [2 , 6, 7].

The results of planning are insensitive to the optimal Q_i and it is recommended to substitute values of lot size using organizational recommendations [1].

4. COMPUTATIONAL EFFICIENCY OF PLANNING MODEL

One of the most important issues in the application of planning techniques lies in the computational efficiency, since realistic problems often lead to large models. In computer science, the **time complexity** of an algorithm quantifies the amount of time taken by an algorithm to run as a function of the size of the input to the problem.
For the planning models it means that the solution time scales in the worst case exponentially as the problem size increases.
A variety of modelling approaches are developed to overcome the computational difficulty in the solution of real-world problems.

Empirical experience shows that the number of computational time of a standard linear program with *m* constraints and *n* variables is found to vary approximately in relation to the cube of the number of constraints in the problem *(m^3)*.

For example, if we try to estimate the computational time for planning with time horizon 1 year for medium enterprise (producing 6 families of products in 6 different department) then if for time periods 1 quarter the planning takes 1 unit of computational time, then for time periods 1 month it takes 17 units and for planning with time periods 1 week – 1728 units.

5. MULTISTEP PLANNING

Planning involve a sequence of decisions that are made over time. The initial decision is followed by a second, the second by a third, and so on.

For multi-step planning the dynamic planning (DP) approach could be used. Original definition of DP is "planning over time." This is in contrast to manufacturing planning models based on traditional mathematical programming that often describe static decisions.

The characteristics of a problem that can be solved using DP are the following:

- problem can be divided into stages (time intervals)
- you make a decision at each stage
- the decision you make affects the state for the next stage
- there is a recursive relationship between the value of the decision at the stage and the previously found optima.

In general the key idea behind DP is quite simple, to solve a given problem, we need to solve different parts of the problem, then combine the solutions to reach an overall solution. The DP approach seeks to solve each sub-problem only once, thus reducing the number of computations. This is especially useful when the number of repeating sub-problems is large. For DP approach we must follows the procedure to formulate the solution to a problem recursively in terms of its planning problems for different time periods, We can reformulate the problem in a bottom-up fashion: to solve the sub-problem for first period and use the solution to build-on solutions to next time period . This is also usually done in a tabular form by iteratively generating the set of solutions for problems.

Modelling requires definitions of states of the manufacturing system as well as the specification of a measure of effectiveness. The state of the manufacturing system is described by states of inventory, the constraints (1) must be satisfied for each step.

The multi-step planning task could be formulated as follows:

For first step task is similar to he task (2) the maximum profit P_1 and the X_1 are found for different I_1 for given I_0, and d_1. The following steps used the results of previous steps

For step ***i*** we have recursively the formulation :

$$S_i = \max(s_i * S_i - C_i * X - h_i * (I_i + X_i/2) + \max P_{i-1})$$

DP has put the best advantage when the decision set is bounded and discrete, and the objective function is nonlinear.

CONCLUSIONS

A *novel and more complex* approach for the manufacturing planning optimization framework to real-world problems is proposed.

Multi-stage production planning is a promising candidate subject for future research. Due to the ubiquitous presence of unpredictable disturbances in the manufacturing environment, for example, uncertainty in processing times, prices, changes in demands, and equipment failure/breakdown, it is of paramount importance to be able to adjust the current plan upon realization of uncertain parameters or occurrence of unexpected events, which is called re-planning.

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RELATIONSHIPS BETWEEN BUSINESS OBJECTIVES AND THE ACTUAL OUTCOME OF THE BUSINESS

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Abstract: *This article discusses the company's production performance evaluation system, which is based on the strategic objectives of a production company. Key performance indicators for shaping the company's manufacturing operations are formed into a matrix that describes the level of strategic planning in production performance. Production performance evaluation system is a resultant tracking model that aids the company to react quickly to changes in business environment, while maintaining security of supply, quality and profitability of production operations.*
Key words: production performance evaluation system, Balanced Scorecard, business strategy, corporate performance monitoring system.

1. INTRODUCTION

Clearly formulated long-term objectives and successful execution are a prerequisite of company`s success. Industrial design of corporate performance starts with the company's vision, mission and strategic objectives, and appears in enterprise's performance indicators, which are divided into different, sometimes linked sub-plans, based on substantive and temporal aspects of the performance matrix. In terms of executing plans, it is important that the intentions, activities, resources, and objectives harmonize. Otherwise, our intentions will remain wishful thinking and cannot be implemented in real life. In order to ensure the implementation of flexible planning, transparency and rapid response to changes, the processes need to be monitored continuously. Corporate performance monitoring system is connecting planning and execution levels of business processes into a coherent whole, for comparing business link-level planning targets and actual results, and identifying the causes of deviations.

2. CORPORATE OBJECTIVES AND STRATEGIES

Company's strategic objectives are based on the mission, which describes the company's main objective for existence [1]. In addition to the main objective, the company needs to define its core values that reflect the nature of the organization. Company's core purpose and core values do not change over time; they define the purpose and nature of corporate existence.
Strategy is developed based on the analysis of the operating environment the company is in, which allows describing the current situation and forecasting the future. The concept of corporate strategy is based on the company's core purpose, core values and vision. The developed strategy is a systematic understanding of organizational goals confronted with the resulting action perspectives that stem from the organization and its environmental analysis. Unfortunately, generally and abstractly formulated vision, mission and strategic goals depend on the verbal formation, that can be influenced by wishful thinking of the management. It is important to establish connections between the development

and formulation of corporate strategy and its implementation [2, 3].

One instrument for strategic communication is the Balanced Scorecard that links performance metrics, derived from enterprise strategy, with the company's vision and strategic critical success-factors, objectives and resources through the four points [4]. Balanced Scorecard is a central communication instrument for strategic management process. The main idea of the measurement model is linking company's financial objectives with operational aspects of business such as customers, internal processes, learning and development. Four aspects of Kaplan and Norton must be considered as a general model that can be used in many different fields within a binding framework [5]. Every company has to shape its design perspectives based on the specifics of its operations that are of strategic importance in terms of its activity [6].

Production Company's operations have three key elements:

- commercial aspect- earnings and profitability of the operations,
- technological aspect- manufacturing operations efficiency,
- aspect of knowledge and skills- staff development etc.

Two types of chains and, consequently, two different strategies can be distinguished when setting objectives and formulating strategy for the manufacturing plant: the strategy of revenue growth and the strategy of productivity growth. Revenue growth strategy puts the emphasis on the market, products, customers and market segments. Origin for the revenue growth strategy development is in the sales department. Productivity growth strategy puts the emphasis on the company`s manufacturing operations and on improving efficiency through the optimization of manufacturing processes, and improving technologies and the response to appearing problems [7,8].

For reaching the target, company may use a variety of strategies. Planning is primarily responsible for the development and evaluation of possible alternatives. Evaluation criteria of alternatives are based on corporate objectives. [9]

2.2 Connections between performance indicators and the development plans

Industrial design of corporate performance is closely linked to setting objectives and decision-making. Production Company's performance design parameters are written on production performance design matrix [Fig. 1], which is the base for the company's production plans, and are divided into different, sometimes inter-linked sub-plans.

From a chronological point of view, we can distinguish from the productivity design matrix:

- strategic-level indicators, which are primarily targeted to develop the long-term framework conditions for the enterprise;
- tactical level indicators, that are targeted to create the conditions for the implementation of strategic plans;
- operation-level indicators, that are aimed to use the conditions created at the tactical level.

Functional distribution is a mostly used way for distinguishing performance design indicators. It is based on the company's value creation process, where in the centre there are the core business processes: purchasing, sales, production, and relations between them. For larger companies, also the production unit layers are distinguished: workshop, factory, or even production-line layers. Functional distribution is originating from the company structure and management level.

From activity-process view, we can distribute production indicators and planning aspects as: input-, output- and process-driven aspects.

- <u>Production input planning</u> can also be viewed as a planning for preparedness of production potential. Production potential includes production factors, resources and materials needed for production operations.
- <u>Production outputs</u> are products and services. Different products and services constitute the product portfolio and the aim of a planning task is to find the optimal production program, based on market demand (the client's needs and the company's production potential). The production planning program is closely related to demand forecasting and technology development.
- <u>Production process</u> or transformation process planning is related to time-scale planning of manufacturing activities.

			STRATEGIC LEVEL	TACTICAL LEVEL	OPERATIONAL LEVEL
Product and production program	**Production program planning**	PRODUCT	Product and production technology development innovation		
			Product life-cycle management	Product quality indicators and quality assurance	
		PRODUCTION PROGRAM	Range of production program- vertical	Functional criterias of the product	
			Range of production program- horizontal	To produce or outsource?	Planing of outsourced and own products
			Market demand forecast	Production program unit-based planning	Production program time-based planning
Production potential	**Production readiness planning**	RESOURCES	Production location and layout planning	Production potential unit-based planning	Võimsuse ja nõudluse tasakaalustamine
			Equipment selection	Equipment maintenance politics	Seadmete hooldus ja remont
			Production capacity	Structuation of production potential	Volume-based planning of the main program
			Production cycle	Quality criterias of resources and quality assurance	
			Investments and estimation	Outgoes, incomes, equibirilium point calculations	Cost price calculations
		MATERIALS	Planning resource demand	Reserve management	Assuring components and resources
				Assuring quality and control of resources and outsourcing	
				Rationing	
		WORK-FORCE		Employment design	Payment
			Personel development plan	Personel training	Recruitment
Production process	**Production process planning**	GENERAL	Selection of production technology and development assurance	Quality assurance in the production process	Quantitative and time-lag structuation of production program
			Selection of production process	Logistics	
		PROJECT	Principles for product management	Capacity utilization	Due-date planning and queue theory
		WORKSHOP		Utilization balancing	

		SERIES	Process management principles	Size of series
		WEIGTH		Syncronization of flow production
				Buffer planning

Fig. 1. Company`s production performance design matrix

3 A CONCEPT FOR EVALUATING MANUFACTURING PLANT PERFORMANCE

For executing plans, it is important that the intentions, activities, resources, and objectives are harmonious to each other. From business point of view, it is profitability of action that is important, however, from customer's perspective security of supply and quality is of greatest importance. In today's business environment, the company must be able to interrupt the production process without any major additional costs in order to rearrange the ordering of production. From production planning and actual results monitoring point of view, such characteristics as profitability, security of supply and quality acquire great importance. To link these processes efficiently, processes need to be:

- transparent, to ensure a timely assessment of process performance in real time,
- flexible, for a quick decision making according to registered processes performance indicators.

From process management point of view, it is important that the process would be structured so that it would be possible to affect the course of the process in time. To ensure flexibility and transparency of its manufacturing processes, we need to be able to evaluate the performance of our processes in real-time, in order to make quick decisions [10].

Key Performance Indicator (KPI) provides business with an overview of the company's production performance [11], which forms a system from three different aspects: product and production program, production potential and production process. This system is company`s activity-specific and depends on the company's business technology and economic performance. Company-specific performance indicators system serve as a basis for forming activity plans, which must ensure compliance with corporate key performance indicators and thus guarantee achievement of business objectives.

Besides planning, it is also of high importance to monitor production performance. To ensure transparency, and flexible response to changes in processes, continuous monitoring is needed. Production performance monitoring system is responsible for continuous monitoring and control execution of the production plans. Production tracking system is directly connected to the level of automation, which enables real-time process monitoring and control.

Company`s production performance monitoring indicators system (Fig. 2.) is binding the levels of planning and execution. It is activity performance monitoring decision-making model that creates a link between the scheduled and actual comparisons, and helps to investigate the cause of deviations. This integral model originates from company`s objectives, activity-specifics and technological and economical capacities.

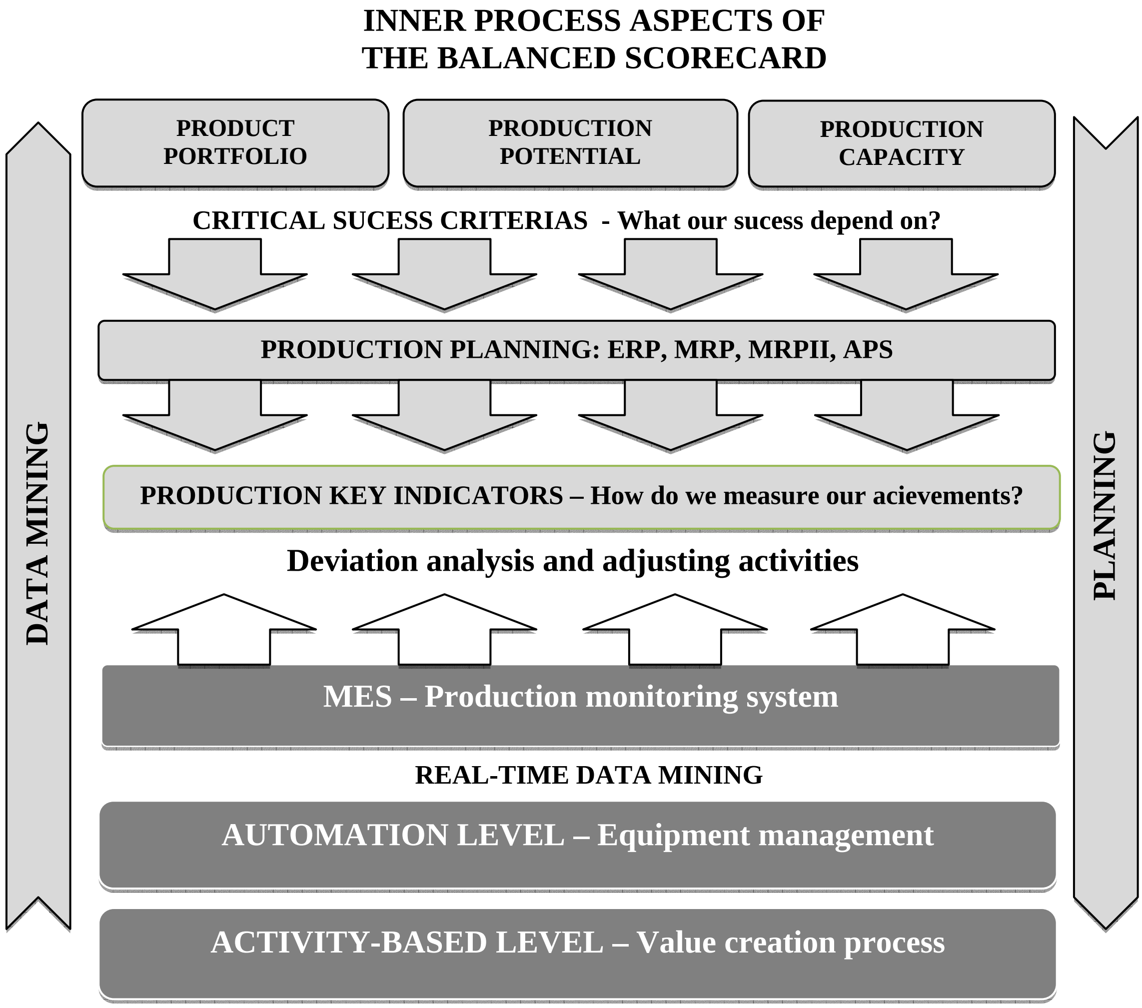

Fig. 2. Production performance monitoring system

4. CONCLUSION

From the company`s point of view, establishing holistic control system for monitoring its performance is critical to the success of the company. The system design is based on the company's manufacturing strategy necessary to achieve their goals and plans for activities and resources, which are necessary for achieving goals that are based on production key indicators. To ensure the production activity transparency and flexibility, companies must evaluate their processes in real time in order to make quick decisions.

Production performance indicators are the basis for objective planning for achieving company`s production plans. Company`s production goals, operational plans and performance monitoring system must form a holistic unity, which is based on the company`s activity specificity, the production characteristics, the strategic objectives and critical success factors. Process-specific activities` key indicators will help the company to evaluate the effectiveness of key processes and its performance.

Performance tracking system helps the company to create a specific action-decision model, which a business needs to maintain flexibility and react quickly to environmental changes in today's rapidly changing business environment. The decision-making model will help the company to make quick and right decisions, make new plans or make changes to existing plans. The company shall have at all times an overview of the company's production activities in order to maintain high product quality, security of supply and production profitability.

5. ACKNOWLEDGEMENTS

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WORKPLACE PERFORMANCE AND CAPABILITY OPTIMIZATION IN THE INTEGRATED MANUFACTURING

Lõun, K.; Riives, J. & Otto, T.

Abstract: *Globalization and higher competition sets companies a demand to search for possibilities how to improve performance and competitiveness. Main resources influencing company's performance are human resources and their skills and competences and machine tools with their technological possibilities. Human resources with their skills and competences and machine tools with their technological possibilities form technological capability of workplace. In this article, role of workplace as one key parameter in formation of company's performance and competitiveness is analysed.*
Key words: production capacity, factory of the future, workplace, lead time, lean manufacturing, optimization of resources.

1. INTRODUCTION

In nowadays, manufacturing enterprises have to meet a hard competition and increasing global demands for more functional products with higher quality. This has caused changes from traditional order fulfilling structures to demand-driven, customized manufacturing with lower waste and "Lean" and "Green" principles introducing, often referred to as the Factory of the Future (FoF) [1].

A company is an entire system that has to find the most effective and efficient ways to use its resources and carry out activities for continual improvement with an aim to be competitive and efficient. The aim of all organisations is profitability and therefore to create outputs that are worth more than the inputs.

Company's performance directly depends on the management of value creation processes: the performance is generated by the efficacy of goods-and-services production processes, associated with external factors of market positioning [2]. This starts from the performance of the workplaces. In the current article the methods and tools for workplace performance optimization are given.

2. ROLE OF A WORKPLACE IN PRODUCTION SYSTEM EFFICIENCY

The performance of the goods-and-services production system [3, 4] is generated by single workplaces. The performance of workplaces is generated by the competencies available, depending on two main factors: (i) the levels of competencies available and (ii) the ability to allocate and coordinate competencies along business processes [2]. Another factor influencing performance of a production system is technological possibilities of machine tools. Research carried out in the framework of INNOMET-EST project [5] showed that technological level of the company and existing competences [6] have direct impact on productivity, competitiveness and sustainability of an organization [7]. Engineering of production systems is described in literature [4, 8] and product manufacturing process and structure of production times in [9].

Workplace is a part of production system that plays certain role in product's manufacturing process. This role is described by (i) technological possibilities of machine tools and (ii) competences (knowledge, skills and personal abilities) of personnel [6]. Together these form capability of workplace that is an important parameter in production planning process [10].

Manufacturing time is a sum of times of different operations belonging to production process: processing, assembly, setup, transport, measurement and control, time for ancillary actions as cleaning, etc, and idle time. If we look at production process in wider concept, not only as pure manufacturing process, times for order revision, technological preparation and design, materials purchasing, storage, delivery, etc are added. Main operations of production process, where tangible assets are created, are manufacturing and assembly, but also surface processing operations. Operations in production in which value is created, are manufacturing and assembly. Non-productive operations occur with manufacturing process [11]. With an aim to minimize time for non-productive operations, lean production principles are implemented [12]. Main typical places and causes for occurrence of non-productive times are:

- Machine-tool and its technological possibilities (e.g. automation rate, spindle speed range, work piece and cutting tool changing time, rapid traverse, etc);
- Worker and its competences;
- Workplace organization;
- Organization of work in manufacturing unit;
- Order handling process (procurement, variability in processes, prevention of non-conformities etc).

Non-productive times in some extent are unavoidable, but every organization should seek for possibilities to minimize them.

Workplace is an important part of the production system. Describing workplace, important characteristics are its location, place in production system and technological capabilities of workplace [13]. Technological capabilities of the workplace are a sum of technological possibilities of the machine tool and competences of the worker. Location of workplace is important in the viewpoint of estimating alternative routes. In case of network manufacturing, location of a workplace in the same route could be also in some other company. Usually, alternative workplaces are possible to use. To minimise transport time, locations of workplaces should be as close to each other as possible or single-level processing should be used [10]. In the viewpoint of optimal use of technological resources, the most appropriate resource for a certain operation should be used. For describing a workplace, two indicators are used, which are also used for initial estimating expediency of the route (see eq. 1).

$$W = \{P_i, M_i\},\ i = 1, 2, \ldots, m \qquad (1),$$

where W – workplace, P – location of workplace; M – machine tool, i – number of locations and machine tools.

We assume that there is one machine tool with certain technological possibilities in one workplace. Technological possibilities of a machine tool give preconditions to carry out certain operations and processing of the detail [14]. If technological possibilities are not appropriate for processing requirements (e.g. shape of surfaces, accuracy of processing etc), then this machine tool cannot be used for the operation [13, 14]. In the same time, technological possibilities of a machine tool are not possible to use without competences of a machine tool operator. List of competences is formed by combination of technological possibilities of a machine tool and operations needed to process a certain product. Technological possibilities of machine tool and competences of machine tool operator determine workplace capability (see eq. 2).

$$C = (\{V\}, \{K\}) \qquad (2)$$

where C – workplace capability, V – technological possibilities of machine tool, K – competences of machine tool operator.

Processing time depends on main and ancillary times that are directly connected to technological possibilities of machine tool and competences needed to use them. The aim is to minimize machining time that creates preconditions to minimize net value of the operation and cost and duration of processing.

Workplace's capacity creates preconditions for achieving efficient realization of manufacturing operation (see fig.1). In case of insufficient conditions, it would be more reasonable not to take the order or consider the possibility of outsourcing. The more complicated and complex are the products, the more actual and effective could be network manufacturing [14, 15].

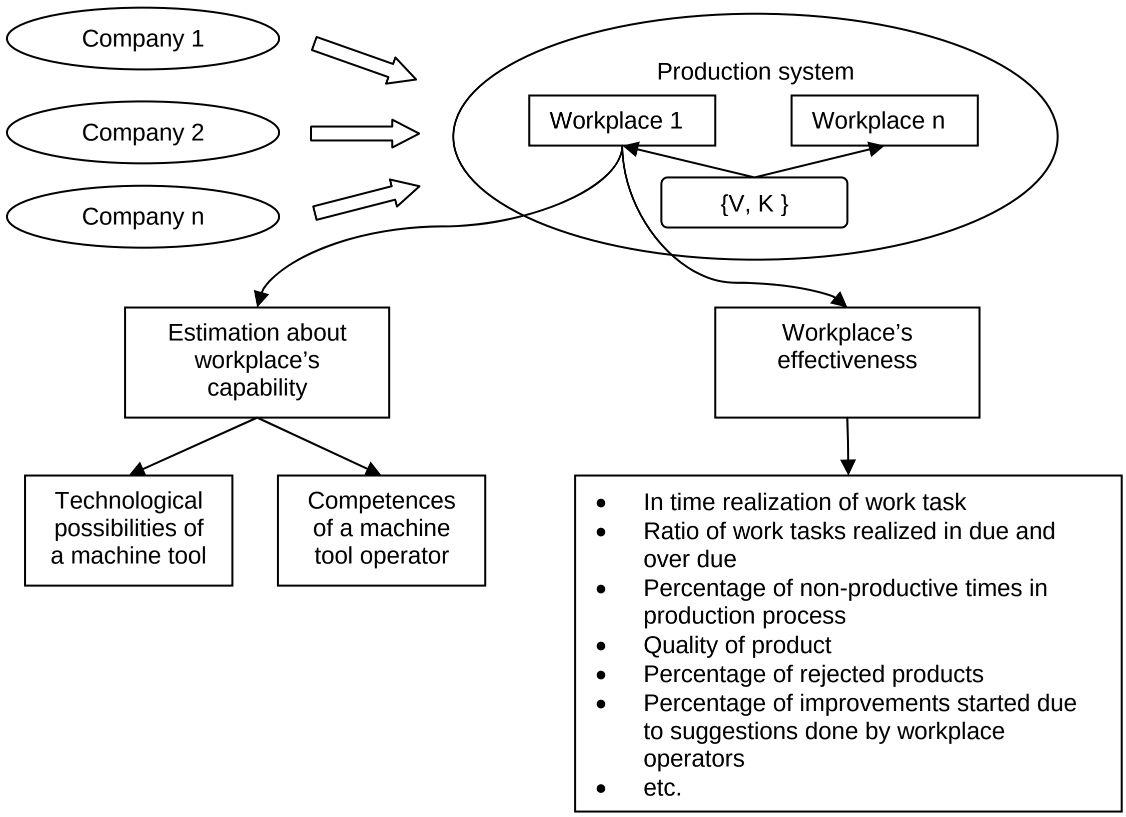

Fig.1. Description of capacity and effectiveness of a workplace

3. OPTIMIZATION OF WORKPLACE EFFECTIVENESS

Estimating the rate of fulfilment of strategic objectives, determining Critical Success Factors (CFS) and related Key Performance Indicators (KPI) is essential [16, 17, 18]. Roots of the effectiveness of a workplace lie in production planning and are realized via order handling process in different workplaces. Production planning task becomes even more difficult as manufactured products are often quite different by complexity and technology. Additional costs typically are caused by poor organisation of production, unpractical production structures, and incompetence of workers.

In [10] was described event and process engineering design model proceeding from the needed complexity. The basic loops in this model are:

- requirement loop, defining technological possibilities/competences needed for order fulfilling; it associates these with existing possibilities / competences and production system technological capabilities;
- behaviour loop, observing performance level (activities) according to order fulfilment measures of efficiency and

compares outputs with expert estimation of system capability.

Requirement loop is a tool of planning. It determines requirements for realizing a certain operation in a workplace. Researches [5, 11] have shown that productivity of a workplace decreases in case of lack of needed competences. The necessity for competences depends on complexity of work tasks [6, 7]. To carry out tasks successfully and with high productivity, level of existing competences has to be higher or at least equal of the level of competences needed. If not so, a company should calculate the rationality of accepting this order. One rational way would be outsourcing the order (fully or partially). Preconditions for development of network manufacturing are good overview about technological possibilities of partner companies, efficient tools for offer and order management and efficient collaboration with partners [10]. Additionally, actual level of technological possibilities has to be equal or somewhat higher of the level of technological possibilities needed for manufacturing the product [13]. To analyse impact of different technological parameters of a machine tool to the criteria of effectiveness (e.g. productivity or net value), the method of Lagrange multipliers could be used [19]. Complexity and high cost of technologies creates the necessity for network manufacturing. Behaviour loop is for measuring work efficiency and for realizing continual improvement principles (see Fig. 2). KPI-s are planned for workplaces taking into account the competences of the operator and technological possibilities of the machine tool of this workplace. We have transformation process where inputs (competences, technological possibilities) become outputs as the result of processes taking place in workplace. Typical outputs demonstrating effectiveness and efficiency of the process are quality, productivity (number of products produced in certain time), net value of the product etc. In reality, deviations may occur, so planned outputs are not achieved: quality non-conformances, time overlapping, resource overlapping etc. These losses have negative impact on the performance, e.g. nonconforming quality means increase of costs because of re-processing or producing new product and/or exceeding time limits. Therefore estimating the performance and analysing the results is very important.

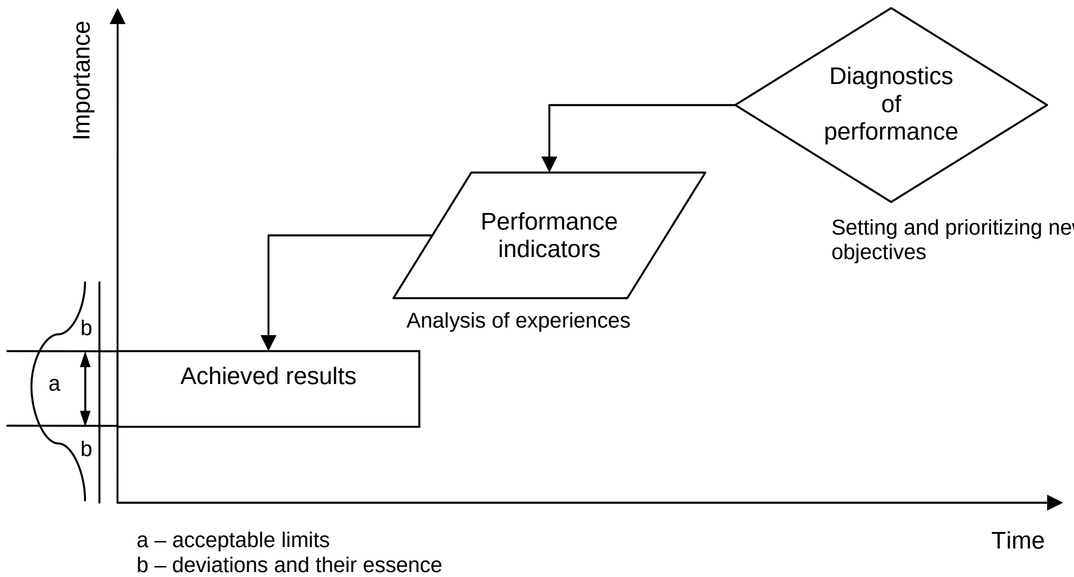

Fig.2. Behaviour Loop interpretation

These losses can be estimated by following quadratic loss function (see eq.3) [20].

$$L(y) = K\,[(y-m)^2 + \sigma^2] \qquad (3)$$

where L is the loss, K = A / Δ, A – loss per unit item, Δ = upper tolerance limit / lower tolerance limit, Y, σ – the mean and standard deviation of the capability, respectively, m – target value.

Additional costs are caused by defects or scrap that occurs after processing and their correction means extra cost because of rework.

To avoid excessive costs, performance indicators should be determined on the basis of experiences that are obtained in order handling. These performance indicators (complexity of processed details, batch sizes, order handling deadlines, productivity etc) are basis for decision-making in the planning phase, but also give input to improvement process. To start improvement actions, occurrence of waste and its reasons have to be determined. This has to be done on workplace basis.

So we reach to proactive (preventive) actions [21, 22] which percentage should increase. In organizational behaviour the proactive behaviour (or proactivity) by individuals refers change-oriented and self-initiated behaviour in the workplace. Proactive behaviour involves acting in advance of a future situation, rather than just reacting. Proactive behaviour can be contrasted with other work-related behaviours, such as proficiency, i.e. the fulfilment of predictable requirements of one's job, or adaptivity, the successful change initiated by others in the organization. Proactivity that originates from workplace is bearer of transformation and improvement process in the organization. Transformation process itself, reactivity and proactivity are main functional processes that company should continually manage, measure and improve.

4. CONCLUSIONS

The article material is approved by the consortium of companies belonging into Innovative Manufacturing Engineering Systems Competence Centre IMECC and the theoretical results are used in e-manufacturing system development, available as demo version at http://www.imecc.ee/.

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INNOVATIVE KNOWLEDGE: THE IMPORTANCE AND FUNCTIONALITY IN THE PRESENT AND FUTURE ENTERPRISES

Maceika, A. & Jančiauskas, B.

Abstract: *The authors of the article carried out a number of studies, have collected and analysed relevant information about innovative knowledge. Applied methods – a survey of scientific literature and other information sources, structural system analysis, a sociological inquiry of the industrial enterprises and public administration institutions personnel and experts evaluations.*
The analysis of the literature sources and inquiry results showed that there are a lot of problems related with attraction of the means for innovative knowledge development. The problems appear in the field of the motivation, learning, risk decreasing, and other resources attraction.
A survey showed that there is a great need for knowledge and skills of staff management in order to have successful innovation activities. To improve the situation it is valuable to start with the existing situation analysis of the company. Innovative knowledge management is important for well-targeted approach as well.

Key words: Innovation, innovative knowledge, industrial enterprise, knowledge management

1. INTRODUCTION

The Lithuanian enterprises and institutions must understand how to evaluate and to use their intellectual potential in the business development in order to survive in the market and secure a reasonable size of the profit. We believe that the innovative knowledge management in the enterprises and institutions would give them quite a lot of economic, social and even cultural benefits.
The goal of the work: to provide a research of the innovative knowledge usage situation in the industrial enterprises and to foresee the ways how to develop this feature to have more benefits and effectiveness in the future.
The subject of research: the innovative knowledge and the development of its usage in the industrial enterprises.

2. PROBLEM STATEMENTS

The authors have an opinion that knowledge is constantly renewed as a resource, even in the application process. As a result, this feature of the knowledge is very useful for all management processes and for motivation of decisions.
However, today we are more concerned about the innovative knowledge, which is associated with the entering in to the new markets, use of the new products, services, manufacturing and organizational processes. Innovative knowledge also related with promotion of customer's needs, higher technology application in the domestic industry, professional activities, cultural development and similar subjects.
William Lazonick [1] referred that central importance to the accumulation and transformation of capabilities in the knowledge using industries is the skill base in which the firm invest in pursuing its innovative strategy. Within the firm, different functional specialties and hierarchical responsibilities characterize the division of labor, and define the firm's

skill base. In the effort to generate collective and cumulative learning, those who exercise strategic control can choose how to structure the skill base, including how employees move around and up the enterprise's functional and hierarchical division of labor over the course of their careers. At the same time, however, the organization of the skills base will be constrained by both the particular learning requirements of the industrial activities in which the firm has chosen to compete and the alternative employment opportunities of the personnel whom the firm wants to employ.

The administrative way to implement innovative knowledge management system through the project is very important to. For example, in Southern Italy the Soveria.it project take a part. This project is cover e-government, e-democracy, and e-factory activities to promote the use of information and communication technology and to develop permament lab for innovation. According to Gianpaolo Iazzolino and Rinaldo Pietrantonio [2] it shows how a too heavy top-down approach can act as a weakness for stimulating the growth of less developed areas and provides a possible solution for it – i.e., a better understanding of the society's needs and a stronger partnership with civil society and local firms.

The empirical research of Jinyu He and Heli C. Wang [3] showed that in a highly innovative firm, incentive based interest alignment is more appropriate for motivating managers; monitoring will normally be less effective, and in some cases may even be counterproductive, as it will tend to constrain managerial discretion, which is necessary for the efficient deployment of a firm's innovative knowledge assets.

By Richard Whitley [4] the increasing importance of academic research skills and knowledge in the development of the new industries means that variations in the dominant institutions governing the development and use research skills also have significant consequences for the rate and type of technical changes in diferent market economies. Additionally, differences in the rate of movement of scientists and engineers between the public research system and private firms, and between firms, affect the flow of knowledge and skills. The development of innovative competences in cooperation with business partners, innovating firms often gain considerable knowledge about new technologies, markets and process improvements from trade associations, industry groupings, suppliers and customers. However, high levels of involvement in industry collaborations, tend to lock firms into current technological trajectories and sectoral boudaries. Strong and continuing collaborations with industry partners, then encourage relatively cumulative development of innoative competences within firms, and not the introduction of competence-destroying innovations. This limits their ability to change innovative competences radically, as well as inhibiting their capacity to absorb quite different forms of new knowledge.

In particular, it has been shown that, first, technological innovations have sometimes preceded science, in that practical inventions came about before the scientific understanding of why they worked (the steam engine is a good case in point; another example is airplane, the aerodynamic properties of which were mathematically elaborated only after the actual development of the artifact) by Giovanni Dosi, Franco Malerba, Giovanni B. Ramello, and Francesco Silva [5].

Rolandas Strazdas and Žilvinas Jančioras [6] providing creativity process management tool "O Generator" which is very important for product innovation development in the companies of creative industries. There are the problems to have original product every time from one side and to decrease the risk of innovation from another.

3. APPLICATION AREA

The main application area for innovative knowledge usage situation research results is development of the industrial enterprises innovation activity. The research involved Lithuanian industrial enterprises and there are questioned 455 personnel representatives. The 90 personnel of public administration institutions representatives were questioned too. The results of the investigation can be useful for these enterprises and worldwide in general.

4. RESEARCH COURSE

As the first step the aim of the research was formulated. At the second step the research of the industrial enterprises personnel the innovative knowledge usage situation value orientation took place. Third step involved the analysis and evaluation of the innovation situation in the enterprises by using an average value method and after the analysis adequate conclusions were stated.

5. METHOD USED

Applied methods – a survey of scientific literature and other information sources, structural system analysis, a sociological inquiry of industrial enterprises and public administration institutions personnel, expert evaluation by six innovation activity specialist.

6. RESULTS

Extended research displayed that less than a half of the respondents properly understood innovation term in the industrial enterprises. To the question "What is innovation?" rightly replied 48 % of respondents, inaccurate answer was received from 40 % of the respondents, unanswered cases constituted 12 %. The situation is better in the public administration institutions field. There we had correct reply from 61 % of respondents, inaccurate answer was received from 38 % of the respondents, unanswered cases constituted 1 %. Average values of respondent's answers are presented in the table 1.

Respondents	The answers of respondents, %	
	Industrial enterprises personnel	Public adminis-tration institutions personnel
No answer	11.87	1.11
Novelty	24.40	14.07
Renovation	1.65	0.56
New idea, product, invention, and so on	8.02	5.19
Process of thinking, turn up, searching, increasing, creating, and so on	6.04	18.15
Introduction and realization of the novelties, technologies, products, services	34.51	46.48
Development of the technologies, products, services and so on	8.57	7.59
New way of thinking how to invest, to create the business	4.95	6.85

Table 1. Average evaluation of understanding of innovativeness (one respondent can have few opinions, for this reason some answers was divided in to several parts, with total sum equal to 1)

Research showed that respondent opinion about innovation term was divided. The answers that innovation is novelty, renovation, something new and the process of doing something was evaluated as inaccurate, because a real innovation has business aspect and shows that the subject was developed and totally introduced in to the practice. The creation it self is only half way to innovation. Innovation is the process of renewing of something and generally means invention implementation and acceptation by the market or society. The personnel of the future enterprises must understand innovation term very well.

For the purpose to establish innovative knowledge and skills, that are necessary for innovative activity success, six experts of the Lithuanian Innovation Centre carried out assessment by using a questionnaire form.

The description of knowledge and skills field	Average evaluation of importance for successful innovation activity, points (1-10)	
	Knowledge	Skills
Economic	7.93	8.42
Psychology	7.93	8.67
Engineering	7.2	7.17
Management	8.3	8.7
The law	7.63	7.5
Personnel management specialization (only for leaders)	10	10
Entrepreneurship specialization (only for leaders)	9.24	10
Total average	8.32	8.64

Table 2. Knowledge and skills that should be given to workers of industrial enterprises for successful development of innovative activities (mean scores)

In the table 2 the summarized results of the expert's evaluations are presented.

The results showed that the knowledge and skills in the field of personnel management, specialized only for leaders, was assessed as most important for successful innovation activity. Their assessment was 10 points in an average. How much less evaluated entrepreneurship field knowledge and skills. This assessment mean score was 9.5 for leaders knowledge, and skills assessment average was 10 points. The lowest ratings were obtained for the engineering knowledge and skills field. Their average grade was 7.2 points for knowledge, skills assessment and an average of 7.17 points was obtained. All researched knowledge and skills was evaluated by the experts as are important for innovation activities. However, engineering knowledge can be obtained from professional consultants, so this type of knowledge is not so important to direct innovation activities, in addition, technological part of innovation can be purchased in accordance with project requirements.

Innovative knowledge – advanced information and skills for theoretical or practical understanding of a subject, which is related to innovation process. Innovative knowledge can be the start line for innovation or result of innovation process. We believe that scientific methods, as innovative knowledge acquiring means, will be more important in the future enterprises. The advanced learning and research methods, new technologies, and more forward-looking personnel can create the necessary knowledge and skills base for doing something original and useful for the society.

We offer this scheme (table 3) for innovative forms of knowledge extraction and detection. It is very useful for facilitation of the understanding of the innovative nature knowledge, which in turn helps to drive the investigator and the company's professional efforts in the managerial decisions making process.

The proposed scheme is also important for finding a future way to understand and describe the features of new enterprise.

Production activities (the areas of innovative knowledge accumulation)	Dominant types of innovative knowledge
Designing of updated or newly created product and service (demand evaluation, engineering solutions, economic evaluations, selection of the production form and technology)	Economic, engineering, management, entrepreneurship, psychology, the law
The improvement of the company logistics (individual connection, the reduction of cost of freight and warehousing)	Economic, engineering, management
Production and sale of products and services (improvement of plant, production and sales processes, working methods, skills, equipment, and devices)	Economic, engineering, personnel management, entrepreneurship, the law
The company's marketing activities (improvement of scientific and practical marketing methods, dealing with the business partners and customers)	Economic, personnel management, psychology, entrepreneurship
Information activities of the enterprise and communication processes (improvement of information and communication systems)	Personnel management specialization, psychology, engineering

Table 3. The areas of production activities where dominant types of innovative knowledge are accumulated

We believe that the company, as evolving socio-economic phenomenon, must be described within disclosure of the systemic entirety of the features. These features are formed by enterprise socio-economic content.

In assessment of industrial workers' information level it is important to understand that the information about the required work must be in a sufficient volume, reliable and accurate. There is important knowledge how to handle information and how to present it for the innovation process participants.

7. CONCLUSIONS

After examination of the thematic problem of this article the following conclusion are stated:

1. For the Lithuanian companies and institutions it is reasonable to learn how to evaluate and to use the intellectual capabilities of people which are working in the production development field.
2. The operating experience of international companies and institutions from other countries shows that this problem exists in many organizations, especially in small and medium-sized. For solving this problem it is possible to do positive work by intelligent management of the innovative knowledge in the companies and institutions. We need to discover specific of innovative knowledge on the basis of its participation in the new processes for creating the new forms of activities, methods, technologies, products and the most similar.
3. The concept of innovative knowledge includes innovative forms of knowledge that are obviously involved in the production process, from design stage recurring and emerging of the products and services to the marketing process at the end. The specific types of innovative knowledge one can identify by using scheme for extraction and detection of the innovative engineering and other forms of knowledge (see the 3 table).
4. New, forward-looking company or institution begins its one from the

understanding of the key features and proper logical and practical its development. Such an essential feature - the activities associated with the company in general and particularly with the new, innovative, engineering, economic - social knowledge, and its management.

5. Research conducted in the country's industry and public administration institutions show not very joyful situation. Innovation concept more clearly understand about 48 percent of the industrial enterprises and 61 percent of the public administration respondents. Results from a study of the other articles, discussions, reports and other items shows that knowledge management in enterprises and institutions of the country is in a state of neglect, because in many cases inconceivable that without a good knowledge, especially innovative, it is impossible to make continuously successful innovations.

6. It would make no sense to prove that even the better educated respondents, who are unable to overcome the business circumstances where more innovative knowledge is redundant, are silent partners in risky business.

7. It is obvious that for our country (but apparently this situation are in the other EU countries also) enterprises and institutions, that the lack of understanding how proper manage the new knowledge generally, and especially innovative knowledge, has become a significant brake of development.

8. We have no doubt that business is impossible without a systematic, continuous creativity development, and creativity is impossible without innovative knowledge understanding and management.

9. The thinking about the lack of investment causes a lot of damage for accumulation of knowledge and for its innovative use.

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THE CREATIVITY OF INNOVATION TEAM

Maceika, A. & Zabielavičienė, I.

Abstract: *This article studies the effect of organizational factors on creativity and personal qualities of people, working in innovation teams. The authors of the study describe three main factors of innovation team's member's creativity: openness, perception and high degree of moral quality. The study also provides definitions of openness, perception and high degree of moral quality, as well as presenting analysis results of the effect that these factors have on creativity of persons working in innovation teams. A person's level of moral development is taken into consideration, when measuring the influence of personal qualities of creativity. This study also provides and logically proves a four-stage classification model of a person's level of moral development. Econometrical methods were chiefly used in uncovering the effects of a person's level of moral development on the factors of creativity.*

Key words: Innovation team, creativity, perception, openness, high degree of moral quality, moral development

1. INTRODUCTION

Team-work in the sphere of innovations is very exceptional. To do this work great creative potential of the team is required. Leading of this type of the team also becomes significantly more challenging. It is necessary to facilitate an atmosphere, where the members of the team are able to unleash their creative abilities as well as improve them. Creative personalities are more sensitive to the psychological climate of an organization and also to their inner sense of motivation to create. The topic of team-work in the sphere of innovation is one that has gained little attention in the academic community. Journals focused on the field of innovation only touch upon the very basic principles of. This means, that it is expedient thoroughly to study the factors that influencing the creative potential of innovation teams, as it is a topic which has not gained much attention from researchers. The results of these studies should create a basis for methodological improvements in the process of forming and managing innovation teams.

The goal of the work: is to make research of processes that happening in innovation teams and to determine what factors have influence on the team member's creativity.

The subject of research: the creativity factors of innovation team.

2. PROBLEM STATEMENTS

Research shows, that organizations show little interest in the process of forming innovation teams. The interests are generally limited to employee selection on the basis of professional competence. It is currently unknown, just how much does a person's perception, openness and high degree of moral quality (representing the need for understanding, openness for novelty and the ability to question rooted views and also the need for personal improvement) influence his creativity. It is also unknown, how the aforementioned qualities are related to a team member's degree of moral development in relation to his value system and his willingness to defend his values.

3. APPLICATION AREA

Main application area for innovativeness research results is development of the industrial enterprises personnel creativity. The research involved 70 representatives of the personnel with an engineering degree.

4. RELATED WORKS

Most theorists believe that creativity is a complex phenomenon determined by many different combinations of components. Academic literature outlines various different models of creativity, combining various components. One of the most widespread models is K. K. Urban's (1991) [1] model, which outlines 6 components of creativity. They are: specific knowledge, skills and abilities, divergent thinking, common knowledge, tolerance of ambiguity, motivation and task commitment.

Creativity is usually associated with a person's need for self-actualization, originality, understanding of his mission in life and internal motivation. M. A. Runco (2004) [2] believes that creativity is a complex combination of different qualities: originality, flexibility, activity, ability to solve problems and accept challenges, ability to determine changes in the technological field as well as culture. C. R. Rogers (1961) [3] considered creativity a quality common to all humans. According to him, the need for self-actualization is the main requirement for creativity to flourish, expand your potential choices and feel satisfaction in creation. Rogers determines these internal conditions needed for creativity:

1. Openness for experience, extension.
2. Internal compass of evaluation.
3. The ability to combine terms of received elements of information in a novel way.

The author also describes external conditions needed for creativity - psychological freedom and psychological safety. C. R. Rogers believes that psychological safety is created in 3 ways:

1. By completely accepting a person's intrinsic value without any prejudices or requirements.
2. Not evaluating other according to your own created value system.
3. Emphatically accepting another person.

C. R. Rogers's presents arguments that analysis of potential opportunities given by innovation teams is very relevant today, because this process uncovering the essential factors and conditions for creativity to flourish. By applying these ideas in practice, we can help managers to understand the importance of reconceptualization for companies' growth and fundamentally change relations between managers and their subordinates. An employee's creativity is currently being valued only as potential possibility to increase the company's profit and no attention is given for creativity as an expression of a person's independence and intellectual prowess. In many cases today's company's managers put so little effort to accept their subordinates without any prejudices or requirements, i.e. accepting them just as they are. Only by understanding an employee's personal freedom to act according to his own beliefs can you begin to speak about any meaningful use of creative potential in companies and innovation teams.

According to another researcher E. P. Simontono (2000) [4] there are two main models of creativity. One of them deals with the process of creativity, studying product and personality. We could designate C. R. Rogers's model as being of this paradigm. The other model, according to Simontono, is the "economic-commercial" model. The author argues, that this model is not based on any theory and only promotes quick studies of manifestations of creativity and invest in creativity as one would invest in an expensive item. A survey of engineers working in industrial companies revealed that this model is the most common one in the Lithuanian industrial companies.

To establish the factors that affect the creativity of innovation teams necessary to make analysis of the values system too.

The pioneer of a new branch of psychology (existential analysis) V. E. Frankl (2005) [5] describes 3 categories of values: creative, experiential and attitudinal values. It is possible to implement creative values by active means. Experiential values are achieved by experiencing something. The authors of this article believe, that experiential values in an innovation team manifests as self-realization in the act of creation. Attitudinal values are determined by a person's relations with the restrictions of his life. Specifically, team work in the sphere of innovation should be considered as a combination of creative and attitudinal values. The company allows the team of innovation to implement and achieve both types of values. It usually require the team to implement creative values and also take a closer look at the attitudinal values creating positive and negative stimuli for creativity. The implementation of these creative values is closely related to the team members' personal creative values: perception, openness and high degree of moral quality.

Perception is the registration and processing of sensual experiences, a reflection of an object, situation or the entirety of an event in the consciousness. Processes of perception are intentional and are used to disseminate the data content of a specific situation. It allows a person to compare the perceived objects with the earlier perceptions of the same objects stored in memory and then recognize them. Perception in this regard is similar to the process of thought in the sense, that it has the capacity to transform the mental image and make it appropriate to make a decision. These sorts of transformations, usually unconscious in nature, may help to creatively solve most problems. Perception contributes to look at the same problem from different vantage points and also to stimulate new solutions as well as new directions of activity.

High degree of moral quality is a personality trait which describes a person's devotion to higher ideals or ideas. It expresses a person's dissatisfaction with the current reality and a desire to change it in a better direction, i.e. the ideal. By outlining possible future scenarios this trait indicates the reason for creativity, its main purpose. A person's low degree of moral quality results in a various negative ways, such as skepticism, nihilism or cynicism. Such an individual drowns in his routine, becomes more primitive and spiritually poor.

Openness to novelties is firstly the need to question rooted beliefs and practices. It is deeply connected with the sincere desire to change and the belief that this will result in a better future. Being satisfied with the current reality and not wanting to superimpose your own values make them lifeless dogmas. The blind and unquestioning following of such values leads to hate of different beliefs and values, mental stagnation, and uncreative thought.

5. RESEARCH COURSE

As the first step the aim of the research was formulated. At the second step the research of the factors that have influence on the team member's creativity took place. For research we selected the factors that affect the team members' personal level of moral development. Third step involved the analysis and valuation of the team members' creativity situation in the enterprises by using econometric methods and after analysis adequate conclusions were stated.

6. METHOD USED

Applied methods – a survey of scientific literature and other information sources, structural system analysis, logic analysis, a sociological inquiry of people working in innovation teams, regression analysis of quantitative survey data.

7. RESULTS

When carrying out the survey on the degree of moral quality, perception and openness definition for the peoples who are working in innovation teams, they defined high degree of moral quality as a need for perfection, perception as the need for knowledge, openness as the ability to change beliefs. The workers were not evaluating themselves, but they evaluated other members of their team. During the survey the factors of creativity (y), openness (x□), perception (x□) and high degree of moral quality (x□) were calculated using indexes from 1 to 5. To establish, how the creativity of people working in innovation teams depends on their openness, perception and high degree of moral quality, correlation regression analysis was made and relationship between several variables by using correlation regression analysis was found. The appearance of regression function was:

$$y = 0.501 + 0.385x_1 + 0.1x_2 + 0.751x_3 ; \quad (1)$$

where y - a person's creativity, x_1 - the person's openness, x_2 - the person's perception, x_3 - the person's degree of high moral quality.

During the survey, data were collected to determine how the team members' personal qualities (openness, perception and high degree of moral quality) are related to their level of moral development. Different people use different ethical standards for their decisions, what also depend on their level of moral development. In academic literature according to S. P. Robbins (2003) [6] the level of moral development of the workers was analyzed by separating it into 3 levels: unconventional, conventional and principal. Each level is also separated into two stages. According to S. P. Robbins' (2003) [6] who provided frame of practical observations logic, we grouped the workers' level of moral development into 4 stages.

People belonging to the first stage are those whose decisions are restricted by the sense of fear. Fear weakens a person's will, smothers initiative, activeness and creativity. It is fear that usually hinders a person's creative powers: fear for your reputation, to be misunderstood or laughed at, that new ideas will be distorted or stolen, that we are not competent, or that we will not be rewarded. A person in fear experiences makes situation when a feeling of insufficient personal safety and creative freedom becomes an unbearable burden.

The second stage consists of employees, whose decisions are limited by their personal interest. They are a lot more likely to express their ideas; however, their interests are usually limited to their own person. Also, they are very competitive and they try to become "the most important". In jobs where accomplishments are handsomely rewarded they can be very productive, however if there are no clear standards of evaluation and this self-serving employee does not feel any direct motivation, his efforts to sincerely work become very limited.

The third stage includes employees who base their decisions on their obligations to the organization. When this workers making decisions and meeting their engagements practical observations rely on the rules prescribed by their organizations.

Employees who practice values not yet accepted or a characteristic to a spiritual organization without regard to the majority's opinion are put into the fourth levels of moral development. Organizations which support spiritual culture admit that people look for meaning in their job. The meaning of spirituality in organizations is to help employees find their sense of purpose in their work according to D. P. Ashmos and D. Duchon (2000) [7]. Spiritual organizations not only provide a person with a task it also acknowledges its value. A spiritual organization stands out from other in the fact that it tolerates its employee's self-expression. It allows them to openly express their opinions, moods and feelings without any fear of retribution.

The survey was aimed at determining the level of moral development of people working in innovation teams. The aforementioned four stages of moral development were the basis for the actual survey. That is why the level of moral development (x) was valued from 1 to 4 depending on the achieved stage. The relationship between person's openness and his level of moral development was found. The appearance of regression function was:

$$x_1 = 0.225 + 0.755x; \quad (2)$$

where x - a person's stage of moral development.

The regression function of the dependence between person's degree of moral quality and his stage of moral development is:

$$x_3 = 0.706 + 0.739x; \quad (3)$$

where x - a person's stage of moral development.

The studies revealed that there is no correlation between persons, working in an innovation team, perception (x□) and his stage of moral development x.

By using this model possible to form up the basis for innovation team creation and its structure improvement. Moral development can be affected, because the innovative team is formed of persons with various levels of moral development mix. It is important to know what part of the team is covered by a higher level of moral development staff. In addition the team leader should monitor the level of moral development and take appropriate measures to motivate it to grow continuously. It is no guarantee that the level of moral development of the team will increase constantly. Growth may stop. In this case, you can change the average level of moral development by changing the lower-level team members to the staff with higher level of moral development. This process can be very complicated and in some cases almost impracticable, because persons with high moral development level are welcome in other creative groups too. For the creation process the feeling of security is also important. If there is a risk that when the level of moral development will be too low estimated and it is possible to lost team membership, then person can spend more time for looking good in the eyes of assessor, but the efforts to create something will be minimal at the same time. The level of moral development and the other values listed in the model can be evaluated only by external evaluators from the set of team members. This also allows for a subjective evaluation of this phenomenon.

Our article examines the unconventional creative team, which has no clear leader, because the autocratic leadership and the free creative process are incompatible. Creator should be free and even competition and preconceived interference with the motivational means or interference in to the creative process can confuse. It is important that staff will be involved in the creation process and will be personally compatible. Theirs value systems must be mutually dependent, and efforts to achieve good results observed and evaluated. If the type of the work is radically changing, the competences of the employees must be reviewed and adapted to the current situation. Here it is good to apply learning courses and other types of training.

8. CONCLUSIONS

After examination of the thematic problem of this article following conclusion are available:

1. Various factors have an influence upon the creativity of innovation teams in a myriad of different ways. We should consider that luck of person's internal motivation drives as a negative factor.
2. The carried out survey of the factors (that is openness, perception and high degree of moral quality) revealed that the biggest influence on creativity was from a person's degree of moral quality factor, which representing the personal trait in seeking perception.

3. Openness, which representing the personal trait of questioning existing concepts and view of the world, is also a significant factor in creative drive.
4. The least important factor which has an influence upon the creativity of the people working in innovation teams was perception. The perception representing a person’s need for knowledge.
5. Different people use different ethical standards for their decisions. This is dependent on their level of moral development.
6. The article introduces a logical grading scheme of the level of moral development, consisting of four stages of moral development.
7. It is proposed that the first stage would include people, whose decisions are governed by their sense of fear, weakening their will, stifling initiative, activeness and creativity.
8. The second stage would consist of people, whose decisions are governed by their self-interest.
9. The third proposed stage comprises of people who when making their decisions or fulfilling obligations use the existing rules and regulations within the organization.
10. People, who foster values and principles, characteristic of spiritual organizations, and not yet acknowledged by their workplace without any regard of the majority’s opinion would be ascribed to the fourth stage of moral development.
11. The carried out study by using econometric methods has revealed, that level of moral development of a persons, working in an innovation team, exerts influence on that person’s openness. The openness is representing his ability to question existing concepts and the high degree of moral quality is representing the need to seek perfection.
12. The person’s perception, which is representing the need to gain knowledge, did not correlate with the stage of person’s moral development.

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A PROPOSAL TO IMPROVE ADAPTATION CONTROL SYSTEM WITHIN AUTOMOTIVE ENTERPRISES

Makraiova, J.; Caganova, D. & Cambal, M.

Abstract: *This article deals with a proposal of alternatives for adaptation control improvement, mainly in its final part, which represents the obtaining the feedback on the process of adaptation and the level of adaptability. It is based on the research, conducted in Peugeot Citroen Automobile Slovakia, Trnava. Definition of essential theoretical terms is followed by a brief description of research and proposal of recommendations to improvement of adaptation management and in the end it is extended with the identification procedure for evaluation of adaptation control system for production workers*

Key words: *adaptation, orientation, questionnaire, adaptation interview, unqualified production workers*

1. INTRODUCTION

The phenomenon of globalizations has been persistent since the last decade of 20th century and is still a factor that influences organizations and people these days [3]. Accelerated changes to the economic system, the effects of integration and the globalization process requires the maximum level of flexibility and adaptability to economic conditions, particularly for employees within corporate organizations. People are no longer willing to passively receive what they are offered, however they wish to experience the feeling of satisfaction and fulfillment at work. For this reason intensive job rotation occurs and business organizations try to ensure quick adaptation to all aspects of a new job position. The corporation contributes to the stability and staff satisfaction from the first working day and thus effectively reduce staff turnover rate, which often occurs shortly after entering a new job and represent unnecessary financial costs. Effective adaptation management can provide benefits for the company in the form of shortening the initial phase, when the new employee is not performing fully, has not yet mastered all of his working tasks and is not included into the stable working team and wider company. The newcomer feels satisfied in turn, while receiving increased support during the adaptation phase, when experiencing some apprehension and uncertainty about the new environment. Managing the adaptation mechanism with respect to the individuality of each person becomes one of the keys to success for business entities today.

2. THEORETICAL BACKGROUND OF ADAPTATION IN THE WORKING PROCESS ISSUE

The basic terms related to the adaptation in working process are „adaptation“ and „orientation“. Since these two terms do not have a uniform interpretation of content in the works of Slovak and foreign authors, the differentiation between them has been captured in the following formulations:

Adaptation at work is a process of confrontation and coping with the changed conditions of the individual when taking a new job, or upon transferring to another position within a company.

Orientation when compared with adaptation is a closer term and is defined as consciously managing processes within a company to accelerate, facilitate and guide the employee´s adaptation process.

The process of adaptation in the working environment is usually carried out on three basic levels, which divide adaptation into working adaptation, social adaptation and adaptation to the corporate culture. [5] Working and social adaptation means adjustment of an idividual to working and social conditions of work, while corporate culture adaptation results in the state of identifying with accepted values and attitudes. These three types of adaptation can not be understood as a time-separated processes, since they occur more or less parallel with how the new employee is integrated in the company structure. However it is quite common that the ongoing, as well as the final level of adjustment is not equal for all employees. Therefore it is necessary to find ways how to detect this status early and correct identified deficiencies.

2.1 Factors influencing the process of orientation

There are two groups of factors:

Subjective factors – arising from the personality of an individual, his previous life and work experience.

Objective factors – arising from the conditions in the company, particular department and specific work position .

All factors should have already been examined in the selection process of candidates to detect certain predisposition to cope with adaptation.. It is important to consider this fact from both perspectives, from the aspect of enterprise as well as each candidate. In short it could be summarized that the process of adaptation will be the most problematic, as there is a greater difference between subjective factors and working requirements, and on the other hand a greater difference between objective factors and a newcomer´s requirements.

All the listed factors influence the adaptation process, but there are some other conditions that contribute to successful orientation, such as:

- well mastered company orientation program,
- full support of the orientation program from the management of the company as well as from the other employees,
- executing of ongoing as well as final control of the orientation process and the correction of identified deficiencies.

2.2 Consequences for a company not conducting an orientation

It is not too difficult to imagine, how significant are the consequences, when the company management does not pay enough attention to the orientation of newcomers. The most undesirable situation in the terms of company is the early termination of employment. If this occurs to a large number of newcomers in one company, this can be regarded as an adaptation crisis. This is a very serious consequence, because the high staff turnover rate of new employees represents a high cost to the company, because it is subsequently necessary to carry out a new selection process. Therefore, the ultimate goal of adaptation management from the company's perspective is to reduce the newcomers´ turnover rate. Influence of sophisticated orientation system on staff turnover rate is shown in figure 1.

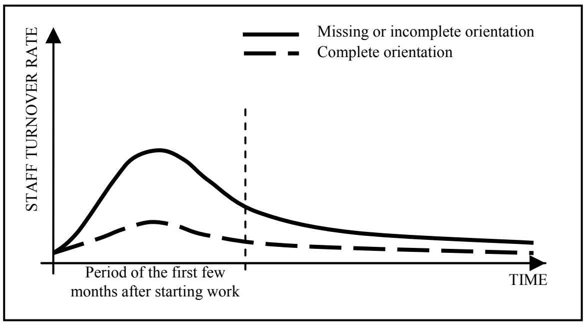

Fig. 1. Influence of orientation system on staff turnover rate [5]

2.3 Evaluation of orientation process and follow-up orientation

An important part of the process of orientation is a formal and systematic evaluation [4]. This importance arises from the need for correction of the orientation program, in the case of certain shortcomings detection. Evaluation of the orientation process, whether continuous or final, is used to obtain feedback for all subjects of implementation of orientation program. Evaluation of the orientation process and adaptability levels, provide both the HR department and direct superiors with a basis for the implementation of improvements, called the follow-up orientation.

3 ESSENTIAL CHARACTERISTIC OF RESEARCH

An analysis of the current state of adaptation management of new employees was carried out in PCAS in 2009. The adaptation control system, in other words, the staff orientation represents a group of tasks, for which the HR department takes responsibility. However the performance itself is carried out in co-operation with supervisors, external and internal trainers and co-workers as well.

All employees are from a socio-professional point of view divided into 4 groups:
1.Unqualified production workers (APF)
2.Qualified production workers (OUV PRO)
3.Technical and administrative staff (ETAM)
4.Engineers and Management (IC)

Based on three criteria, firstly, the group size, secondly, the importance of the group, and finally expected recruitment volume in the next 2 years after the survey, a target group of workers was selected, on which analysis and the suggestions were focused. This selected group was the APF group, because it represents the largest group (see tab. 1), that mainly participate in manufacturing activities and it is the group with the largest recruitment activities to be expected in the future (see tab. 2).

The group of employees	APF	OUV PRO	ETAM	IC	Total
Percentage	50 %	31 %	15 %	4 %	100 %

Table 1. Group size

Year	APF	OUV PRO	ETAM	IC
1st year	1247	537	86	25
2nd year	600	102	13	6
Total	1847	639	99	32

Table 2. Expected recruitment volume in next two years after the survey

The process of adaptation management was studied at two basic levels:

1. At the recruitment level – although the adaptation management in general is expected to begin the first working day, there are some subjective and objective factors (mentioned above) that influence adaptation and it is necessary to identify their impact in the applicant´s selection process. For this purpose the company PCAS use the selection simulation tests which detect whether candidates have such subjective characteristics that correspond with the requirements of particular working position.
2. At the training level - most of the orientation is carried out through various training courses which begin on the first working day. The first training that all newcomers receive is the introduction course. Its aim is to know the values of PSA group, get familiar with the principles of safety, the basic policy and strategy of the company, its goals, methods and indicators of the quality system as well as all administrative aspects.

After the introduction course, all newcomers go through a set of professional training courses, both external and internal, which are held either in external training centers, or directly in the factory. Both, internal and external training are aimed at acquiring a variety of professional skills related to job content and they contribute to successful and fast adaptation of new employees. Thus they represent the large part of the orientation program, which would not be complete if it did not provide feedback on the training in the form of evaluation. Subjects of evaluation are trainees themselves, then trainers and managers as well. For this purpose the company has created specific evaluation forms.

After finishing the training program, employees are assigned the status of „operational staff“ and they are expected to achieve a high degree of working and social adaptation as well as adaptation to corporate culture. This fact was verified by designing a questionnaire, that was sent to 75 members of APF staff. After statistical evaluation, the questionnaire proved to be a very effective tool to obtain feedback directly from employees and detect the level of employee satisfaction, which leads to working and social adaptability.

1. I know the hierarchical structure of my superiors.
2. I know who should I contact in a case of doubt, or when there is a problem.
3. I know my colleagues and I am interested in them.
4. Within the team of my colleagues I feel equal.
5. I feel important and valuable at work.
6. The atmosphere within the team is very friendly and warm.
7. Our supervisor always informs us of all facts that matter.
8. My supervisor gives me the opportunity to express my views and he is interested in them.
9. My supervisor always appreciates my well-done work.
10. My supervisor takes care for parity with others.
11. My supervisor leads us to mutual respect and tolerance.
12. My supervisor takes the active care of development and progress of our team.
13. I know my competence and responsibility in the workplace.
14. I completely manage all my work tasks.
15. Training that I attended after starting work in the external trainig centers made me sufficiently prepared to perform work tasks.
16. I consider the internal training that were conducted in the factory training centers sufficient to master work tasks.
17. I was thoroughly familiar with the principles of safety.
18. I can orientate myself well in the spatial structure of my workplace and the whole department.
20. Working conditions such as lighting, noise, dust, temperature and humidity seem suitable for me.
21. Social equipment (dining room, bar, changing rooms, toilets, etc.) is sufficient for me.
22. Time range and frequency of breaks and lunch break is sufficient for me.
23. I was informed about all working conditions, social equipment and breaks management already during the selection process.
24. I know the requirements of the employer for the work rate, which will be required at the stage of full operation.
25. Have you ever been asked to perform other activities outside of your job description?
26. Have you ever been forced to perform an activity without prior instruction?
27. I was familiar with the values accepted by PCAS.
28. I agree with these values.
29. I have a positive attitude and relationship to the company PCAS.

Table 3. The list of questionnaire questions

The designed questionnaire offers the opportunity to receive through a formal way the information about the level of adaptability of new staff to the new conditions. All the questions from the questionnaire are listed in the table 1. It contains 27 statements, which are rated by employees according to the following legend:

1 - the statement is true,
2 - the statement is almost true,
3 - rather disagree with the statement,
4 - the statement is false

and two questions which are given statement yes or no. The first 12 statements are focused to evaluate social adjustment, a further 11 statements along with 2 questions to monitor the degree of working adjustment and the last 3 statements are included in the questionnaire to identify the degree of adaptation to the corporate culture. The questionnaire is suitable for new workers, who have already had enough time from their starting day to learn job skills as well as for integration into the social structure and they are expected to achieve a high rate of adaptability. It is a tool of anonymous collection of information, which is suitable for larger groups of workers to reflect accurately the actual situation. The questionnaire is evaluated by arithmetic mean of assigned values for the entire group of participants taking the arithmetic mean determined first on each statement separately and subsequently for each group of statements. Finally, it is necessary to establish dividing values for the categorization of results.

3.1 Summary of research findings and proposed improvements

All results obtained through the questionnaires were subjected to statistical evaluation and summarised together with the results of personal observation and other used methods. Finally it can be stated that the adaptation management of APF newcomers is overhauled, focusing mainly on working adaptation. As the adaptation process is carefully planned, all the methods used in the analysis were focused to reveal certain shortcomings in the existing system of adaptation management. Consequently the group of improvements was designed, which were precisely tailored to specific business and specific time. A this point, one of the proposed improvement, which is widely applicable in practice for many businesses should be highlighted, which represents an adaptation interview.

3.2 Content and form of adaptation interview

The adaptation interview should consist of the similar questions as used in the questionnaire, also divided into 3 groups of questions focused on adjustment to working conditions, social conditions and corporate culture.

The adaptation interview should take the form of informal structured interview using questions prepared in advance and providing space for employee´s free responses and insights. The adaptation interview is performed by a specially trained person who must meet the following requirements:
Although the adaptation interview has an individual form, the results are summarized for the group of employees and are anonymous. The person responsible for the interview will discuss the results and conclusions with competent persons who are consequently trying to design and adopt improvements, that can help actual employees to eliminate dissatisfaction and for future employees this can bring the effects in the form of streamlining the adaptation process. Thereby the adaptation interview becomes a tool for permanent improvement of adaptation control system in the company.

3.3 An identification procedure to evaluate the orientation course for production workers

After the conducted research, the focus was placed on creating an identification procedure for evaluation the orientation course for production workers. The main goal was not to create a unified procedure of evaluation, but to provide a base methodological frame where all the suggested steps of evaluation are detailed. These can be adjusted by the enterprise following its own specific conditions. This could be helpful in facilitating the process of identifying key weaknesses in the adaptation management. [6] The suggested procedure consists of 5 main steps presented in figure 2.

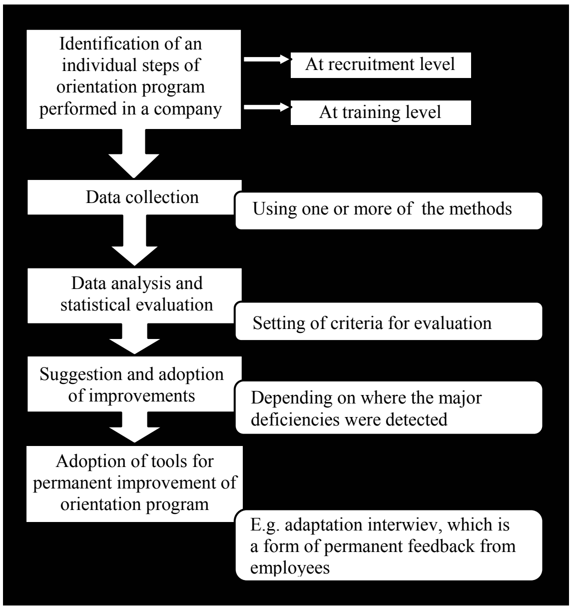

Fig. 2. The identification procedure for evaluation of adaptation control system for production workers

The first step of this process represents the identification of individual steps, that can be stated as parts of orientation program, performed in the company. This section should be focused on two main parts. At the recruitment level it should try to identify, whether the recruitment staff pays sufficient attention to compare all objective and subjective factors that influence the adaptation during the early stage of working performance. At the training level it is necessary to identify all trainings and determine, whether their performance meets the requirements of the adaptation control system. As the second step the data collection needs to be undertaken, using some of the mentioned methods: questionnaire survey, self-observation or interviewing. In the next phase of this procedure, it is necessary to analyze and evaluate all the collected data and for this purpose the criteria of evaluation must be established. In the fourth phase the improvement steps should be proposed and adopted and tools for permanent improvement of orientation system as well, if necessary, which represent the last phase. As an example, the adaptation interview, should be mentioned.

4. EVALUATION OF THE BENEFITS

Before conclusion it is necessary to emphasize that all suggested solutions after the application in practice can bring several advantages, both for employees and ultimately to the company. The most important in the term of company seem to be the reducing of staff turnover rate and consequently reducing the cost of further selection process and training.

5. CONCLUSION

The aim of the research was to propose practical ways, which may contribute to a better adaptation control as well as increasing staff satisfaction. Since the whole concept was tailored for the specific company in specific time, in this work the author tried to select those parts, that can be used anywhere in practice. Usefulness of the proposed solutions is nevertheless very large, because it allows to modify the questionnaire and adaptation interview´s questions according to the requirements of a certain company and especially depending on what kind of adaptability is in superiors´ focus.

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Classification of Supply Chain Practices According to Customer Values in Automotive Industry

Maleki, M.; Liiv, I.; Shevtshenko, E; Cruz-Machado, V.

Abstract: *Supply chain spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption aiming to contribute to the end customer. In the current research data about six customer values namely quality, time, cost, customization, know-how, and respect environment is collected in automotive industry through a trade-off based questionnaire in order to identify customers preferences in this specific industry. Thereaftercustomer value data is discussed and analyzed using Bayesian network.Finally, supply chain practices which are contrubuting to those values are classified into two major groups as manufacturing and logistics practices. Supply chain decision makers can benefit from the outcome of this research to find out variety of practices that they can implement to improve the performance of their supply chain based on what is expected by consumers.*

Key words: Supply chain, customer value, automotive industry

1. INTRODUCTION

Supply chain (SC) refers to the complex network of relationships that organizations maintain with trading partners in order to procure, manufacture and deliver products or services. It encompasses the facilities where raw materials, intermediate products and finished goods are acquired, transformed, stored and sold to end customer in downstream end. These facilities are connected by transportation links along which materials and products flow. SC consists of many companies, individuals and institutions which are cooperating with each other. SC management is the coordination of material, information and financial flows between and among all the participants. There is large number of paradigms that can be used in order to reach the aim of supply chain management. Besides, in order to reach these objectives it is required to integrate diverse amount of entities which are operating along the SC. Classifying SC practices is one step toward integration in which SC players are performing as a unified body.

In the current research data about six customer values namely quality, time, cost, customization, know-how, and respect environment is collected from end customer through a trade-off based questionnaire. The data set is benefiting from 118 responses from automotive industry. Thereafter, the data is analyzed and discussed using Bayesian network. In the next step, supply chain practices are classified into manufacturing and logistics practices and connected to customer values (Fig. 1).

This research is organized in five sections. The second is dedicated to state of the art which covers both supply chain integration and customer value. The third section analyzes and discusses the customer values collected data. The forth section introduced a table in which supply chain practices are connected to customer values. And finally conclusion is given in the fifth section.

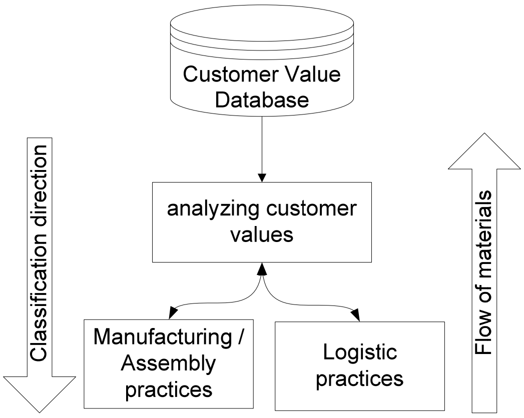

Fig. 1. Framework for classification of SC practices based on customer values

2. STATE OF THE ART

2.1 Supply Chain Integration

Supply chain integration is the combination of efforts to integrate supplier ,customer information and inputs into internal planning through cross- business relationships with internal cross-functional teams [1] [2]. In macro scale the integration can be eather internal or external. The internal integration focuses on the integration of processes and transactions inside organisation in order to develop its competitiveness. External integration encompasses both customer and supplier integration. Customer integration is the process of acquiring and assimilating information about customer requirements and related knowledge. Supplier integration is the process of acquiring and sharing operational, technical, and financial information and related knowledge with the supplier and vice versa [3].

In the literature SC performance indicatorshave usually categorized into four groups: quality [4], time [5], cost [6], flexibility [7], and green [8]. They have also been grouped by quality and quantity, cost and non-cost, strategic/operational/tactical focus, and supply chain processes [9]. In the fourth section supply chain practices are extracted from the previously done research.

2.2. Customer value

Although body of literature has extensive theoretical materials on customer value, due to absence of measures few empirical studies are available in this area [10]. Besides, only few companies have the knowledge and capability to actually assess the connection between their industrial practices and the value their customers perceive. Nowadays, since the companies define themselves in the context of their supply chain, it is critical for them to link their supply chain practices and align them with requirements of final customer. Graf and Maas [11] argues that there is no concrete definition of customer value but generally there are two theoretical differentiable approaches regarding company perspective and customer perspective. The company perspective stream is closely related to relationship marketing, which aims at developing and maintaining profitable business relationships with selected customers. But the customer perspective is focus on value generated by a company's product or service as perceived by the customer or the fulfillment of customer goals and desires by company products and/or services. The Blocker [12] emphasizes the fact that customer value research in business-to-business markets burgeons, many scholars circumscribe its progress to domestic and western markets studies and call attention to the lack of consensus on how to model customer value.

Due to the subjective nature of customer value most scholars have resisted to categorize it in terms of different values. The research on customer value in the current research is performed under six terms as: Time [13], Quality [14], Cost [5], Respect environment [15] [16], Customization [17] [18], and Know-how [19].

3. THE QUESTIONNAIRY DESIGN FOR VALUE ANALYSIS

Customer value data is collected through an innovatively designed questionnaire in which trade-offs among customer values are investigated by a comparison of states in pairs. Five different states are given to the respondent to select according to his / her preferences. As the respondent picks one state two digits will be stored in the data set.

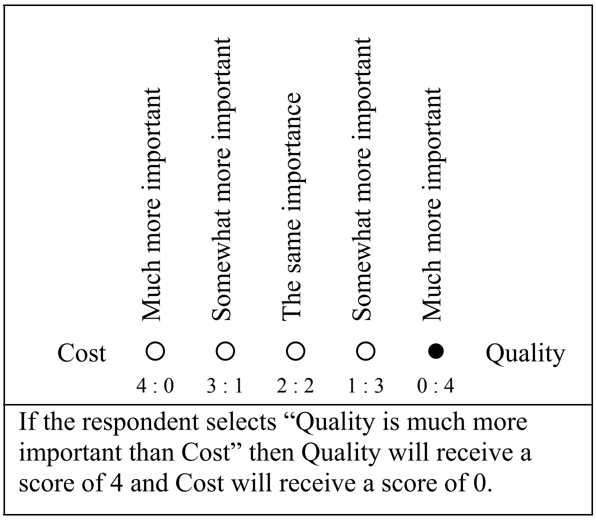

Fig. 2. The questionnaire design

For example, in case if quality is much more important than cost to the respondent then quality receives a score of 4 and cost receives score of 0 that are stored in the database (fig. 2).

Following this numeric approach facilitates the data mining phase.

Due to the strength and robustness of Bayesian network in identifying mutual influences between variables it is used in data mining phase. Besides, since Bayesian network is rooted in probability theory it can handle several different types of variabls at the same time. Data mining is done by using Bayesian network through employing PC algorith.

4. ANALYSIS OF CUSTOME VALUE DATA

The data set of this research benefits from 118 responses from end customers from 24 countries. Bayesian network is employed in order to have concrete analysis of the collected data and to identify the mutual influences among values. Figure 3 illustrates the Bayesian network of customer values. Each of customer values is represented by one node with five states. The important point is that the values of this figure are extracted from a pair wais questionnaire.

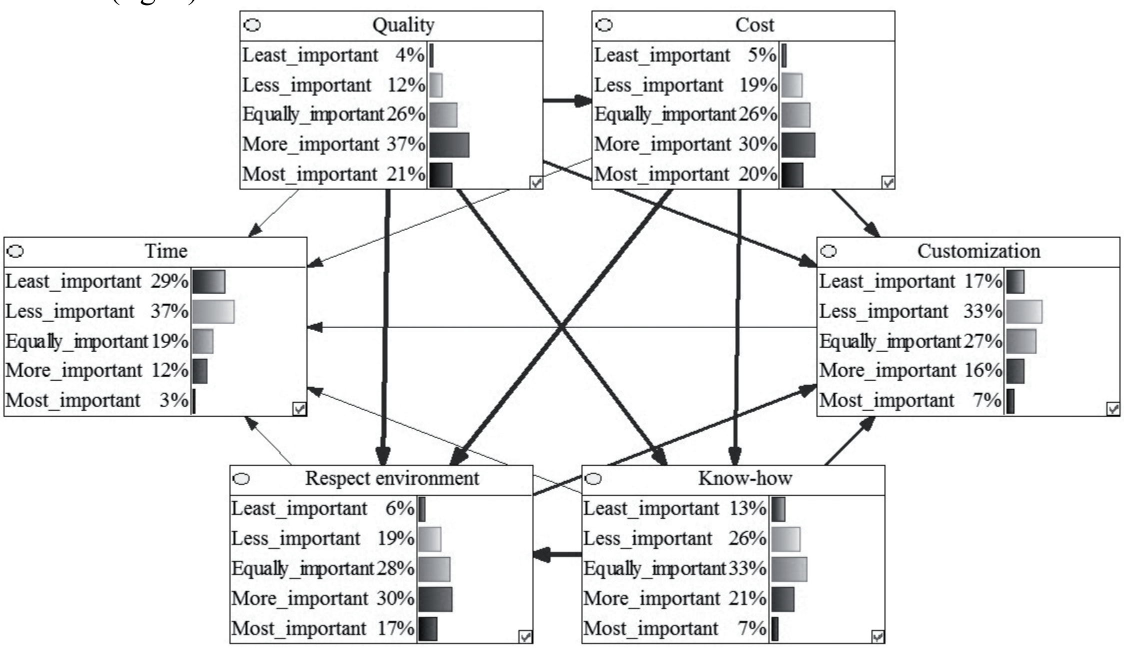

Fig. 3. Customer values presented by Bayesian network, thickness of arcs illustrate the strength of influence

Therefore, if we take cost into account it says for 20% of respondents cost is the most important value comparing to other values and for 5% of them the cost has the least importance. In other words, in a situation when there is a trade-off between cost and other values 20% of respondents has picked cost as the most important value.

Based on the finding of this analysis quality has the most influences on other customer values with four strong influences on them. Cost is the next important value with three strong influences which is followed by customization, know-how, respect environment, and time. Time is the least important value which receives influences from all other five values. Besides, 29% of respondents selected time as the least priority in the trade-offs with other values.

An important point in this analysis is that respondents are answering questions based on the way they perceive each specific value. Therefore, marketing scholars also may benefit from it as well as supply chain decision makers.

5. CLASSIFICATION OF PRACTICES

During the development of supply chain the different paradigms has been introduced where each paradigm encompasses a variety of practices to be employed in different sections of supply chain including manufacturing / assembly practices as well as logistics practices [20].

	Customer values supply chain practices	Time	Quality	Cost	Customization	Know-how	Env. friendly
Manufacturing / assembly practices	Apply life cycle assessment						↑
	Batch sizing	↓		↓	↑		
	Cooperate with product/ production designers to decrease environmental impacts		↑				↑
	Cross functional operations				↑		
	Cycle time reduction	↓		↓			
	Decrease work in process			↓			↑
	Demand-based management		↑				
	Flexibility to demand change				↑		
	Implement standards		↑				↑
	Joint designing / planning	↓	↑	↓			↑
	Lead time reduction	↓		↓			
	Manufacturing transparency to customers					↑	↑
	Modularization	↓		↓	↑		
	Reduction of raw materials variety			↓			↑
	Setup time reduction	↓		↓			
	Use recyclable materials						↑
	Number of practices	6	4	8	4	1	8
Logistics practices	Apply life cycle assessment						↑
	Decrease inventory levels			↓			↑
	Flexibility	↓		↓	↑		
	Implement standards		↑				↑
	Information sharing with customers					↑	
	Joint logistics planning	↓		↓	↑		↑
	Just in time	↓		↓			
	Lead time reduction	↓		↓			
	Modularization	↓		↓	↑		
	Supplier relationships	↓	↑	↓	↑		
	Use green energy						↑
	Visibility of upstream/downstream inventories	↓		↓			↑
	Number of practices	7	2	8	4	1	6

Legend: ↑ increase the performance of customer value; ↓ decrease the performance of customer value

Table 1. Classification of supply chain practices for customer values

Table 1 represents a set of practices which are rooted in different paradigms. This table illustrates the influence of any specific manufacturing / assembly or logistics practices on customer values. For instance cycle time reduction as a manufacturing / assembly practice reduced both time and cost for the end customer. Moreover, some of practices can be used both as manufacturing / assembly or logistics practice such as modularization. However, there are different interpretations of the same practice in these two contexts.

6. CONCLUSION

This research is taking one step toward supply chain integration by connecting supply chain practices with customer values. Six customer values are analyzed in this research and they are connected to manufacturing / assembly and logistics practices in automotive supply chain.
The proposed classification can be used by automotive supply chain decision makers in order to identify variety of practices which are beneficial for their specific case based on their customer values. Automotive supply chain decision makers may benefit from the findings of this research to identify the most relevant practices for their system.

7. ACKNOWLEDGMENTS

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FROM PRODUCT CENTRED DESIGN TO VALUE CENTRED DESIGN: UNDERSTANDING THE VALUE-SYSTEM

Randmaa, M.; Howard, T.J. & Otto, T.

Abstract: *Product design has focused on different parameters through history- design for usability, design for manufacturing, design for assembly etc. Today, as the products get bundled with service, it is important to interconnect product, service and business model design to create synergy effect and offer more value for the customer for less eford.*
Value and understanding the value-system needs to be in the focus of business strategy. Value can be created, exchanged and percieved. It can be tangible (physical products, money) or intangible (information, experience, relationships, service). Creating value is usually a co-creation process, where customers, suppliers and manufacturers all have therir part.
This paper describes a paradigm shift towards value-based thinking and proposes a new methodology for understanding and analysing the value system.
Key words: value centric design, value-system, co-creation, value network analysis, value activity cycle, value distribution.

1. INTRODUCTION

Globalization and information technologies have made the economic landscape more transparent, customers smarter, more demanding and networked. However, not only the changes in the landscape of economics have influenced the customer behaviour. Michael Etgar has brought out major changes in social sphere [1]:

- social and cultural changes: more time is used for entertainment, sports and education- social and psychological cost of free time increases,
- demographics: growth in the number of smaller families and single people- increased outsourcing of various home maintenance activities, growth in semi-prepared dishes,
- entry of women into the workforce: women`s time spent on household activities decreases- growth of telemarketing and Internet based shopping,
- globalization: integration of economies- Western-like patterns increase,
- technology: the Internet- the cost for interaction between buyers and sellers decreases,
- recession: increase in the number of unemployed- market value of time for many consumers has decreased,
- cultural changes, New Age beliefs and behaviour- search of self-fulfilment e.g. bread baking; shopping combined with entertainment- purchasing has become less of a cost factor and more of a value-producing factor in itself,
- Increased efficiency of the consumer as a producer: increase in the general level of education in a market- more efficient consumption, consumers need less time for their in-house performance of various activities.
- Vargo, Lusch and Morgan also state that individuals become increasingly micro specialized- there is an increasing need for specialized services [Vargo, Lusch and Morgan 2006].

It is due to these dynamic changes that new retailing formats develop and consumers want to change their mix of value providers. Social and psychological cost of time changes. How consumers value different activities, products and services changes dynamically depending on customers` context and life-style.

Also the wishes of industrial customers have changed- industrial customers value how well value propositions harmonize with their existing components, processes and strategies [2].

Expansion of collaborative technologies allows businesses to organize their value creation processes in new ways. Process-centric view of business changes for human-centric view of business, which means that people are seen as the active agents of business rather than processes. Verna Allee [3] is developing a new promising theory and methodology for understanding the value network within and outside a business.

There may be some major opportunities to apply co-creation models between different parties of economy (customers, suppliers, retailers, producers etc.), that would change how value is created, delivered and perceived [1]. It is our ambition to contribute to the shift towards value-based thinking by opening up some new perspectives for understanding the value system and noticing new product, service and business model design potentials.

2. THE THEORY OF VALUE-BASED THINKING

This section establishes the context in which the new paradigm of value-centred design has arisen and introduces how to view a value system or network.

2.1. A paradigm shift from product centric design to value centric design

Recent studies in marketing, engineering design and business development have found that it is not tangible goods that the customers want [4]. What customers value is what effect these products have on them. Two widely used examples of this idea are the drill and the bicycle. Customers buy holes (solution) instead of the drill (product). Similarly they do not buy a bicycle (product), but a mean for transportation (self-service) or emotions that a bicycle creates (ownership). Function of the goods is to enable services [4] and to provide less identifiable experiences and emotions [5]

Ratio between created value and cost (not only monetary cost) needs to be high to be competitive on global markets. However, recent findings that people's choices in economic experiments often deviate substantially from those that would maximize their immediate material payoffs have generated substantial rethinking of the postulates of human decision-making. The most well-known example of this phenomenon is Linux (open-source software, developed by programmers voluntarily). It is therefore essential that in order to provide the best, most competitive offerings, a company must invest a sufficient amount of time in understanding what it is their customers, partners and suppliers value [2].

Companies create value by their offerings and customers judge the value of products and services. Nevertheless, no two people can have the same experience- each experience derives from the interaction between the staged event and the individual's prior state of mind and being. Therefore perceiving the value is individual and context dependent. Consumers expect new products to harmonize with their values and lifestyles, and industrial customers expect products to mesh with their existing components in a work-system or a production process.

Value for customers is created throughout the relationship with the company, partly in interactions between the customer and the supplier or service provider [2].

The authors have found in previous researches through literature, example cases and practice that seeing value from a multi-disciplinary viewpoint opens up some unexploited opportunities for the companies to create competitive advantages by overcome barriers within a value system, design integrated products and services, work more effectively, co-create value with customers and achieve long-term relationships with customers.

2.2. The value system

In Porter's value chain concept, the stream of values is one-way, company-centric and the market is separated from the value creating process (product is made ready and then offered on the market). However, this concept has proved not to be suitable in the context of intangible products (services, knowledge, financial products, and experiences). New approaches in science and economy show that the "value" can also be shared or co-created (open innovation, open source software, strategic alliances etc.) by combining different assets and resources into a value in the same process (value star) [6] or in interlinked activities (value network).

Value propositions are born by objects which can be products (physical goods), services, experiences, events, persons, places, properties, organizations, information or even ideas that describe quantifiable benefits that individual organizations, making an offer promise to deliver. As a result, propositions may include many interlinked activities and actors that are able to create value in many other configurations other than a sequential pattern.

Success of a company depends on how efficiently it can convert one form of value into another within its network. In order to understand how any type of value is created, it is necessary to understand the value dynamics within the system.

The value creating process can be seen as a value star, where all activities done are participating in the process of value creation. By linking many value stars into one value system, value network is formed (Figure 1). Within a value network besides tangible goods and finance, also intangible values can be exchanged and shared (information, customer base, knowledge, relationships, experience etc.), without being converted into tangible values.

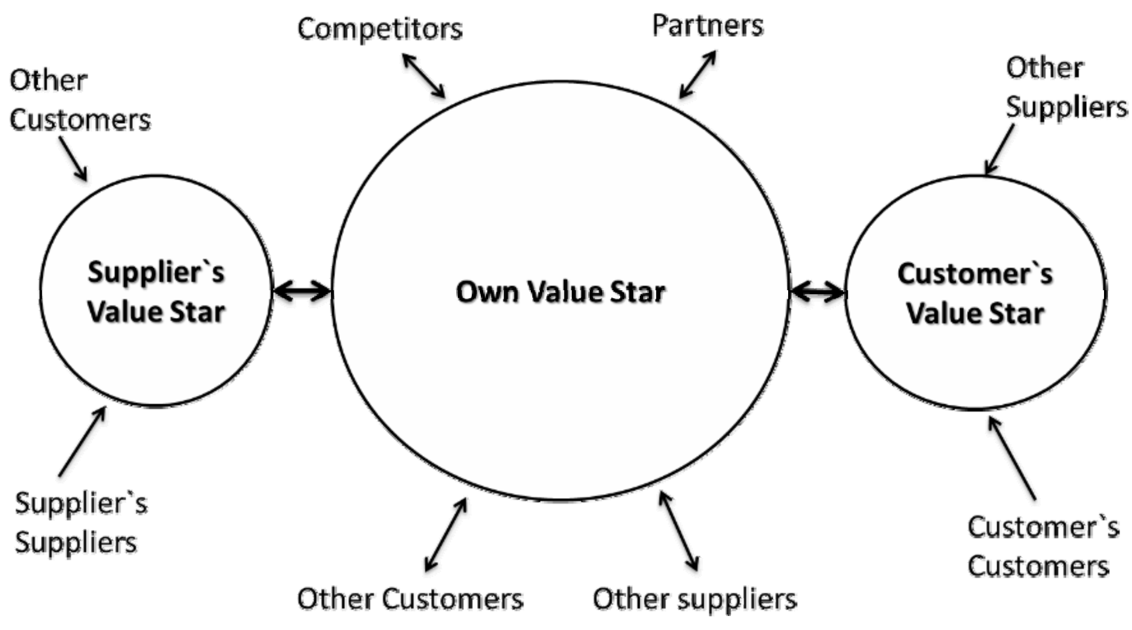

Fig. 1. Value stars connected into a value network

We see that understanding "value creation" in a wider, more interlinked context can unlock some potentially undiscovered market spaces for co-created values and therefore be an essential step for re-configuring businesses for better fit in global knowledge economy where customers, suppliers, partners, employees and relationships are seen as potential co-creators of value and experience. Our previous research affirms that value-based thinking often enables to have a better understanding of the problems within a value system and therefore assures discovering more effective solutions.

2.2.1 Value Network Analysis

Verna Allee has developed a Value Network Analysis approach in order to understand processes within and around business to be able to re-configure them for a better efficiency and long-term sustainability [3].

Allee defines Value Network as a set of roles and interactions that generate a specific business, economic, or social good. Therefore it can be said that Value Network is any group of people engaged in a purposeful activity. As long as people experience a sense of reciprocity and perceived value or accomplishment from the interactions, people will stay engaged.

Value Network Analysis shows roles, transactions and deliverables. It helps to form questions about optimizing the value flows in the Value Network. The prospect of her Value Network theory is greater agility of businesses from greater capacity to collaborate.

We take value-based thinking and Value Network Analysis as a starting-point for value-centred product, service and business design. We try to analyse different roles and activities (instead of roles, transactions and deliverables, as Allee does) in order to find new ways to distribute activities between different parties and therefore create more value for less cost within the value system.

3. VALUE-CENTERED DESIGN

This section proposes a new methodology for value-centred product, service and business model development.

3.1 Value activity-cycle

In order to understand value seen from a customer's point of view (value in customer context), it is vital to get insight into the activities of the customer needed to possess the value, which is where the customer values are perceived [7]. This can be seen as the frame for the total customer experience, as it brings in a time dimension of the value. Vandermerwe [8] has developed a graphical information model to get insight into the Customer-Activity Cycle (CAC). The CAC focuses on the activities that the customers go through to get the benefits of the offered products and services. It consists of three stages containing activities in relation to the utilization of the company's offerings: *pre* – before use; *during* – in use; *post* – after use. The activities are placed on a cycle, to illustrate how they are affecting the customer, the central stakeholder in the middle. [8], [9], [10].

We have developed CAC further, resulting in the Value Activity Cycle [2], as a tool to conceptualise value systems, focusing on the supplying network around the customer and the possibility to reconfigure this and to support the customer continuously in the activity cycle. Creating Value Activity Cycles and and also un-bundleing the companys` activities needed to configure and offer value propositions. within a value creating network makes possible to see some interlinks and opportunities between the customer and the companyes.

What is interesting to explore within this cycle, besides the supplying network, are the inherent and the maybe unused recourses of the customer as these are adding value to the total value system [6]. Vandermerwe's focuses on how the company can *add value*, by looking at the *critical points* which are representing value gaps, that hold opportunities for the company to fill. What are also important to elaborate from this customer cycle are the *recourses of the customer* which can add value on the same level as the company.

Donald Normann [6] and his work with emotional design, describes that long-lasting emotional feelings (memories) take time to develop, and they come by sustained interactions, which are important to see as a process of co-creation between customer and company [11]. The value creating activities are not only a process within the company; co-creation experiences are a new paradigm of value creation.

3.2 Value distribution analysing matrix

In order to make potential interlinks within a system more clear, it is beneficial to analyse actors` activities within activity cycles in 4 perspectives-

- Why the actors are acting like that? (their needs and wants),
- Can they act differently? (their potentials, resources),
- Why don`t/can`t they act differently? (their barriers, restrictions) and
- How do different activity distribution strategies impact the value system?

For doing this, we propose value Analyzing matrix from activity perspective (Table 2). This matrix shall be filled in for every activity within the value system [2]. When the company has discovered all these 4 perspectives for all the activities and actors within a system, it is more likely able to see the big picture about the situations the customers, itself and other actors within a system are in. It is now possible to see potential interlinks for value co-creation, sharing, transaction

4) Product transportation	Customer	Furniture shop	Transport company
Needs, wants	Wants transportation service to be precise, in time. Service provider should to be polite, have clean shoes. Service needs to be at low price and fast.	Service can enhance customer experience and therefore potentially form long-term customer relationship/ base.	Wants more customers and higher prices. Wants to save money by optimising transportation routes.
Potentials, resources	Has a car, could transport the product himself. Man power/resources through friends to carry and drive.	We can start our own transportation service business.	We can start working only for furniture shop, if we make a contract for long enough period and good enough fixed prices.
Barriers, restrictions	Does not have a car or the car are too small to contain and thereby transport the product.	This business is not as profitable as our core business- selling goods.	Sometimes we can not deliver goods fast enough, because we try to optimise our routes, or the addresses given by furniture shop are not valid.
Impact	Customer feels that the product is expensive- there are added costs.	It is good to have long-time relationship with a customer, do statistics.	More work
5) Product assembly	Customer	Furniture shop	Assembly company
Needs, wants	Wants product to be assembled correctly and not damage apartment when carried inside.	In order to reduce storage ground, products must be stored before assembled.	Wants to assemble the furniture at the manufacturing factory- it is easier like that, no need to carry tools.
Potentials, resources	Could find some time to assemble the product. Would like to improve home environment by himself. Has friends, who can help if needed.	Could assemble the products at shop right after purchase. Could start our own assembly service business.	Could start working only for furniture shop, if we make a contract for long enough period and good enough fixed prices.
Barriers, restrictions	It is difficult to assemble products by himself because instructions are complicated, assembling requires special tools.	This business is not as profitable as our core business- selling goods.	-
Impact	Customer feels that the product is more expensive- there are added costs.	It is good to have long-time relationships with customers, can do statistic	More work

Table 1. Value analyzing matrix from activity perspective

and find ways to overcome barriers within a system.

It is possible to see the need and purpose of product, service or business model development and also foresee some risks that are in the value system [2].

4. CONCLUSION

Changes in economic, social and technological landscape have created a need for seeing value creation from a more interlinked, multi-disciplinary viewpoint. Understanding the value-system opens up some unexploited opportunities for the companies to create competitive advantages by overcoming barriers within a value system, designing integrated products and services, working more effectively, co-creating value with customers and achieving long-term relationships with customers.

Proposed Value Activity-cycle approach combined with Value distribution analysing matrix is a tool for detecting un-used potentials within a value-system. Recent research through literature and case analysis [2] shows that this methodology can be very prospective for designing value-centred products, services and business models.

In order to validate the methodology and prove its practicality, further work will be done by applying it on existing and developing businesses.

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SOFTWARE DEVELOPMENT PLATFORM FOR INTEGRATED MANUFACTURING ENGINEERING SYSTEM

Riives, J.; Karjust, K.; Küttner, R.; Lemmik, R.; Koov, K.; Lavin, J.

Abstract:
This paper will focus on the concept of how to reduce the complexity of connectivity in an integrated manufacturing engineering system using Enterprise Service Bus (ESB) approach. Software platform is developed for designing and implementing the interaction and communication between mutually interacting software subsystems and modules for manufacturing engineering systems. The developed approach enables a manufacturing engineering systems to make use of a comprehensive, flexible and consistent integration and to reduce the complexity of the applications being integrated.
The main objective of the current study is to analyse ESB systems and integrate the data and activities considered with products, supply chain and shop-floor management processes.
Key words: enterprise service bus, e-manufacturing, integrated manufacturing management systems, computer integrated manufacturing.

1. INTRODUCTION

The increasing competitiveness in global and local markets highlights the importance of design, quality, productivity, multi-company collaboration, optimal price levels and production process predictability. The manufacturers are now under pressure to keep and increase their places in the market. To improve their ability to innovate, bring products to market faster, and reduce manufacturing bottlenecks, the manufacturers have been improving their product development and management abilities. In the recent years has been seen growing investments in the area of integrated manufacturing management systems.
Modern companies cannot take success for granted by living on their existing niche. They are forced to develop and modify the products and management systems constantly. This requires them to cope with high dynamics and continuously adapt to changing environments. Every situation the business company faces an enormous tasks.
It needs to perceive large numbers of external stimulations to support management decisions and effective the information flow through the company. An effective enterprise behavior relies on mapping perceived patterns of stimulations to the right set of actions. This requires a number of non-trivial and highly sensitive mappings, which is the complexity that every enterprise has to handle [1,2].

2. INTEGRATED MANUFACTURING ENGINEERING SYSTEM

With emerging applications of internet and communication technologies, the impact of e-intelligence is forcing companies to shift their manufacturing operations from the traditional factory integration philosophy to an e-factory philosophy. According to [3,4] there is a tight integration of:
a) e-Business (SCM, technology infrastructure, CRM, dynamic decision making);
b) e-Manufacturing (outsourcing, collaborative planning, technology structures, real-time information);

c) e-Maintenance (predictive technologies, information pipeline, real-time data) [5].

In Fig. 1 there is presented the integrated manufacturing management system structure, used in IMECC applications. It integrates the information considered with the products, resources in the manufacturing network and manufacturing planning environment.

The main objective is to integrate the data and activities considered with products (product families), supply chain and shop-floor management processes.

There is possible to have real life information from the products, about the technological capabilities, costs and available resources inside a company but also in a agreed amount inside a group of companies /cluster/. The system gives the possibilities for flexible communication between the companies and customers but also between the companies and subcontractors (partners).

Technological resources of the companies are described inside the system TECHNOL, which main functions are described on the Fig.1. Additionally TECHNOL could use the functionality of the technological expert system TEXPERT, which gives advices for selection the most suitable manufacturing method, about the alternative manufacturing processes or cooperation possibilities between the companies. The methodology of estimation of working place performance in a certain workplace is given in [6].

Supply chain knowledge is linked with various PDM, PLM, and/or ERP systems for carrying out manufacturing planning and scheduling operations for the product and/or group of products [7,8].

The main objectives of the integrated manufacturing concept are to:

- maximize the availability and flexibility;
- assure reliability and maintainability;
- synchronize the customers and supplies (companies) and/or supplies and subcontractors;
- gather and use the knowledge for more effective management;
- optimising the utilization of technological resources.

The framework given in a Fig 1. gives us the possibilities for having various manufacturing information inside the company but also sharing the necessary information between the companies. With this framework in place a general information (existing technological resources, the capabilities of the resources, most suitable methods for machining, etc) could be easily divided between the companies and critical information can be easily linked back to the corporate business systems enabling a real time view of plant operations.

At the current time in the networking manufacturing three main information flows are under the control:

a) offering and order management information flow;

b) resource utilization and sharing information flow;

c) manufacturing planning information flow.

The real time connection into manufacturing gives to the enterprises more accurate view of ATP (available to promise) and CTP (capable to promise) information. This becomes essential in supporting an e-business/e-manufacturing strategy, as a company must have a real-time view of its ability to fulfil customers orders.

For realizing e-Business or e-manufacturing loops virtually every enterprise must cope with information system integration. There are three main pillars what is necessary to fit together [9]:

a) XML is a data format – a tag-based language for representing data;

b) Web Services are methods – a set of standard techniques for requesting and providing services;

c) SOA is a Framework – an architecture to communicate with other systems.

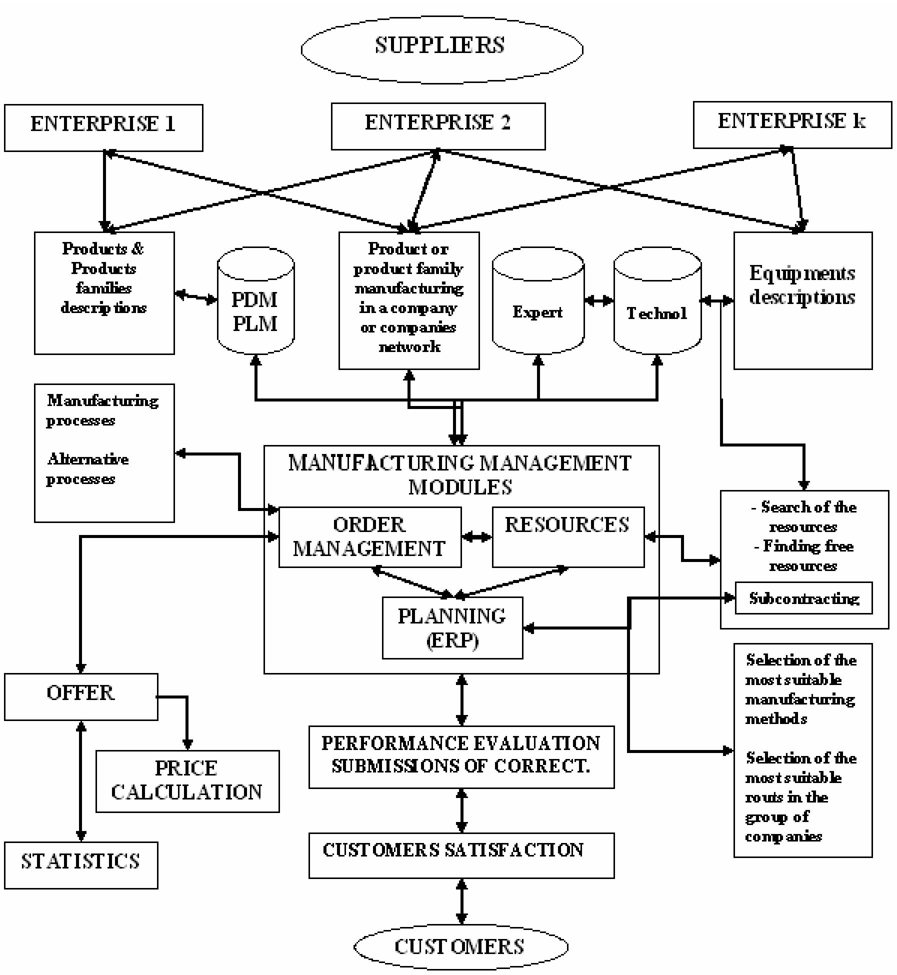

Fig. 1. Overview of manufacturing engineering system

3. SYSTEM ARCHITECTURE

In IMECC's integrated manufacturing engineering system's architecture is based on service based architecture that uses events as triggers. This architecture is called SOA 2.0 or Event-Driven SOA, which is a form of service-oriented architecture (SOA), combining the intelligence and proactive ness of event-driven architecture (EDA) with the organizational capabilities found in service offerings. In Fig.2 is brought out the schema of combined SOA and EDA.

For IMECC's integrated manufacturing engineering system also processing Complex Events is required (Complex Event Processing – CEP), it is noted that CEP can get maximal use from SOA [10].

Event-driven architecture (EDA) is perfectly suited by its nature to support automatic data synchronization mechanisms in redundant environments while maintaining loose coupling [11].

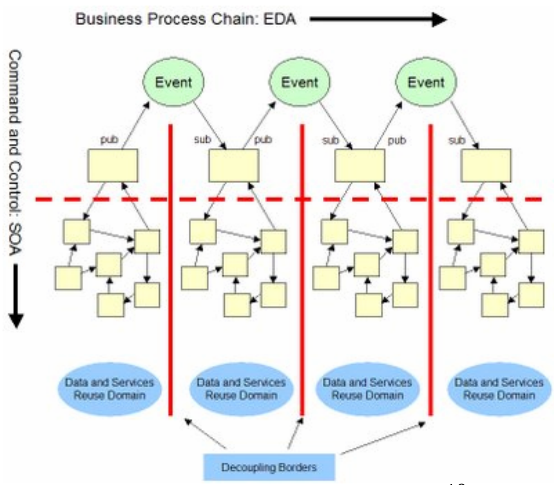

Fig. 2. Combined SOA and EDA [10]

Complex Event Processing means evaluating and analysing events and therefore registration complex events as simple events in certain timeframe. CEP is being used for recognizing abnormalities, threats and opportunities. It is also possible to deliver more complex business logic through CEP.

The backbone of SOA in event-driven enterprises is the Enterprise Service Bus (ESB), which combines messaging, data transformation and intelligent routing services to connect distributed applications across an enterprise while assuring reliability and transactional integrity [12].

In this project was used the Enterprise Service Bus (ESB) approach for enterprise integration backbone and to treat IMECC's integrated manufacturing engineering system's stand-alone modules as one of Integrated Resources. To realise ESB approach the Mule ESB was used.

Mule ESB is a lightweight Java-based enterprise service bus (ESB) and integration platform that allows developers to connect applications together quickly and easily, enabling them to exchange data. Mule ESB enables easy integration of existing systems, regardless of the different technologies that the applications use. Integrated manufacturing engineering system's detailed architecture schema is brought out in Fig.3 and IMECC manufacturing engineering system prototype general architecture schema in Fig.4.

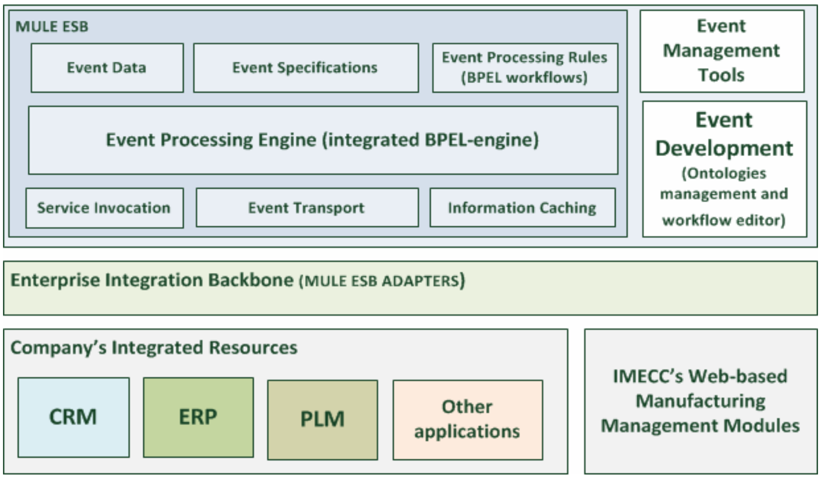

Fig. 3. Integrated manufacturing engineering system's detailed architecture

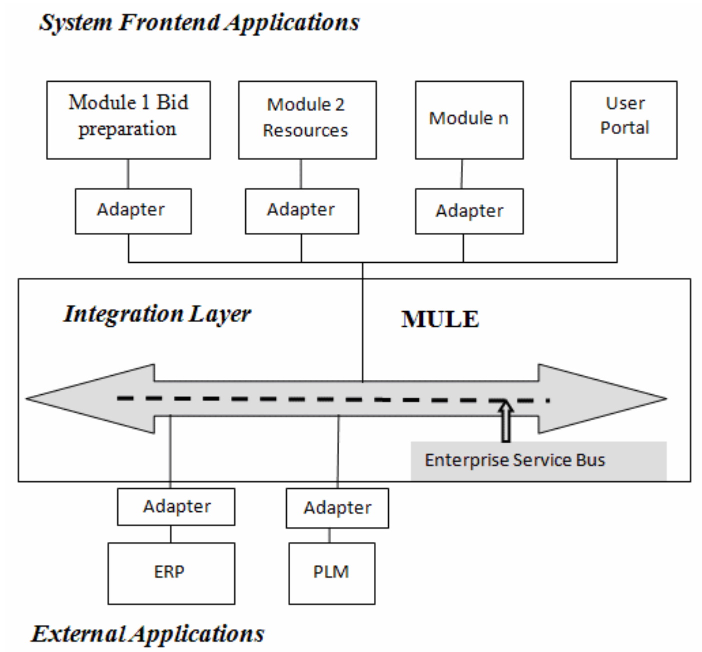

Fig. 4. General architecture of integrated manufacturing engineering system prototype

Web-based manufacturing management modules are integrated through Mule as company's other resources. Event processing is done by BPEL engine, that is integrated with Mule ESB using BPEL workflows as event processing rules.

4. MESSAGE MODEL

Existing business software applications are not interoperable because they use proprietary data models and message sets for business-to-business (B2B) communication, industry consortia and standards development organizations (SDOs), such as the Automotive Industry Action Group, have responded to this problem by publishing standard messages for interoperable B2B data exchanges, their approach has several shortcomings that impede standards adoption [13].

The REA model is much better than any competing semantic model for multi-company supply chain collaboration. The Internet as a means of coordination is driving supply chain collaboration very quickly, but there is no accepted standardized semantic model that can actually encompass all supply chain activities [14].

As a semantic web, REA can link economic events together across different companies, industries and nations. The links are activity-to-activity or agent-to-agent or person-to-person, not just company-to-company. This means each individual in a REA supply chain can be linked directly to each other individual.

Adopting an all-embracing ontology as a basis for sharing meaning, and as a foundation over which to build up information and knowledge exchanges, remains a very unlikely scenario, since in practice, multiple ontology's and schemas will be developed by independent entities [15, 16].

We suggest to use REA principles for all sub-domain and company specific ontology's. These sub-ontology's are mapped with IMECC's top-level ontology to provide central definition to events, that should be discoverable outside one subsystem or company.

5. CONCLUSION

During the work optimized concept of reducing the complexity of connectivity in an integrated manufacturing engineering system event driven architecture combined with SOA approach based on Enterprise Service Bus (ESB) is described. Software platform is developed for designing and implementing the interaction and communication between mutually interacting software subsystems and modules for manufacturing engineering systems. Subsystems and modules of IMECC's integrated manufacturing engineering systems are handled as company's other internal resources and connected through ESB.

Event development and management is based on BPEL workflows and event processing is achieved with BPEL engine integrated with ESB. For better connectivity between different companies and sub-systems we use ontology's and ontology mapping between sub-domain ontology's. Ontology's are based on REA concept, to provide overall model for defining events and related resources and actors.

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Offer management in the networking manufacturing

Riives, J.; Lavin, J.; Karjust, K.; Koov, K.

Abstract:
The value creation process do not start and end at a company`s borders but span to the complete supply chain through to the customer. B2B framework covers relations between the customers and supplies. The basic to this framework are price requests and offers. The main objective of the current article is to develop the structure and functionality for offer management in the networking manufacturing.
The offer management objectives and key functionalities have described. The principles to achieve best results and risk management tasks have also given in this article.
The criteria of efficiency in offer management process in the case of a single company and in the condition of networking manufacturing are considered.
Key words: e-business; offer management system, open architecture for information exchange; procurement system structure, KPI-s and their estimation mechanism, self learning system.

1. INTRODUCTION

The manufacturing process starts from the B2B contacts or customer-supplier relationship [1,2]. Price requests (RFQ) and offers compilation are the key functions in the pre-processing stage. It must be quick, accurate, flexible, informative, comprehensive and observed. Offers, product requirements order conformations, order status inquiry, forecasting, etc are inseparable parts of e-business. The limitation of available resources and tremendous pressure in terms of fulfilling the order, leads to develop supply chain management processes and networking manufacturing systems [3,4,5]. Web-based technologies are widely used to achieve the further described criteria in the offer management process.

With emerging applications of Internet and communication technologies, the impact of e-business is forcing companies to shift their manufacturing operations from the traditional local factory level to an e-supply chain and networking manufacturing philosophy.

Offer management is tightly integrated with the product structure management and BOM as after defining the product and its structure we can calculate the product’s price. From the other hand it is closely integrated with the enterprise resource planning systems (ERP).

The most important modules that an ERP systems supports are: sales, marketing and distribution, enterprise solution, production planning, quality management, assets accounting, materials management, cost control, HR, project management, financials and plant maintenance [6,7].

From the ERP system we can get the input information data to the calculation of product’s price (material cost, purchase product cost, labor cost, overhead, special conditions dependent cost etc.)[8,9].

There are many outsourcing environments already in web for subcontracting different services, e.g. Freelancer.com, Odesk.com, Grabcad.com, 3dshower.com, Guru.com, project4hire.com. Subcontracting websites for manufacturing like mfg.com or tech2select.com are especially rapidly growing, which shows that web is

becoming important channel for networking manufacturing.
In this article we are mainly focusing on composing RFQs on web-based environment efficiently and making joint offers.

2. PROCESS STRUCTURE AND FUNCTIONALITY OF MANAGING RFQs

Offer management is usually one of the basic processes in businesses, that has important influence to all other processes. In networking manufacturing environment it is crucial to manage price requests (RFQ) and offers efficiently to be profitable and flexible. Offer management is important part in ERP software packages and exchanging RFQ-s is basic concept of extended supply chain.
RFQ management process is divided into four stages:

1) sharing information connected to RFQs between suppliers (manufacturer, who manufactures product or offers service);
2) selecting suitable RFQs for making offers;
3) joint offer process;
4) submission of joint quote and liability.

During the first stage customers (manufacturer, subcontractor, agent, who orders a product, part, service) publish RFQ-s to the web based environment (Wall). RFQ-s can be:

- Open RFQ, that can be seen to all users of a wall, this types of RFQ-s are used when there is no previous experiences in the field or entering to the new part of wall (field);
- Targeted RFQ, that is seen by suppliers, who belong to the group chosen (specified) by customer. Targeted RFQ-s are based on technological capability and previous experiences;
- Closed RFQ, which is targeted by customer to specific supplier and not seen by other suppliers.

On the second stage supplier makes an initial choice from RFQ-s published on the wall according to technological capability and available capacity. Choice is based on criteria's according to RQF and described products, details or services:

- Available technological capability (feasibility and quality);
- Available capacity, (delivery time, delivery quantities, flexibility);
- Profitability (income, profit, economical efficiency).

According to these criteria's supplier decides which RFQs need response (makes offer). Responding to RFQs suppliers can choose between two alternatives, which form the basis for a variety of operating principles:

<u>Alternative I (see Fig.1).</u> Offer from one or multiple supplier. Supplier has all necessary technological capability and available capacity to make product, detail or services described in RFQ with needed delivery time, quantity and quality.

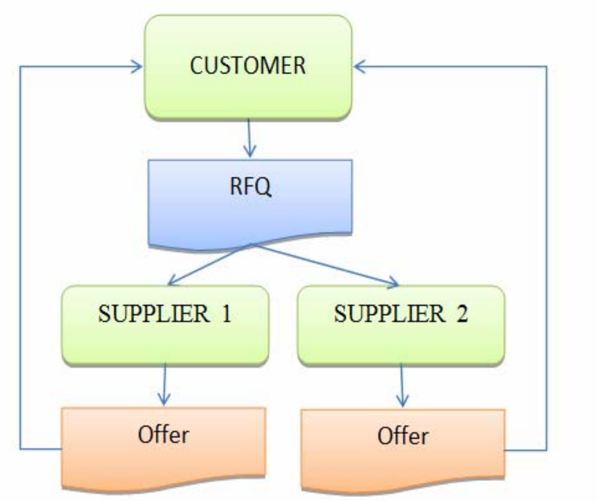

Fig.1. 1:1 or 1:n customer-supplier relationship

Alternative II (see Fig 2). In the case of joint quote supplier doesn't have necessary technological capability or available capacity to fulfill order. According to the economical profitability and available capacity of a collaboration supplier agrees to take responsibility and is ready to manage (coordinate) the compilation of joint quote and filling order in cooperation with other suppliers.

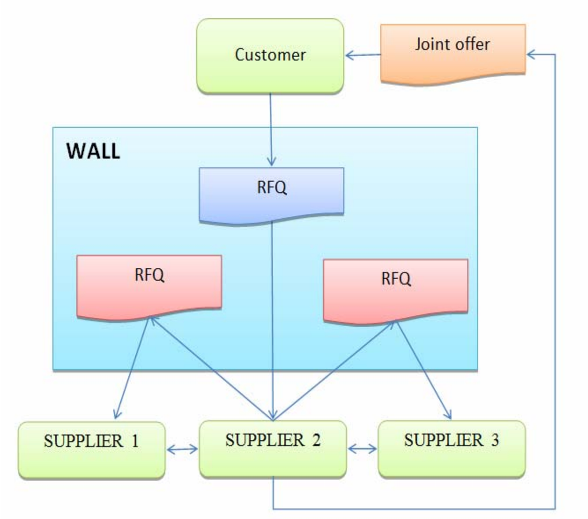

Fig.2. Joint offer preparing schema

In the case of joint offer, supplier compares technological capability and the available capacity to make an offer, described in RFQ. Supplier compares the needed technological capability and capacity with the available and basis on this estimates the needed additional resources.

According to this information, supplier makes RFQ-s for needed capacity to outsource and publishes RFQ-s on the wall. Fourth stage declares that Supplier X takes all responsibility for the offer.

As preparing joint quote we are dealing with co-operation between suppliers. In both phases there should be only one supplier which takes full responsibility. Supplier that takes the RFQ to make offer also takes full responsibility for the works needed to fill the order, when it is not agreed otherwise. According to this, only this kind of RFQs are taken from the wall, where the works done by supplier has a high percentage.

3. OBJECTIVE FUNCTIONS OF A OFFER MANAGEMENT PROCESS

Objective functions for the previous process can viewed from two aspect. From the company perspective, the main goals are:

- Co-operation between suppliers and customers, that increase effectiveness and liability of process participants;
- Addition to the co-operation it is also competition with other suppliers or customers. Feedback from the wall gives us comparison about quality and prices;
- Participating in this kind of process gives company possibilities to specialize more and therefore is developed more competitive skills, knowledge's and technological capabilities.

According to process centered view we can divide wall's goals to operative goals as managing offers and strategic goals as long-term co-operation goals.

From co-operation aspect we can point out longer-term goals like:

- Creating active economic environment, where it easier to exchange information and knowledge;
- Co-operation and balance for competition, that supports competitiveness of companies;
- Increasing competitiveness of companies.

For measuring effectiveness of the wall and also activity of customers and suppliers there is feedback sent to the wall and got from the wall.

To get feedback from the wall and to make analyses it is important that there is critical feedback sent to the wall.

Information about suppliers and customers is being analyzed and main key-performance indicators (KPI) are published, that help to estimate wall's or

part of wall’s (field) effectiveness and suppliers’ reliability, delivery certainty etc.
These KPIs are: order delivery certainty, delivery accuracy, reacting speed for changes during filling orders, price level accuracy (real price and offered price), etc.
Feedback from the wall gives us constant control over quality of service.
Based on key performance indicators overall rating for supplier/customer can be formulated. This overall rating can be criteria for selecting suppliers or responding to RFQs.
Feedback collected by wall can makes wall self-learning system, where: feedback can help to choose possible suppliers to whom send RFQ-s and more reliable clients and helps to propose available technological resources.

4. RISKS WITH JOINT VENTURES AND MANAGING RISKS

In case of simple order from one supplier and also when participating in larger supply chain, both customer and suppliers have to take account risks like: quality risks, delivery accuracy risks, risks of cost management. The possible risks could be managed through previously described KPI-s. Major risk group with wall is liability and efficiency risks.
Wall can be seen as balance for demand and supply. When there are not enough orders on the wall, suppliers will get passive and where there is not enough suppliers, customers will leave.
Main question here is how to create this kind of system (wall) that has critical mass of customers and suppliers and balance between customers and suppliers and RFQs.
The practice has shown that the main problem is with these RFQs, that are not interested to one supplier and the supplier is not ready to take responsibility when making offer, but in co-operation these orders can be done.
In this case we need „third party“ with following responsibilities:

- Make offers to this kind of RFQs that participants are capable to fulfill, but each percentage in whole work is relatively small;
- Make joint offers when needed capacity is too large for one supplier;
- Connects small and medium size companies to offer for large orders while being responsible for the offer.

To increase relibility of the wall, it is necessary to decide previously who will take the responsibility when:

- Single supplier is not enough interested to take responsibility;
- When there is not such a company that can take responsibility.

5. OPTIMIZING WALL’S DATA FLOWS

Main focus in this article is concentrated for optimizing offer management process.
There are the following target functions for optimizing wall’s data flows:

1. Providing stable quality
   - Reducing „noise“ in the system, this means that information should be targeted better:
   - Optimal feedback system;
   - Eliminating false information and structuring information flows.
2. Reducing delivery times
   - Automatic and semi-automatic composition of offers;
   - Making information exchange faster (additional information about RFQs);
   - Finding optimal delivery time through joint offers.
3. Cost efficiency
   - Avoiding double entry for information through whole RFQ management process;
   - Learning capability with historical data about RFQs and offers.

When optimizing information flows, wall should be capable:

- Create new RFQs based on previously entered RFQs;
- Incase of targeted RFQ, provide optimal list of suppliers;
- Describe RFQ as accurately as possible

In this process phase, which is delivering suitable RFQs to suppliers, suppliers act based on technological capability and available capacity. It is important that system can select suitable RFQs based on technological capability and available capacity.

Wall should also suggest possible joint describing technological capabilities in system and information about available capacity. Also this requires describing the products, details or services that are RFQ's objects.

To optimize data flows, wall should be able to:

- Communicate with the system, that describes technological capability and available capacity;
- Describe products to find suitable technological capability;
- Provide overview and additional information about customers, so that suppliers can estimate the probability of ordering by customer.

In the final phase of RFQ process – composing joint offer – there are following scenarios:

- Supplier orders only one operation from other suppliers;
- Supplier orders whole assembly unif or component from other suppliers;
- Supplier outsourcers the whole order.

Third scenario only exists when RFQ contains many products or when leading supplier (supplier being responsible for offer) has advantages comparing with other suppliers. This can be in case of targeted price request or stronger background.

In case of first and second scenario suppliers need to describe the product data to make the wall work efficiently.

To optimize information flow, wall should be able to:

- Offer possibilities to fill the order in co-operation, this means calculating most profitable configurations for joint offer;
- Compose price requests automatically or semi-automatically;
- Enable supplier to automatically submit offer to certain operation, when the product is described;
- Offer suppliers from whom to ask offers, same way as wall suggests customer in case of targeted price requests.

Sending joint offer and taking responsibility is done by supplier leading the composition of joint offer after getting all sub-contracting offers and selecting subcontractors.

Wall should be enable to compose joint offer automatically, which means that system selects best sub-contracting offers.

To achieve wall's efficiency, there is option to send joint offer when all required sub-contracting offers have received. There should be also control-mechanisms that filter out reasonably high sub-contracting offers, which can make the whole joint-offer incompatibles and reduce reliability of the supplier.

6. CONCLUSION

An important factor for the successful cooperation is the design of the communication network structure and the inter-enterprise process if it. We must remember that nevertheless that in the market we are as competitors, successful results and efficiency we can achieve only through overall cooperation. Network engineering must consider the production capabilities, existing resources, and competences of the involved companies as well the market demands and the life-cycle aspects of the products. This engineering also includes the approach of how the product`s value can be maximized collaboratively by selecting the right partners for the joint manufacturing, as well as the optimal distribution of the different adding-value steps within the network.

7. ACKNOWLEDGEMENTS

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KNOWLEDGE MANAGEMENT FRAMEWORK FOR PRODUCTION ROUTE SELECTION IN MANUFACTURING ENTERPRISES

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Abstract: *Knowledge Management (KM) for production routes (PR) selection in manufacturing enterprises is important for reuse of historical data for production reliability process improvement. In this paper, we propose a new Data Mart (DM) structure as a part of KM framework for storage and reuse of PR data. Well-known tools such as Product Data Management (PDM) and Enterprise Resource Planning (ERP) systems, PDM-ERP middleware, and DM are applied in current research. The framework facilitates decision making process through a reliability analysis module, which combines the data stored in the DM with data received from a Failure Mode and Effects Analysis (FMEA) table. In the case study we introduce how the developed framework can be used in a manufacturing enterprise.*

Keywords: KM, PDM, ERP, Data Mart, PDM-ERP Middleware, Master Data Management, Production Route.

1. INTRODUCTION

1.1 Background

The rapid development of computers and manufacturing techniques has made the collection and storage of a large amount of data affordable for manufacturing enterprises. Yet, data are not directly useful for decision making. Rather the extracted knowledge is more important. Knowledge is a combination of data, information, skills, and individual interpretation. It is an understanding of circumstances or facts, gained through association or experience [1]. However, the shortage of knowledge or bad management is common to many organizations: small or medium; and is caused by difficulties while implementing Knowledge Management (KM). According to the statistics, only 20% of organizational knowledge exists in an explicit form, is documented and reusable. This leaves the most of the knowledge in tacit form, residing within persons, which is based on individual experience and activities [2].

The common problems that organizations face today include the absence of basic or older knowledge to discover the new one; the disability to manage it; the technical documentation of projects being stored in separate files on various locations. Furthermore, a majority of design and production knowledge is stored only in the brains of engineers. It makes the maintenance of older products designed by engineers who already left the company more complicated. These problems can cause serious difficulties to present engineers, who do not possess specific knowledge and experience related to previous projects [3]. In this paper, we propose the DM structure for PR selection that alleviates the impact of those problems of KM.

1.2 Objective

To sustain an organizational KM, we developed a structure for a DM that enables effective and less time-consuming way of storing technological knowledge - PR and application it for product production. The proposed structure is a part of our KM framework, for which we describe the process how this functionality can be applied in a manufacturing enterprise. In the case study we introduce how the developed DM and KM framework can be integrated with various information systems of a manufacturing enterprise and what advantages can be achieved after the implementation.

2. CONCEPTS AND TOOLS APPLIED

PDM system is the software that manages product data of design files generated by Computer Aided Design (CAD) systems. It allows the standardizing of items, storing into repository and controlling document files, maintaining Bills of Materials (BOM) and document revision levels, and displaying relationships between parts and assemblies. It gives a quick access to standard items, BOM structures and files for reuse, reduces the risk of using incorrect design versions and increasing the reuse of product information [4].

ERP system is a cross-functional enterprise system driven by an integrated suite of software modules that support the basic internal business processes of a company. ERP systems can serve as a platform for trans-organizational data management [5].

PDM-ERP Middleware is a standardized communication interface between PDM and ERP systems. It allows for design and management of easily adaptable workflows to exchange data and integrate processes between these two systems [6].

Data Mart is a repository of data gathered from Operational Data Stores (ODS) and other sources, but is adapted for one task. The goal of the DM is to meet the specific demands of a particular group of knowledge users in terms of analysis, content, presentation, and ease-of-use. Users of the DM can expect to have the data presented in terms that are familiar or in a format they want to see [7].

3. DM DATABASE STRUCTURE DEVELOPMENT FOR KM

Implementations of DM in several domains such as commerce, telecommunication and medicine have been thoroughly researched. Unfortunately, a similar research has not been done in manufacturing, despite of the potential benefits. Different reasons can be outlined. For instance, the majority of researchers in manufacturing are not familiar with DM methods and tools; many IT researchers are not familiar with the complexities of manufacturing; the few researchers that have skills in both DM and manufacturing area may not have an access to proprietary manufacturing enterprise data [8]. The purpose of the DM is to store actual PR that were used in production for some previous orders and analyse it, as they may not match the default PR that were defined in the ERP Master Data. Currently, the ERP systems do not support reusing PR from older production orders. The functionality of DM is provided by the following modules: Reliability Analysis Module and Production Route Selection Modules which are served by a common database. The first provides robust decision making process which combines the data stored in DM with the data received from a Failure Mode and Effects Analysis (FMEA) table [9, 10]. The second will be described later. The proposed technical architecture of the DM depicted in Figure 1 is designed to be flexible and ERP agnostic and can be integrated with various ERP and PDM systems on the database level without requiring special software, if an access to a certain system cannot be obtained due to organizational or economic reasons, the data contained therein can be stored in the DM. Figure 2 illustrates the structure of the DM, based on the Kimball bottom-up data warehouse design methodology [11]. This dimensional model contains data about concepts that are part of the manufacturing process. The dimensional model provides an easily communicable medium between people who understand the manufacturing process and IT workers who develop the software. It also provides the actual database structure of the DM. The table *FactProduction* in the Figure 2 represents a consolidated measurable result: produced quantities, cost, production time etc, about a single operation. A dimension table, such as *DimEmployee* or *DimMachineCenter*, represents the data about a real-world entity with relevant attributes that are commonly used by the users of the DM. An item in the PDM may have several attributes: various dimensions, weights, materials used etc; that are only applicable to a certain product class or a group. Similarly, when describing capabilities of machine centers, each can support a set of operations within specific limits which vary for different materials. To store a potentially large number of attributes, a flexible parameter handling was developed. The table *DimParameter* (Table 1-A) contains definitions of all possible parameters that a product can have.

Table 1-A – Sample parameter definitions

ParamCode	Name	UnitCode	Type
RST	Stainless Steel		MAT
bendR	Bending radius	mm	LEN
th	Thickness	mm	LEN
cutL	Cutting length	mm	LEN

"Bridging" tables (Table 1-B) maintain associations that describe the parameters of all machine centers in the company.

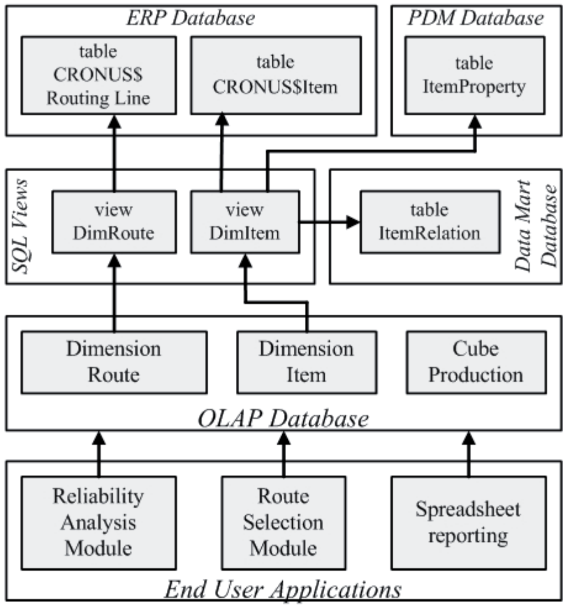

Figure 1 - Technical Architecture of DM

Table 1-B - Sample parameter associations for machine centers

Mch. Cen. Code	Oper. Code	Param Code	Mat. Code	Param Value	Param Max Value
M_02	02_bend	bendR	*	0,5	10
M_02	02_bend	th	RST		5
M_02	02_bend	th	FE		10
M_04	17_cut	cutL	*	100	1000

This serves a foundation for the PR Selection Module when searching for optimal routes for new products (Figure 4).

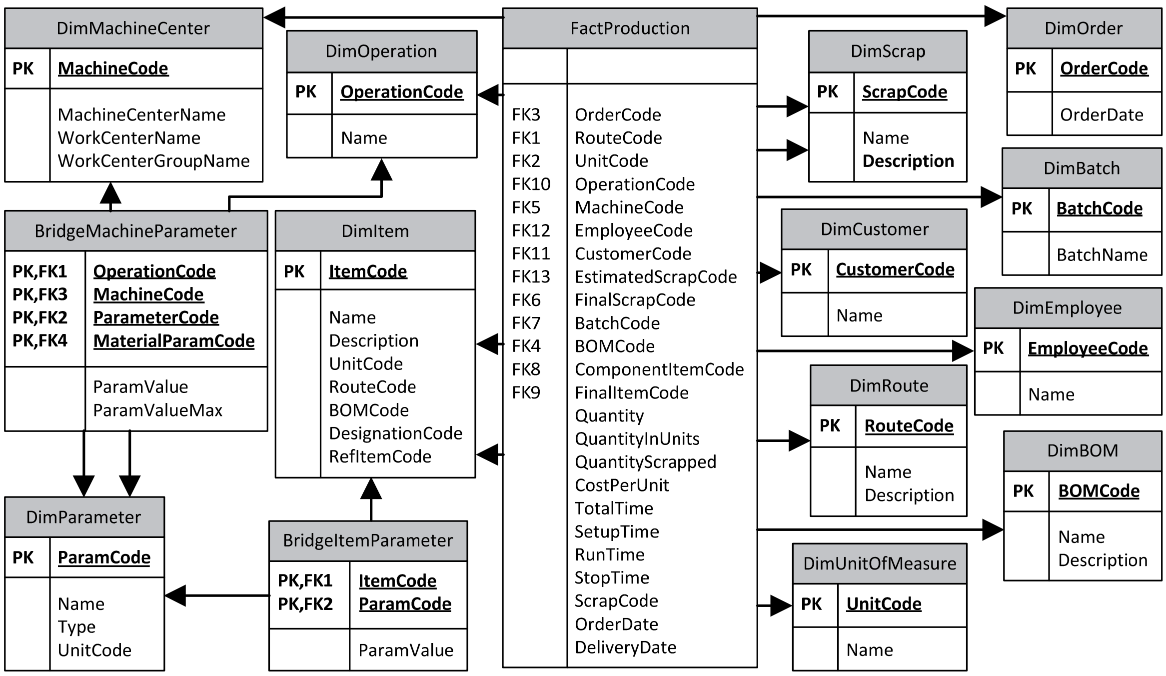

Figure 2 - The structure of the Data Mart

4. CASE STUDY

4.1 KM framework description

The process of KM framework starts from a CAD system (not shown in the figure, but is the part of PDM environment) shown in Figure 3, where a design engineer creates a new product/item.

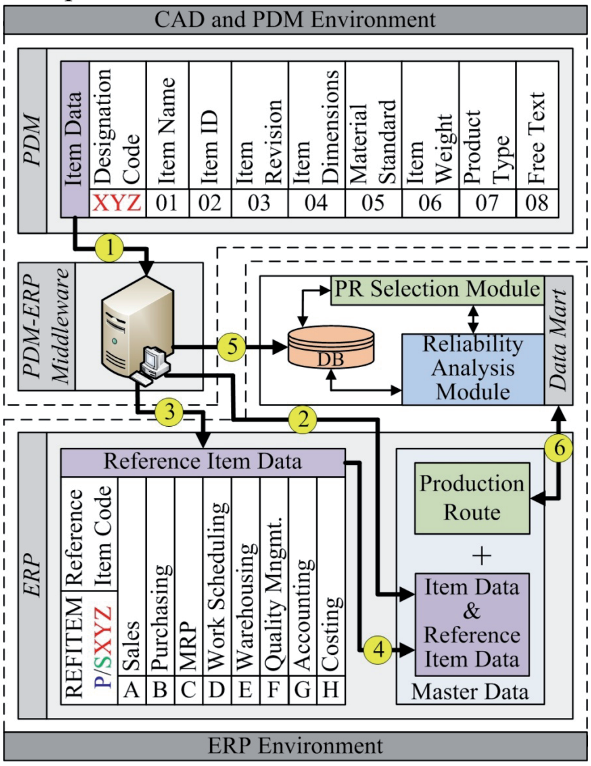

Figure 3 - KM Framework

Along with CAD models and drawings, the engineer defines Item Data in the PDM system. The item Data contains different attributes that are "packed" under a general Designation Code ("XYZ"). The ERP system contains templates - Reference Items - that simplify the creation of new items. It contains various ERP-specific parameters - Reference Item Data - that is identified by a unique Reference Item Code ("REFITEMP/SXYZ"). In the case study, this coding is divided into three parts. The first part (prefix) REFITEM marks that this is a template, not some particular item. The second part implicates the procurement type of the item, where "P" is for in-house produced items and "S" for subcontracted or purchased items. The last part - Designation Code ("XYZ") - is an item key that is used to logically connect data between PDM and ERP systems. Each specific item or a group of items has its own unique Designation Code. When the product design is finished in the CAD system and approved in the PDM, the engineer starts to send every item of BOMs from lower level until upper level, according to the specified workflow to the ERP system.

The PDM-ERP Middleware transfers Designation Code and the accompanying the Item Data from the PDM (arrows labeled by 1 and 2), finds a Reference Item Code by a matching Designation Code (along with the set of Reference Item Data from ERP) and copies them into ERP Master Data (arrows 3 and 4). The final step (arrows 5 and 6) describes a similar process where the middleware may find PR in the DM (matched by a Reference Item Code) for the given item and copy it into ERP Master Data.

4.3 Discussion of example

A case study for ABB Machines that produces wind power generators and electrical motors is used to illustrate. The product consists of two main items: stator and rotor. In order to start utilizing the KM framework and deploy it in daily product development and manufacturing, the DM needs to be filled by the data that usually exist in brains of engineers. In other words, they have to externalize tacit knowledge into explicit form and store it in the DM. The PR Selection Module implemented in the DM is described in Figure 4. This module is flexible and allows the management of PR in different steps.

Step I. Suppose the KM framework has been recently deployed and the empty DM needs to be filled with knowledge of PR. The process starts (as was early described) in CAD and PDM Environment where an engineer creates 3D models of a stator and a rotor and fills the necessary data in the PDM system. During item design, physical attributes are defined: overall dimensions (thickness, width, height and length) and material standards. Using the physical data, the CAD automatically calculates weight. After completing the design process, engineer makes check-in of the item to the PDM system that automatically generates and assigns Item ID and Revision Number. Also, engineer defines the item key or Designation Code (for example for stator: "XYZ"; for rotor: "ABC"), Item Name ("Stator", "Rotor"), Product Type ("WPG 3.6 MW") and Free Text. When the item is completely defined in the PDM system, the engineer approves it and sends it to the ERP system. By this time, a Reference Item should have been created in the ERP system (for stator "REFITEMPXYZ" and for rotor respectively "REFITEMPABC") that also includes the Designation Code ("XYZ" or "ABC") and other external data. According to the workflow, the middleware aggregates Item Data from various sources to the ERP Master Data. A new PR in the DM can be created by engineer using own experience based on the item physical data (Item Data) that was previously entered in the PDM. The engineer defines machine centers or operation names, the amount of needed time and adds additional comments. After the PR is completed and applied to the specified item, the middleware copies it into the ERP. The ERP generates and assigns a PR ID and releases the PR to production (step IV). Similar actions are done for all new all new items.

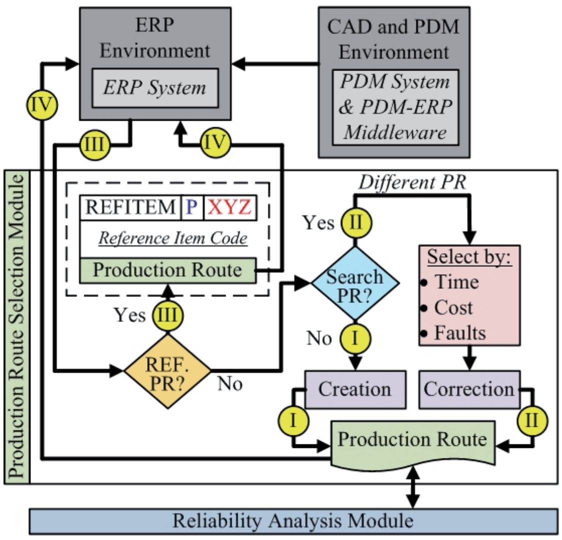

Figure 4 - PR Selection Module in DM

Step II. In the future, (e.g. in 5 – 10 years), if (another) engineer needs to create a new stator/rotor based on an item produced years ago, he/she can easily search a similar PR by physical item data: overall dimensions, material standards, weight and item name. ERP search engine examines all PR in the DM, narrows the scope and displays the results by Time, Cost and Faults. According to these criteria, the engineer selects the most suitable PR from the list and makes corrections if needed, after that the ERP generates a new PR ID and saves it. Finally the applied PR is released to production (step IV).

Step III. This step is more applicable for items or projects that are produced frequently and the DM already contains PR of a certain Reference Item Code, so they are searchable. When the engineer runs the workflow, the middleware copies Item Data from PDM along with Reference Item Data from ERP to the ERP Master Data. Note that in this case the workflow rules apply only for in-house produced items (Reference Item Codes that contain "P"). At the same time, the middleware finds a set of PR by Reference Item Code from the DM and copies them to the ERP Master Data: the item physical data is combined with a set of PR by a matching Designation Code. The engineer inspects the PR, makes corrections if necessary using Reliability Analysis Module and then releases it to production (step IV). If the middleware did not find any PR by a Reference Item Code, he/she needs to return to step II or I.

Step IV. The last step shows the result of previous steps, how the completed PR moves from the DM to the ERP environment where they are released to production in the form of PR cards.

5. CONCLUSION

In this paper we presented a new Knowledge Management (KM) framework for Production Route (PR) selection along with the case study to show how to apply it in a manufacturing company. The framework represents the item data flow between different systems. The core component of the framework is a Data

Mart (DM), which stores PR and combines them with data from PDM and ERP systems. The selected PR is analysed by a Reliability Analysis Module that allows increasing the reliability of the production process and mitigate possible risks. The most reliable PR from the DM can be reused for production of new items. A special middleware is used to integrate and synchronize data between PDM and ERP systems and DM. This solution allows users to find the best PR based on the previous experience that is internalized into the DM. Even an experienced engineer may not remember all the specific details of the production. With this framework, he/she can recognize that a particular approach that has worked once for a similar task or problem in the past can work again.

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REAL TIME PRODUCTION MONITORING SYSTEM IN SME

Snatkin, A.; Karjust, K.; Eiskop, T.

Abstract: *The main objective of the current study is to analyse real time production monitoring systems (PMS) and to offer better solutions for small and medium sized production companies. PMS is the alternative to manual data collection and should capture most of the required production data without human intervention.*
Practical part of the study is focused on selection of suitable PMS, its adaption and mapping manufacturing process (determining key factors, etc.).
Key words: production monitoring system, remote monitoring, real time information, manufacturing execution system.

1. INTRODUCTION

The objective of the paper is to give an overview of advantages and possible drawbacks of a PMS before starting to implement such system in a specific SME. SMEs are more flexible comparing to larger companies and can faster implement a new way of doing business. Also the result of changes can be seen earlier that simplifies the research.
In a fiercely competitive market, companies cannot afford the waste of time and resources to perform work that can be done in a better and faster way with advanced solutions. One of the advanced solutions can be a real time PMS. It is a production tool that collects and distributes necessary data when various events occur in a shop floor. The main aim of a PMS is to prevent small disturbances having large effects. In this way a PMS will decrease the number of unscheduled production stops, improve cost-efficiency and simplify the production planning.

2. PRODUCTION MONITORING SYSTEM

The task of a PMS is to collect and distribute real time data of events on the shop floor. This data must be understandable and useful for decision making. Monitored data should help the production team to respond timely on the events that may affect the desired result.
Such system should also alarm and inform respective department concerning all recognized faults.
PMS is not just display boards that show production data, it also has a reporting and administration module, where stored data can be analysed to find trends, estimations and projections for easier decision making and production planning.
Proactively detected faults will decrease wasted time and improve overall equipment effectiveness.

2.1 Manufacturing Execution System

Production monitoring and machine data collection is one of a Manufacturing Execution System’s (MES) functions.
Historically, each software editor had their own definition of an MES which was generally based on the capacities of their own tools or on the expectations of their customers [1].
Several of the major automation providers offer now MES solutions, including Emerson, GE, Honeywell, Invensys, Rockwell and Siemens.
MES integrates separate data collection systems. It is like a linkage between the

shop floor and office. It should solve the problems of the lack of integration between the Enterprise Resource Planning (ERP) systems and the control systems on the plant floor.
MES position in the factory automation system can be described in different ways. To understand on what enterprise automation level it is positioned, a pyramid diagram can be used. Please see Figure 1.

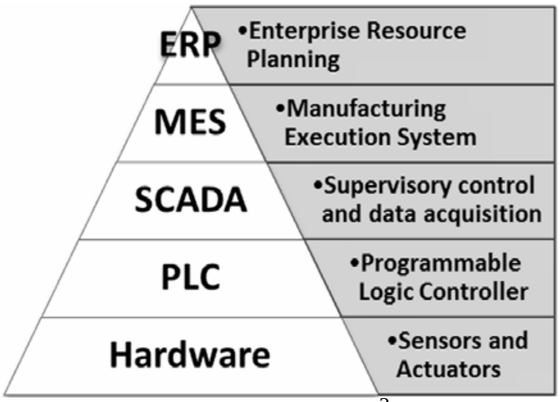

Fig. 1. Automation Pyramid [2].

The standard of International Society of Automation ISA S 95 best describes the architecture of a MES into more detail, covering how to distribute functionality and what information to exchange internally as well as externally.

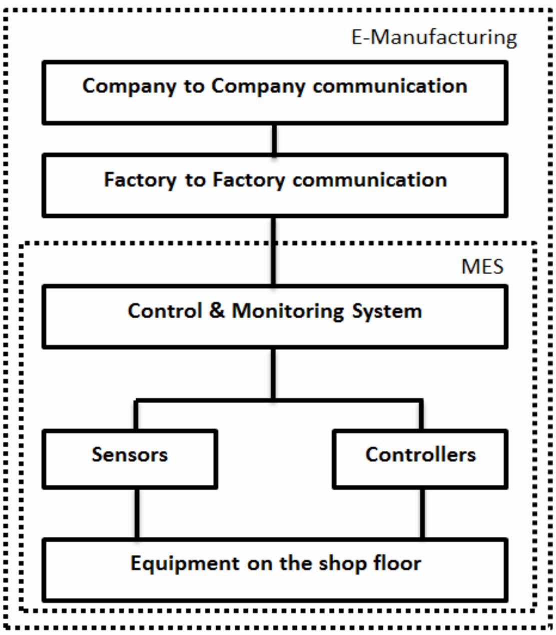

Fig. 2. The diagram of the e-manufacturing and MES.

MES is overlapping with the Product Lifecycle Management (PLM) system in the production phase [2,3,4]. It means that changes made by MES during the production (machine adjustment, tolerance change etc.) may have influence on the PLM workflow (changes in drawings and CAM).
From e-manufacturing point of view, a MES is the lower level of factory automation and communication systems [5]. Please see Figure 2.

2.2 Real time information handling and classification

The idea of a real time PMS is not to give some information simultaneously as the event occurred, but provide the production team, as fast as possible, with the accurate and meaningful data. But it should be enough time to respond timely on these events.
It will always take some time (seconds, minutes or even hours) to analyse monitored data and respond on it. And the goal is to try to decrease this time.
Real time production monitoring information can be classified into two main groups. One group is related to the status of resources and another one to the status of jobs. Information on actual or potential disruptions may relate to resources or jobs. Machine breakdowns, material or tool shortages and longer-than-expected processing times give resource problems. Job related disturbances arising from planning systems and customers include changes in priority, reassignments of jobs to orders and the emergence of new jobs. Quality problems may relate to both resources and jobs [6].
Classification of real time information helps to understand how the desired PMS should be structured.
The first step of real time data in the monitoring process is detection. Data can be detected by sensors, operators, barcode scanner etc. Understanding the detection process will lead to effective use of real time data capture devices, and removal of

unnecessary and useless devices. Then data should be classified and identified. For example, transferred to respective department or handled automatically. And the last step is diagnosis and analysis [6].

There is no reason to store all collected data in the database. Good decision will decrease running costs and improve performance of the database.

3. CONCEPT OF A PRODUCTION MONITORING SYSTEM

Production data collected on the shop floor may be incorrect, mostly due to human intervention or improper production monitoring system. The human factor is more common in this case. That is why a PMS should capture most of the required data without human intervention.

When an unscheduled outage does happen, time is spent notifying support resources that a problem has occurred, time is spent for the support resource to respond to the issue, time is spent troubleshooting and finally time is spent to resolve the problem. But predictive nature of continuous remote monitoring more often avoids unscheduled outages by addressing the issues before they affect machine operation and product quality [7].

The benefit of installing an efficient real time PMS is the immediate access to all required production related information by the relevant personnel. And it should be enough data to clearly identify the reasons of production stops, time loss etc. At the same time, presenting too much information can confuse or even distract operators.

The most important requirements of any PMS are that the system is economical, accurate and easy to set up on a production line. And it has to be capable of providing straightforward connectivity to switches, sensors, PLC outputs and other common industrial equipment. If the true production data can be automatically captured and presented in a simple, understandable way to the operators, they will become a more integral part of the improvement process [8].

Relatively simpler systems may have greater potential for real-time control [9].

An effective production monitoring system should be at least comprised of the four elements: collection, display, analysis and data storage (see Figure 4).

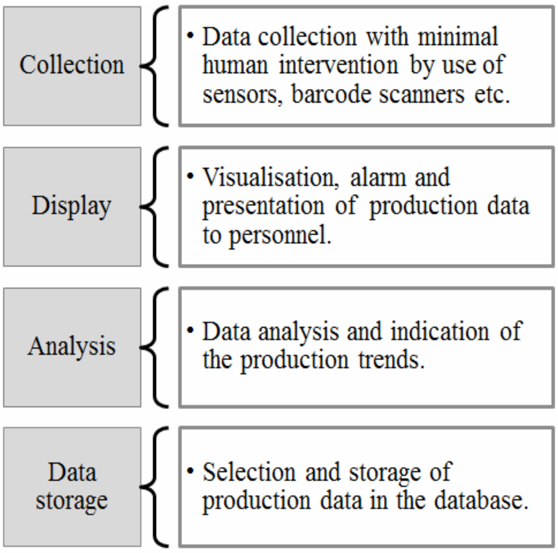

Fig. 4. PMS modules.

Alarm system is also one of the basic capabilities of a PMS. Fault annunciation should be properly understood by the personnel to act in a timely manner. And an advanced PMS should provide the possibility to review historical site alarm activity.

Visualisation of data can be made through displays, andon boards and mobile solutions, like smart-phones etc.

4. PMS INTEGARION ON THE SHOP FLOOR

Because of the high cost of deployment of automated manufacturing systems, machines are not integrated on most shop floors [10]. Production industry still gathers most of the data in the shop floor through manual inputs.

Despite the fact that number of automation providers offer MES solutions, such systems are mostly monolithic, insuffici-ently configurable, and difficult to modify.

Installing such software and integrating it with current systems is found to be a challenging and costly undertaking [11].

Localized solutions can be more affordable and even more strengthen the advantage of an automated production monitoring. Especially during the economic recession, companies are more precisely weigh the pros and cons of investing money in a new production system. And faster return on investments can be the decisive moment when choosing a production monitoring system, though alternative MES systems can offer a wide range of additional functions.

When calculating costs of a PMS, not only software and hardware investments should be calculated. Possible consultation and support costs must be taken into account. If system is developed and integrated in cooperation with the production team, these costs can be decreased.

In case of modern manufacturing equipment, a monitoring system is assumed to be a part of the machinery. Installing wireless sensors (so called “smart dust”) on machinery can be one of the solutions. Before that, models should be developed that reflect the correlation between the state of the machine and the monitored parameter. All these will enable the detection of failures and critical modes of operation. Installing a monitoring system, based on wireless sensor nodes, is relatively cheap and it can be fitted to both old and modern manufacturing equipment [12]. Wireless sensors eliminate the cost of cables that also simplifies the install.

In real life wireless monitoring is used infrequently in shop floors [13].

5. TRENDS

The trends of PMS solutions can be summarized as follows:

- Standardized plug & play connectivity
- Real time performance
- Web-based architecture
- Scalability and re-configurability

It is evident that the amount of information collected from control systems increases tremendously with the degree of increased automation on the shop floor. Manufacturing systems grow because of the need for more complex processes to meet the needs of increased product functionality [1]. It means that PMS has to be connected to more equipment and process more data at the same time.

In addition to these trends, there is future direction to self-learning and decision making system that maximally eliminate human intervention.

General trend is to use PMS for improvement of the production processes by applying: statistical process control, mathematical modelling and optimization of the production process [14-18].

7. CASE STUDY

The monitoring systems are designed for four workbenches in Tallinn University of Technology (TUT) and for two work lines in private company JELD-WEN Estonia. The data collection and display modules are completed, but the development of the analysis module is in progress.

Measuring devices will be assembled on a controlled machinery to conduct measurements. It will provide early warnings of machine degradation or impeding accident. The characteristics chosen for monitoring and the measurement equipment selected are outlined in Tables 1-5.

Sensor	Measurement
Optical / Hall effect sensor	Spindle speed
Accelerometer / piezoelectric sensor	Spindle vibration
Infrared temperature sensor	Bearing temperature
Clip-on ammeter	Current
Magnet / Hall effect sensor	Carriage mechanism position

Table 1. Metalworking lathes, 1K62B and 16A20 (TUT)

Sensor	Measurement
Optical / Hall effect sensor	Spindle speed
Accelerometer / piezoelectric sensor	Spindle vibration
Infrared temperature sensor	Belt friction point temperature
Clip-on ammeter	Current, load

Table 2. Milling machine DYNA MECH. EM3116 (TUT)

Sensor	Measurement
Temperature sensor	Coolant temperature
Accelerometer / piezoelectric sensor	Working table vibration
Optical / magnet sensor	Wire feed speed and brake
Conductivity meter	Water (coolant) salinity
Clip-on ammeter	Current, load

Table 3. Wire-cut machine AGIE AC 50/120H (TUT)

Thus, in TUT the milling, wire-cut and lathe machines are set up for monitoring.

Sensor	Measurement
Rotary encoder	Line speed
Optical sensor	Material availability on the line

Table 4. Output of planer line Weinig 141 (JELD-WEN Estonia)

Sensor	Measurement
Optical sensor	Count of material from the in-feed
Optical sensor	Count of material reaching machine

Table 5. Input of the painting line Makor (JELD-WEN Estonia)

In the private company JELD-WEN Estonia the output of planer line and input of the painting line are designed and set up for monitoring (not workbenches).

8. FURTHER RESEARCH

Each production SME has differences in manufacturing processes, equipment, priorities and capital resources. That is why such questions still need to be answered:

- Which data should be collected first?
- Which data have to be saved and for how long in the PMS database?
- Is it possible to design a "plug and play" PMS solution that is suitable for most of the production SMEs?
- What is the easiest way to connect different data formats and communication interfaces?
- How to visualise the production data to make it clear to all personnel?

9. CONCLUSION

The real time PMS systems designed for TUT and JELD-WEN Estonia enables to continuously acquire data from the shop floor with regard to efficiency, malfunctions and productivity. This leads to improved production capacity and cost-efficiency, helps to achieve desired production goals. Development of the data analysis module has been foreseen as next task in improvement of PMS system.

10. ACKNOWLEDGEMENTS

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TECHNIQUES TO REDUCE COSTS SUSTAINABLE QUALITY IN THE INDUSTRIAL COMPANIES

Stan, L.; Mărăscu - Klein, V.

Abstract: *Performance organizations requires sustainable design analysis and process optimization manufacturing and mining products and services to reduce quality costs in industrial companies. Article based on presentation of the link between sustainability and quality costs, presents the main methods and techniques to counter industrial companies and focuses on sustainable techniques for reducing quality costs in industrial societies. Modern techniques but effective design (robust design), manugfacturing (Lean Six Sigma System, Lean Process Principles, Just-In-Time Production, Total Quality Management) and post-sales activities enable the development op processes based on responsible use of resources by eliminating waste and transfer internal and external users of reliable cost related to quality and professionalism.*

Key words: techniques, sustainability, cost reduction, quality, industrial companies

1. INTRODUCTION

Referring to all practices to achieve balance between the socio-economic and natural environment, sustainable development concept „catering for the needs of the present without compromising the ability of future generations to meet their own needs"and decisions about how the decision in any such action man or environment. This is the most common definition of development given by the World Commission on Environment and Development (WCED) report in "Our Common Future".

Opening of the sustainability showed how companies can make savings. Today, sustainability is 99% in cost reductions and 1% in reducing the environmental impact thathas PR value. Companies that implement quality programs can reduce the cost of quality by 25% in half in 18 months, and a further reduction by half in the other18 months. With a right, so you can reach world class status inthree years.

2. COST IMPACT ON QUALITY

A method for quantifying the quality refers to the measurement of quality costs, or non-quality costs,a measure indicating how much does it cost annualy to provide quality management activities and industrial company, the products and services and related activities.

2.1 Actions that require reducing quality costs

As cost reduction, using of prevention (training quality, design process, removing the cause of failure, change process, quality audit,maintenance and environment al audit) as well as concepts assessment (tests, measurements, evaluations, problem analysis, inspection,verification), which started trading in the underlying industrial companies

2.2 Elements of direct or indirect impact on quality

Almost all the costs of quality generators have direct or indirect impact on the environment and society. Identify in this regard internal defects (scrap, repair, unscheduled service activities, removing defects, lost production time, use more resources,waste processing technologies, scrapand other waste) but external faults

(returned products, customer complaints due to reductions in billing, recall products within warranty expenses, legal costs, reduced availability of product operation,malfunction,replacement and red uced safety)

2.3 Quality Measures imposed to reduce costs

The life cycle of a product from design to implementation, use and recycling, industrial companies must be responsible to correct, mitigate or eliminate the losses caused. Other ways in which quality-related costs can be reduced: using calculations at the preliminary studies or by a decision taken by the leaders of the industrial company.

3. MODERN DESIGN TECHNIQUES FOR INDUSTRIAL COMPANIES

Actions aimed at countering the negative and positive development involves:

- Design changes
- Stimulating action to find solutions to reduce the negative implications; promote project-delay
- Promoting the development of monitoring programs of environmental harm
- Defining the rules to introduce new types of projects, with little effect on the environment
-Defining the appropriate institutional environment
- Initiating actions to inform and educate the public

At the stage of design or redesign products resource consumption issues and environmetal impact must be considered. Techniques useful in the design are: robust design, target costing and value engineerin. Robust design takes into account the three dimensions of quality cost, expressed in total cost quality triangle: Unit Manufacturing Cost, Life-Cycle Cost, Quality Loss Cost.

In terms of sustainability, the three types of costsshould take into account the impact on resource use and waste management. Life-Cycle Cost refers to the specific costs of the product operation (supplies power, warranty, repairs), and take into account the environmetal impact of product and related services. Quality Loss Cost identify the economic consequences of deviation from the target and customer losses, manufacturer and society. Design method "Target costing" is an essential element of manufacturing employment costs in a cost target and focus more on reducing use of material resources, energy.

4.METHODS AND MANUFACTURIN TECHNIQUES AND FIGHTING FOR INDUSTRIAL COMPANIES

Modern manufacturing systems known as LeanSix Sigma offer a range of techniques and methods to counter industrial companies, aimed at resposible use of resources: Lean Six Sigma System, Lean Process Principles, Just-In-Time Production, Total Quality Management.

In the table below are the individual characteristics of the methods specified are:

No crt.	Modern Manufac-turing	Features
1.	Lean Six Sigma System	clear direction of quality costs sustaine competitive advantage
2.	Lean Process Principles	flow value and perfection of the process
3.	Just-In-Time Production	production based on the forecast and actual demand
4.	Total Quality Managem ent	manufacturing process control, delivery, customer service, quality management

Table1.Important characteristics of modern manufacturing systems

5. THE LEAN SIX SIGMA SYSTEMS

Lean Six Sigma is: improving quality and efficiency of processes based on a strong project and quantitative approach with clear target setting. For long-term success and sustainability of excellence in operations, techniques must be supported by an organizational philosophy that complete context of transactions.

The principles of Lean Six Sigma:

-Thinking long-term emphasis on providing value to industrial society
- Make the correct process leads to desired results
- Developing staff and partners
- Solving the fundamental problems of the systemas a key learning-improvement

Lean Six Sigma Implementation

- Is a flexible system for achieving and sustaining business success
- Is focused on deep knowledge of customer requirements, to improve product quality and minimizing costs
- Is a unique business process, the analysis allows industrial companies to drasticaly improve profitability by designing and monitoring business activities, daily, in ways that minimize losses

In recent years, Six Sigma was sometimes combined with histograms which led to a methodology called Six Sigma slope.

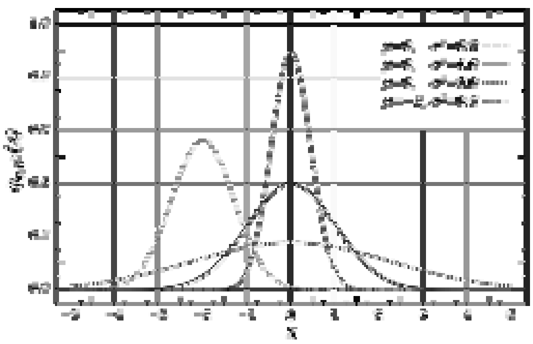


Fig. 1 Six Sigma Slope

Advantages of the method Lean Six Sigma: When these pieces are in place, Lean Six Sigma's relentless pursuit of product quality and process speed leads to corporate success and to personal success for the people who contribute to that journey.

DMAIC – pattern to improvement (and use of data and process tools) can naturally divided into the five phases of problem solving, DMAIC: Define, Measure, Analyze, Improve, Control.

6. LEAN PROCESS PRINCIPLES

Lean production is a production psilosophy that reduces the time between customer order and manufacturing, delivering the required product by eliminating waste.Lean production uses less of everything compared with mass production or mass, half the manufacturing space, half the investment of equipment, design half hours a new product.

Principles of Lean process

- Perfect quality first
- Minimize losses by eliminating activities that do not add value
- Continuous improvement - flexibility
- Long-term relationships with customers and suppliers
- Focuses on the evolution and change and not is only an idealized technological level

Lean implementation process

-Refers to a new dynamic process of evolution of production, which covers all aspects of industrial operations (product development, manufacturing, organization and human resources, customer service)
- Is focused strictly on customer-supplier networks, systemic process driven by a set of principles, methods and practices

Benefits of Lean process

- Requires much less storage of stocks, resulting in fewer defects and a growing variety of products
- Production is a phenomenon that seeks tomaximize the results of human labor
- Is a way of thinking, adaptability to change, to eliminate losses and continuous improvement
- There are many tools and techniques that, used together, maximizing human resource performance in industrial companies

7. JUST IN TIME METHOD (JIT)

Just in Time (JIT) is based on the idea that production activity must be calculated and designed with great precision so that inventories are minimized. It is a process-oriented and applied primarily to manufacturing firms, should ocur only what sells and just in time

The principle of method:

Reduction or elimination of stoks minimun raw materials, parts, subassemblies, finished products lead to lower overall costs, regardless of production volume

Implementation method J.I.T. requires achieving the following fundamental actions:

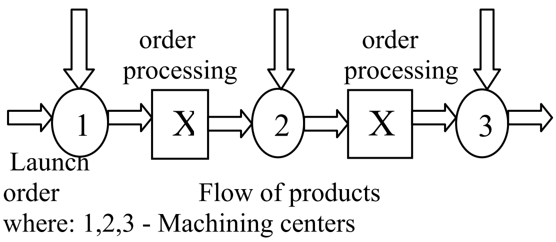
- Location rational organizational links in order toreduce costs of operations that do not create value
- Reduce training time, made to achieve a timely change of series
- Achieve maximum reliability of the machines to reduce parking costs due to their accidental falls
- Achieving quality productions
- Carrying out quality control on the principle of "total control under selective screening"
- Creating a partnership with suppliers
- Education and training of the workforce using the most effective methods

JIT material flow

Two basic methods governing the flow of materials:

- Pull method (pull)
- A push (push)

The "pull"method, management schedules allow reception of all raw materials and production begins, before knowing the demand.



where: 1,2,3 - Machining centers
x - Intermediate storage

Fig. 2 The conventional (push method)

Another way to organize the flow between producer and final assembly is to use the "push"

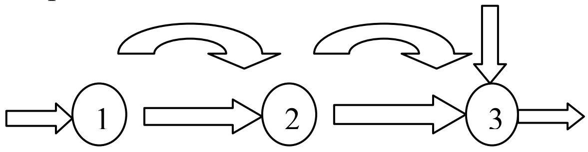


Fig. 3 J.I.T. System (pull method)

Advantages of JIT method

- Reduce costs by reducing inventories, reducing scrap, reducing the work and reduce changes from the original design;
- Increase revenue by improving product quality and increase sales.
- Reducing investment, both by reducing storage space and minimizing inventory;
- Improve the personal labor is very well prepared,motivated material attached to the results of the company and responsible work
- Sizing ranges of products undertaking able to develop new products, in accordance with requirements market

8. TOTAL QUALITY MANAGEMENT –TQM

TQM - is a complex process that causes a continuous quality improvement of product/services to meet customer requirements in the context of increasing labor productivity and profit industrial organization.

TQM principles method:

By introducing the notion of total quality optics has changed throughout the organization in quality:

- Replacing the periodic verification of product quality preventive control
- Introduction of quality at the micro level, method"zero defects"
- Quality should be provided and certified the rules recognized/valid international ISO

TQM implementation plan includes:

- Specifying the tasks of top managers;

- Appointment of a committee to adapt TQM system;
- Appointment of a coordinator of implementation;
- Detection of human and financial resources;
- Establishment of company quality policy;
- Inform all employees;
- Start training and preparing action as to the whole company;
- Start of first quality improvement projects

Benefits of TQM method:
- Require innovation, flexibility and financial potential
- Strengthen employee motivation and creativity, thus creating the potential for greater innovation
- Enable better mastery of the processes in planning, design, distribution
- Result getting high quality products and services, timeliness of delivery, all at competitive prices
- Create conditions for the even the manufacture, ensuring proper use of production capacity and reduce costs
- Ensure strengthen market position
- Management is a new business approach
- Planning and organizing production.
- Organizing events

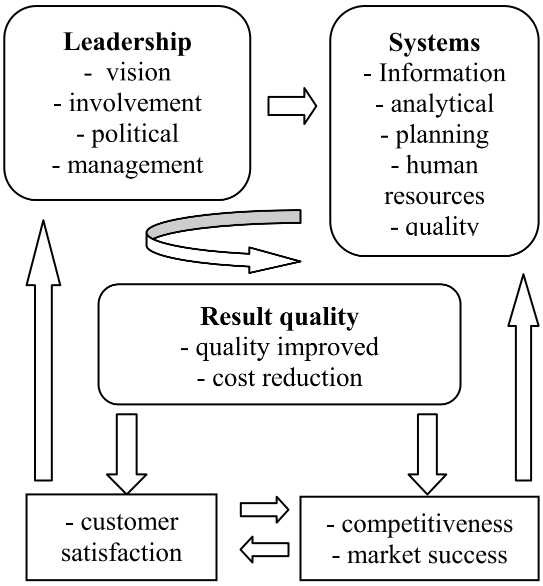


Fig. 4 The total quality management in industrial companies

9. Post-sale activities

Offering sales and service solution complete and integrated modern methods production set, allowingsales department to effectively manage the entire cycle of orders, and all activities post-sale, providing thus delivering orders on time and efficient management of all female dogs distribution. Thus, we obtain reduce operational costs, acceleration, stimulation productivity and increase sales, fund improvements in satisfaction customers. Applications include a wide range of customer oriented processes - the distribution and sale of products and professional services management requirements for service, warranty and returns, production and operations management, in production management, ofers project case studies and economic.

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12. CONCLUSION

The central concept is the enterprice organizational sustainable in which the corporation is building in partnership with stakeholder processes and mutual relations. Modern techniques but effective techniques but effective manufacturing (Lean Six Sigma System, Lean Process Principles, Just-In-Time Production, Total Quality Management) it is envisaged that modern, flexible, able to lead to outstanding performance by eliminating waste and reducing costs representing the safe way to excellence. Implementation of standards these methods proved to be a program that works and can be adopted not only production but also in services. Customer requirements are for an existing industrial esentiale. If we look at society and the environment as final customers of any organization, it makes sense and optimization efforts in terms of sustainability. The company may record the following types of costs: the cost of pollution, waste, accidents, interruptions of transportation or communication paths, and if they are identified early design phase could be minimized.

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KPI PERFORMANCE INDICATORS FOR EVALUATING EMPLOYEES ON INDUSTRIAL PRODUCTION LINES

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Abstract: *The article analyzes the performance indicators-KPI which represents the focal point that can make the transition from the development of individual activity to overall organizational performance in the industrial enterprise. Benefits performance indicators - KPI's are represented by forecasting revenues and they capitalize the opportunities in industrial production lines, they minimize risks of non-imposed standards, improving the overall decision about the risks of supply interruption as an interactive dash board and ability to manage the portfolio of suppliers, to reduce production down time, to increase customer satisfaction and improve profitability by being able to anticipate supply chain risks, evaluation of work force data by examining reports for staff and expenses of industrial companies.*

Key words: KPI performance indicators, evaluating employees, production lines, industry

1. INTRODUCTION

In the medium/large sized industrial organizations, a timely and effective evaluation of staff performance through strategic tools, should be able to design an integrated system of key performance indicators (KPI), structured hierarchically at all levels and organically linked with the strategic objectives and tactical organization. [1]

Key Performance Indicators (KPI) are performance assessment tools that identify the extent of achieving the desired parameters in the industrial production lines, which is of major importance for the success of the manufacturing company.

2. PURPOSE, NECESSITY, IMPORTANCE OF KPIs

KPIs represent a landmark that helps company employees and managers to understand the relevance of their work and the results to be attained. They can be predefined or chosen by the company management in order to assess the competence and how they assume the individual business goals. If implementation is needed, we see that in 90% of the cases, respondents fully or partially correlated the reward of employee with their KPI results.[5] This leverage leads to a breakdown of discipline in the department-level strategic objectives,teams and individuals and to focus their efforts towards achieving activity performance.

2.1 Benefits of KPI application in the industrial companies

The benefits of indicators KPIs on reports due to the application in industrial companies are:

- They offer a perspective about the documentation and organizational performance indicators
- Success in their use is facilitated by the selection, the degree of alignment with the company internal organizational objectives and a detailed documentation facilitates their understanding and use of standardized company
- Improving the time of response to market changes
- Identifying costs that can be eliminated

- Workforce optimization
- Improving the overall decision compressed into a single dashboard, interactive, due to the risks of supply interruption
- Improved ability to manage the portfolio of suppliers, through the identification, evaluation and monitoring of multiple areas of risk exposure associated to suppliers
-Identifying, predicting future earnings and capitalization opportunities
- Minimizing the risk of non-imposed standards
- Creating a picture of the market by combining the risk management and management strategy
- Reducing production downtime
- Improving profitability by being able to anticipate supply chain risks
- Ad-hoc analysis of forecast scenarios that determine the impact of changing a supplier contract or changing conditions for profitable growth
- Evaluation of labor through dashboards and reports on data related to personnel and the related expenses [8]

2.2 Main stages of industrial development company with KPI

In the scope of developing a customer oriented and efficient organizational culture, the KPI is implemented gradually in the industrial company structures, together with a performance management system, in the following stages:

1.establishing key principles and organizin processes leading to performance
2. team training and training materials
3.organization's training in presentation of the individual role in the performance management system
4. evaluation and certification in real situations of the managers directly involved

2.3 Methods of application of KPIs in manufacturing firms

For a successfully implemented performance management system, effective method must be applied by KPI, as it follows:

-A set of performance indicators KPI which represent a common language between the company departments, depending on: income, cost and quality, adaptable and interconnected
-Identifying periodic verification means which are designed to enable performance monitoring and reporting of all participants in the trial, reporting daily performance panels representing the starting point for the improvement activities [9]

3. GRAPHICAL PRESENTATION OF KPI

Key performance indicators KPIs are measures for the performance of the duties, operations and processes which are essential for the business; performance can be regarded from more perspectives: from a strategic, operational and team perspective. Based on the trends within the company or by benchmarking the KPI's may be appreciated

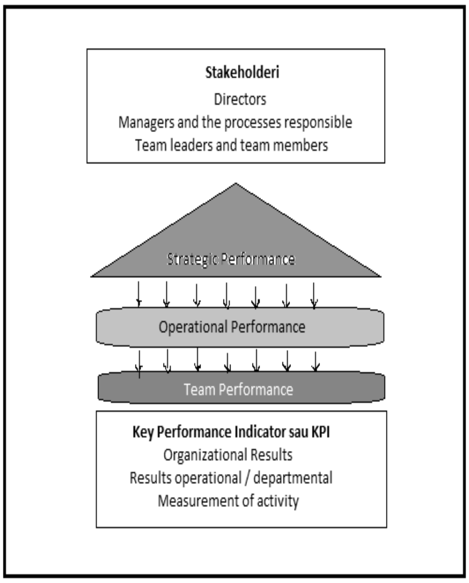

Fig. 1. KPI - Key Performance Indicators
Source: Adapted from APQC survey on the performance measure

We also took into consideration the following aspects:
- Comparing the practices used in the performance measurement projects of the

industrial production lines
- Identifying the major difficulties encountered in the industrial projects KPI
- Presentation of key success factors for the KPI projects
- Transferring the insights and experience of the industrial production lines by launching a dialogue between the companies interested in performance measurement indicators.

The study results are highly relevant for the local business environment due to the diversity of respondents as regards the industry to which they belong and the size of their company. Responses were collected from companies of various industries such as: retail, manufacturing, energy and utilities, financial services, pharmacy, food industry, professional services, IT, construction, engineering, etc.
- 76% of the industrial companies surveyed recorded a turn over of more than 12 million RON in 2011, and 79% have over 120 employees
- The industrial companies in the survey recorded a turn over of EUR 5 billion in 2011 and they had over 50,000 employees.
- 85% of the respondents hold management positions in the industrial companies, thus attaching a representative quality to the expressed opinions.[5]

4. USE OF INDUSTRIAL KPIs IN PRODUCTION LINES

If we refer to the use of key performance indicators on industrial production lines we find that:
- 81% of the industrial companies already use KPIs, and the trend is increasing as another 19% plan to use KPI in the future
- The main reason for adopting KPI was to follow up the fulfillment of the strategic objectives (75% of respondents), other reasons being the transparent reporting of the results as well as the evaluation of departments and employees, and in 40% of the companies used consultants.

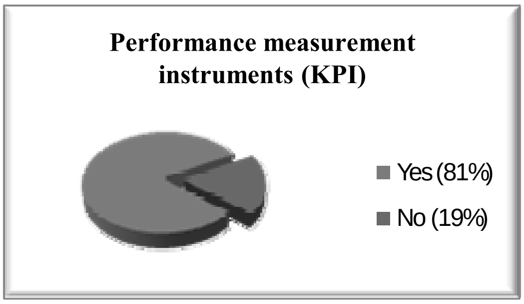

Fig. 2. Performance instruments (KPI)

Regarding the intention to implement KPI in the future industrial companies not included in their activities using key performance indicators, the surveys recorded the following results: 42% responded positively, 12% are interested in implementing KPI and 46% don't know.[5]

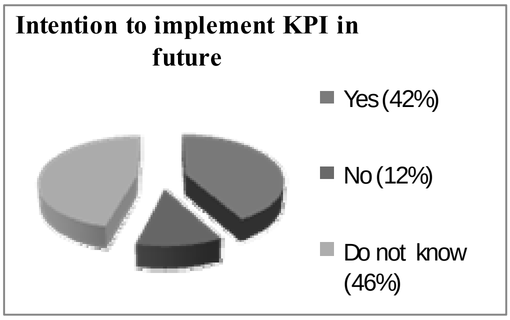

Fig.3. Intention to implement KPI in the future

In terms of the companies understanding and approach, the key performance indicators KPIs percentage ranks on the following levels:

No. crt.	Actions	Percent
1.	degree of use KPIs, trend growth in the future	81%
2.	the use of individual indicators	74%
3.	down approach, based on strategic objectives	66%
4.	degree of use in all departments	31%
5.	correlation between indicators of different departments	21%

Table 1. Percentage presentation of KPIs based on the actions taken [5]

5. KPI DASHBOARDS APPLICATION BY PERFORMANCE

The strategies used by companies to build stronger links between the performance on industrial production lines and the strategy of using customized or general performance dashboards.[2] Examples can come from a wide range of functional areas and industries, such as human resources, retail, real estate development. On average, an organization that uses a dashboard was able to implement its first dashboard project in 51 days, 60% of the time necessary to the organizations that have used customized dashboard solutions accomplished in 88 days, as shown in chart below: [4]

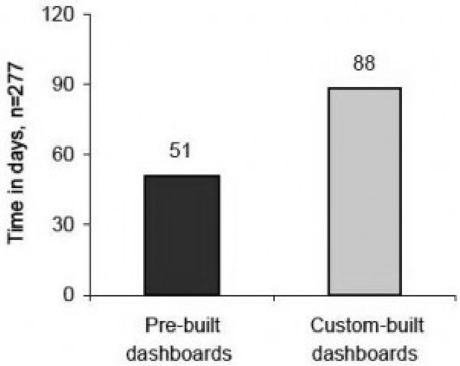

Fig. 4. Time used in implementing KPI
Source: Aberdeen Group, 2010

An Aberdeen Group report released in2010 shows that the time required to change a dashboard is, on average, only half the time to make changes to a customized solution developed dashboard.[6]

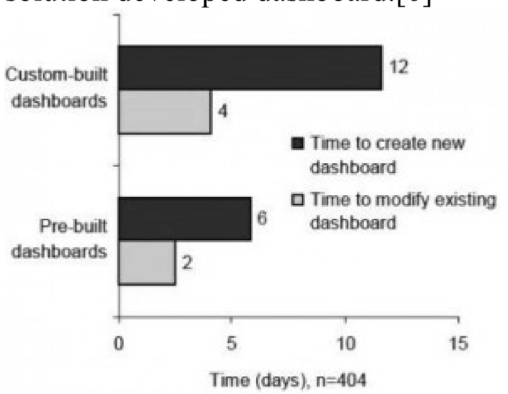

Fig. 5. The time difference between the use of custom dashboard and the overall
Source: Aberdeen Group, 2010

Research results show that companies using dashboard solutions were 45% more likely to have dashboards that can be adapted to the industrial organization of production lines. The natural reaction is the focus of employees on activities to be evaluated. It is essential for the system to measure the activities that lead to fulfilling the objectives.[3]

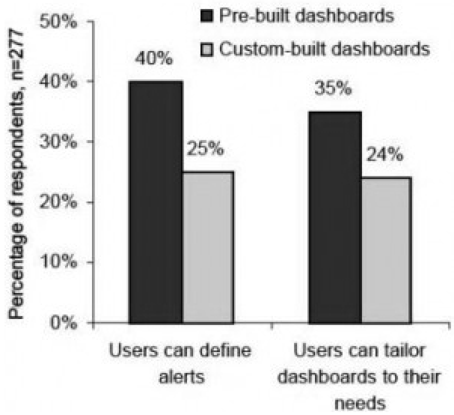

Fig.6. Creating dashboards according to domestic needs
Source: Aberdeen Group, 2010

According to the study industrial organizations using dashboards generated solutions are two times more effective than other organizations that have a business intelligence program(40% vs.19%).[6]
Thus, the industrial organizations applying key performance indicators have a better understanding of the organizational performance as regards the alignment of KPI's used at an operational level with strategic objectives at a corporate level and an understanding of the overall execution.

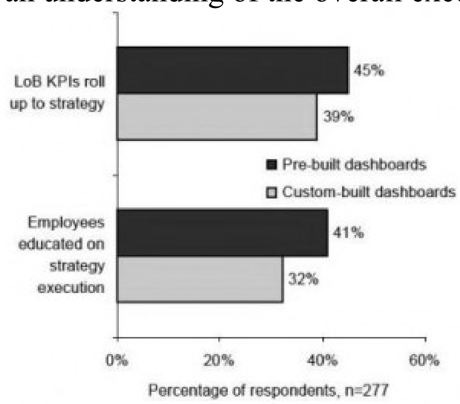

Fig. 7. Applying KPIs in the execution
Source: Aberdeen Group, 2010

The main benefits of pre-built performance dashboards:
- Allowing a faster implementation process
- Are easy to adapt to rapid change
- Are much easier to customize in house, through configuration, not by coding.

7. EXAMPLES OF KPI's REGARDING THE EVALUATION OF EMPLOYEES

a) **Personnel turnover** - measures the rate at which employees leave the organization in a period of time
Variations: employees who leave the organization in a certain period, employees who left the organization over the past 3 months; age of employees, loyalty; staff turnover
b) **Orders delivered with damaged products** - measures the rate at which orders contain damaged delivered products
Variations: orders damaged frequency of defective deliveries
c) Income / call completed successfully: Measures the average income obtained as a result of a successful call.
Variations: average revenue per call ended successfully
d) **Complaints of crew members**
- Measures the number of complaints made by crew members to employer in a certain period.
Variations: complaints from crew members
e) **The average weekly work / employee**
- Measures the average number of hours worked by an employee "full time equivalent" (FTE) week
Variations: average work
f) **Time saved thanks to innovations**
- Measures the time saved by introducing the innovation process.
Variations: hours saved due to innovation
g) **Awards for innovations received by the organization**
-measures the number of public appreciations for innovation, which the organization receives

h) **Unplanned absenteeism rate**
- Measures the percentage of days of absence unannounced of the total work days available. Unplanned absences occur when such notification is made in less than 24 hours.
Variations: unscheduled absences [7]

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9. CONCLUSION

The study results confirm the interest of companies in the design, implementation and use of KPIs on industrial production lines, and the benefits deriving from the existence of performance system.

1. Implementation by the critical successful factors by the support of the managerial team, availability and hence the quality of primary data

- 94% periodic use of KPI by companies applying indicators
- 53% use of synthetic reports
-50% department heads responsibility
- 9% use of the balanced scorecard [5]

2. Benefits of the companies that have successfully implemented performance indicators KPIs:

-76% correctly measured indicators
- 55% of indicators have an important role in decision making
-56% KPIs enable rapid identification of areas of action in crisis
- 90% of measured values generate reactions from managerial team [5]

3. Support generated by arguments such as know-how, insights, experience, speed of implementation of performance indicators in the company, and also by the reserves, which explains that implementation of performance indicators KPI is not a priority for some of the companies, which prefer to achieve their goals by using internal resources. 70% of the companies consider that it is appropriate to cooperate with external consultants. The employees motivated by the important work done in the company are more focused on the purpose of their performance.[5] With the implementation of KPI indicators on industrial production lines, there were designed implementation systems and global industrial production and found that there might be some differences on the implementation of KPIs in terms of indicators summarizing all depataments of industrial companies. This may change depending on the complexity of indicators of the macro thought production.

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METHODOLOGY FOR CONFIGURATION OF ROBOT WELDING CELL FOR SMEs UNDER CONDITIONS OF SMALL AND MEDIUM SIZED PRODUCTION USING MIG/MAG PROCESS

Talalaev, R.; Sarkans, M.; Laansoo, A.; Veinthal, R.

Abstract: *Increasing competitiveness in global markets and quality requirements for produced goods require reduction of prices in welding industry. Solution to the problem in metal working industry lies in implementing welding robots for large scale production. In case of small and medium series production the use of welding robots is economically and technically more complicated and requires considering different aspects.*

In the current article the methodology for configuration of robot welding cell for SMEs is presented. The research is limited by conditions of MIG/MAG (GMAW) welding, nevertheless it can be expanded to other technologies.

The basis for this research is the implementation of four different robot welding cells in SMEs. Information collected during the process is analyzed and recommendations are given.

Key words: robot-welding cell, SME, small series production.

1. INTRODUCTION

In Estonia and in the Nordic countries there is an increasing demand for implementation of welding robots due to deficiency of qualified hand welders.

The research is conducted under the framework of IMECC project (Innovative Manufacturing Engineering Systems Competence Centre) the subproject of which considers automation of processes for SME-s using robotized welding cells. This project includes several issues from implementation of robot welding cell to welding technology of the product.

The basis for this research is the implementation of four different robot welding cells in SMEs. Information collected during the process is analyzed and recommendations are given. According to the research, while implementing the robot welding cell certain issues must be considered to ensure the correct configuration of the robot welding cell and to guarantee the suitability for SMEs needs. This approach enables to divide the complex process into more easily manageable topics. The main domains to be considered are the following: product, technology, jig, components of robot welding cell. Criteria for each domain are proposed.

For decades robots were used only for mass production. Robots usually conduct repeated and long-term actions. Mainly the cycle time and its reduction is the main criterion for such systems.

When implementing a robot in small and medium sized production the criteria also change. In case of small production batches the importance of rapid setup and implementing of new products is more important than only short cycle times.

For configuration of the robot welding cell for SMEs it is vital to consider the following issues (Figure 1):

• Product (product families, classification of products);

• Technology (welding technology, production process);

• Jigs (main criteria for jigs considering robot welding);

• Components of robot welding cell (main criteria for selection of components);
• e-Manufacturing (maintenance of the cell, user support).

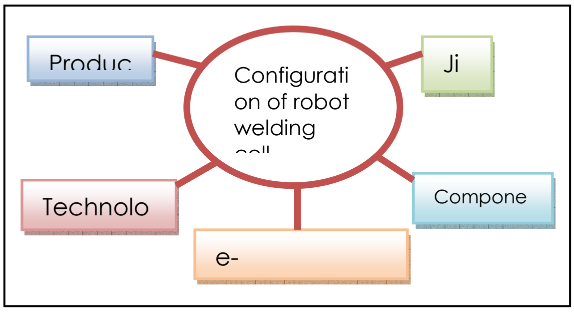

Fig. 1. The main criteria influencing the configuration of robot welding cell

The main company profile in Estonia is SME therefore the fulfillment of their tehnological needs is an important issue. One of the main directions is the implementation of new technologies known as trasfer of technology. To make it possible several stages must be considered according to the enterprise needs.
As they lack the resources considering knowledge, finances and manpower for implementing of new technologies, it is important to make this process as plain as possible.
In this article the methodology is proposed to make selection of components for welding robot cell and to implement production technology which is suitable for enterprise needs.
Enterprises qualify as micro, small and medium-sized enterprises (SMEs) if they fulfil the criteria laid down in the Recommendation by EU (Table 1).

Enterprise category	Headcount: Annual Work Unit	Annual turnover		Annual balance sheet total
	AWU	million €		million €
Medium-sized	< 250	≤ 50	or	≤ 43
Small	< 50	≤ 10	or	≤ 10
Micro	< 10	≤ 2	or	≤ 2

Table 1. Enterprises size definition in EU, based on [1]

In addition to the staff headcount ceiling, an enterprise qualifies as an SME if it meets either the turnover ceiling or the balance sheet ceiling, but not necessarily both.

2. METHODOLOGY

Transition to automatic or robotic welding does not only involve obtaining devices and programs, but also planning, organizing and leading the entire work process. A flexible welding system is better in case it is not clear whether a certain product is going to stay in production for a long period.
In planning also weld fixures should be considered. It should be possible to fix the welded detail to the fixture and later remove it quickly and easily.
In case of automatic/robotic welding quality requirements can be stricter than in case of hand welding. Products produced applying new technology should be tested before transition to automatic welding. It must be considered that quality requirements and control may change.
Other regulations and criteria infuencing this process and final product must be considered. Fixing devices must be renewed. Positioning devices may appear necessary to maintain accuracy and quality of welds. In case of automatic welding all phases are performed by machine (mechanically or electronically). Automatic welding can be partial or complete. If the device performs one or several similar operations, the process is called fixed automation. In case the device performs different operations, the process is called flexible automation. Flexible automation is recommended in case of SMEs.
Multiple-programmed robots are the most flexible. The task of the automatic system is to reduce production costs, raise productivity and quality of welding. Thus, different operations can be performed, while using less floor space, the amount of

unfinished products can be reduced and production capacity increased.
Production will be a success, if the process is carefully planned, economically justified, supported by cooperation of management, designers, engineers, workers and maintenance team [2].

2.1 Definitions, scope

During the research several terms used for describing the system. The most used and essential ones are given below.
TIG welding process is perfectly adapted to very thin products, making it possible to obtain high quality welds, with a low output. Welding speed is between 100…500 mm/min, although in automated welding higher speeds are possible. The welding parameters are determined by the nature and composition of the base metal, the thickness to be assembled and fastening method. The parameters set out in Table 2. Parameters can be adopted as starting values for the adjustment of machines.

Thickness	Preparation for TIG welding
0,5...2 mm	No preparation and without gap; no filler
<5 mm	60° V chamfer or no preparation with gap equal to half its thickness
>5 mm	70° V chamfer – gap = 2.5 mm

Table 2. Preparation steps for TIG welding

For thin steel products, MIG/MAG welding is the process most universally employed. For thickness higher than or equal to 20 mm, it is ideally suited. For thinner materials, the conventional MIG/MAG process is more difficult to use; in this case, the pulsed mode makes it possible to obtain satisfactory operational weldability. The wire is of carbon-manganese type according to standard NF EN 440 for solid wire, with the possible addition of alloying elements: molybdenum, nickel and chronium, principally, in order to obtain the properties of mechanical strenght in the molten metal.

The wire is chosen according to the base metal and mainly the mechanical properties that weld must guarantee [3].
The method takes its name from the type of gas which is used: MIG (Metal Inert Gas) or MAG (Metal Active Gas). The full name of the method is Gas Metal Arc Welding, abbreviated to GMAW.
The MIG/MAG welding method is becoming more widely used than any other method of welding (see Figure 2). Among the reasons for this is the fact that productivity is high and that the method can be easily automated. MIG/MAG welding is gaining ground at the expense of manual metal arc welding, which used to be the most common method. Today, MIG/MAG welding is the most widely used method of welding in Europe, Japan and the USA.

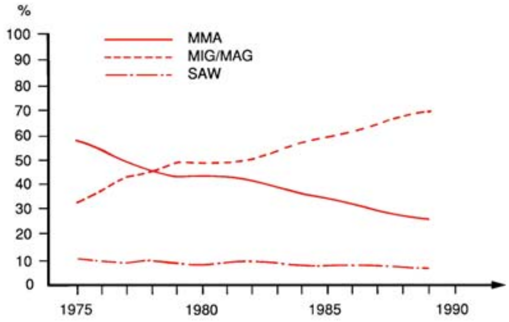

Fig. 2. Proportions of various welding methods in Western Europe. MIG/MAG, MMA (Manual Metal Arc welding) and SAW (Submerged Arc Welding) [4]

The diagram clearly indicates that MIG/MAG welding is an increasing trend and is more widespread than other alternative welding methods. The main welding methods applied in Estonia are TIG and MIG/MAG. To some extent other methods (FSW, SMAW, spot-welding, laser welding) are used. The automation necessity of these methods is not big. Automatic welding is considerably more effective than hand welding. On the other hand, it is not easy to apply automatic welding for SME-s, as core competence and resources are missing.

For thinner material (thickness 2 mm and less) the CMT (Cold Metal Transfer) welding process can be used. The basic operation mode of CMT is characterised by an arcing phase during which a molten droplet is formed on the end of the wire electrode and a weld pool created. After a set duration the wire electrode is fed forward to make contact with the weld pool /base material creating a short circuit. During this phase material transfer is initiated and the arcing current substantially reduced. After a defined period the electrode is mechanically retracted, this rearward motion aiding in pinching the molten globule into the weld pool. The arc is then reignited and the cycle repeats. The process is unique in that not only is deposition controlled by the forward and rearward motion of the electrode, the electrical characteristics are also controlled with the result that material transfer takes place at both low current and low voltage. A typical CMT transient waveform and definition of cycle instantaneous values is shown in Figure 3.

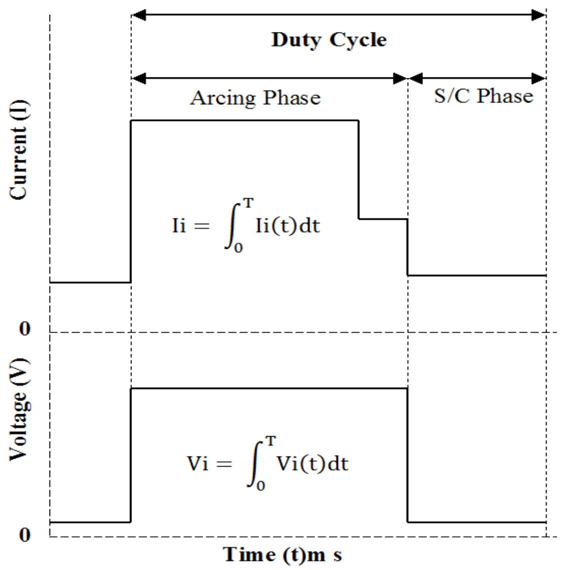

Fig. 3. CMT cycle instantaneous current and voltage values based on electrical transients. One duty cycle is shown considering Arcing Phase and S/C Phase accordingly [5]

2.2 Product analysis

To select suitable products for robotic welding, the enterprise studied several product designs. Products were grouped and weld types were analyzed. The most important data for robotic welding qualification were the following: production quantity, product size, product mass, type, length and number of welds. After studying the data the test weldings was performed. Visual control of test welding was carried out, photos were taken. As a result, welds for lab tests were selected and micro/macro polishes performed to prove the adequacy of welds to quality standards and process needs.

2.3 CMT process implementation

To be convinced about the necessity of robotic welding by means of CMT process in SMEs, product suitability analysis and welding tests were conducted. Objectives of this study were the estimation of welding parameters for robotic CMT welding for small or medium production series.

Goal was to find optimal welding parametres for the welding process in order to achieve the best results. The above described methods were used for this process. Method of product analysis was established to have a better overview of products and create product families for welding.

Potential products for robotic CMT welding process were found and suitable welds were chosen for the experiments.

Experiments were conducted according to information obtained from literature and using welding parametres given by CMT power source. The fabricated specimens were inspected visually among which a certain amount of specimens were chosen for laboratory research. According to the metallographic analysis it was possible to decide which types of welds are difficult to perform and where problems might emerge using CMT power source welding parametres.

Base materials and filler metals were recommended by company and used also for manual welding. Goal of these exeriments was achiving maximum welding speed and productivity of welding with acceptable quality of the weld.

3. ROBOT CELL CONFIGURATION

For configuration of robot welding cell several steps must be followed:

• product portfolio analysis and technology charting;

• product classification according to production times and production quantity;

• welding process analysis, evaluation and verification;

• selection of jig design and clamping elements;

• selection of robot welding cell components based on product and welding process analysis.

Based on these steps recommendations are given below.

3.1 Product classification

Classification of products for a robotic welding cell can be done by grouping the products according to welding time and production capacity. This recommendation is done based on research of 4 robot welding cells and their products. The groups are following:

• products with big production capacity and short welding time (20 seconds to 5 minutes);

• products with medium production capacity and medium welding time (5 to 30 minutes);

• products with small production capacity and long welding time (30 to 90 minutes).

3.2 Welding process

The analysis of welding process is an important issue when implementing products for robot welding. The technological process (welding) must have the primary focus becuse the automation process is technolgy-based.

By gaining the clear understanding about the process itself, the automation of the process can be carried out by the means of the process knowledge.

Also the welding process (MIG/MAG, TIG) must be verified before the implementation of the robot welding cell. It can be done by welding tests and laboratory analysis of welds.

3.3 Fixture design

To connect product and robot welding cell components together the fixture for welding must be designed. It is important to follow the next requirements:

• the fixture should be strong and light but rigid enough to ensure accurate alignment;

• the fixture must permit quick and easy positioning by positioner, balancing of the fixture may be necessary;

• jig accuracy and elaboration must not be greater than required, only essential product dimensions must be controlled in a fixture;

• a fixture must be built around the work and be located and clamp components in position;

• the fixture must ensure a single correct assembly only;

• the fixture must permit freedom of movement to avoid residual stress in the completed weld;

• welded joints must be readily accessible for welding - by slots or other means, the fixture should readily present seams on the reverse side of the object;

• for final accuracy the parts must be pre-bent in the fixture, if necessary;

• clamps must operate quickly, screws and moving parts must be protected against weld spatter;

• grounding of the workpiece is important in fixture design, since it affects the arc action, quality of weld;

• fixture design must enable the welded product to be easily removed.

3.4 Robot cell components

After the analysis of the product and welding technology and fixture initial design the robot cell components must be selected. Main components and issues must be considered for robot complex are:

- robot – (size, accessibility);
- manipulator – (accessibility, welding position, capacity, size);
- welding device – (number of parametres, adjustment, welding process, capacity);
- control devices (programming, device connection, control);
- safety options (guarantee of operator safety).

3.5 Deployment

Before making final decision about the robot welding cell implementation the payback time and efficiency must be calculated. Accordingly to product nomenclature and production capacity the range can be different.

Deployment time can be rather long. As SME-s usually have many products, preprogramming is necessary and the usage of the robot under maximum load is limited. Breaking point is achieved about two years after deployment. Proportion is then between welding and programming can be 50/50 accordingly and a year later 80/20 in favour of welding. As soon as all products have been inculcated, the programming time is between 5 to 10 %.

CONCLUSION

Configuration of robot welding cells using division of tasks enables to introduce complex technologies in SME-s.

This approach is not final and needs additional development.

The classification is based on analysis of 4 different robot welding cell implementation projects.

The main steps needed for configuration are: product analysis, welding technology analysis, fixture design and selection of robot cell components. Although theses points do not cover the all issues, they are most important. Further research is needed considering calculation of payback and welding time.

ACKNOWLEDGEMENTS

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PRODUCTION PLANNING WITH THE SUPPORT OF THE MEGATRENDS AND GIGATRENDS

Taucean, I.M.

Abstract: *This paper' objectives are to proposes and emphasizes the need to analyze and foresee a company's activity, from the point of view of megatrends and gigatrends. These are defined and explained how we can use these to plan the future, to make company's plans and strategies.*

Companies have been trying to predict the future for long time, but they encounter problems when faced with reality.

It is a challenge to recognise new trends in every line of business. Trends are viewed as important indicators for companies. Companies that anticipate trends correctly and adjust accordingly will gain greater market share, and will have success.

Thus, companies should use these in the process of planning to minimize risks.

Key words: production planning, prevision, megatrend, gigatrend.

1. INTRODUCTION

The need to analyze and preview a company's activity is very important when we take decision about the strategies and plans for a lifecycle time view of an enterprise. But prevision and forecast for a long and very long time is problematical, hard to predict, unsure and questionable (especially when we analyse small and medium enterprises).

The paper' objective is to consider in a company prevision and planning activity the megatrends and gigatrends. But how can you define and use "tera-trend"? But "giga-trend"? Megatrend is classically defined for a period of 10 years (see "Megatrends" by John Naisbitt [1], [2]). Gigatrend may be several decades, up to 100 years (see "The Next 100 Years: A Forecast for the 21st Century" by George Friedman [3]). Teratrend may be thus over 100 years, most likely several centuries.

How can we use these trends to plan our future, or for a company to make plans and strategies?

Production planning of course should be correlated with trends, previsions, forecast, scenarios made by the company for future success [4].

From the point of view of management functions there should be trends of decision, planning, organizing, coordinating and controlling (figure 1).

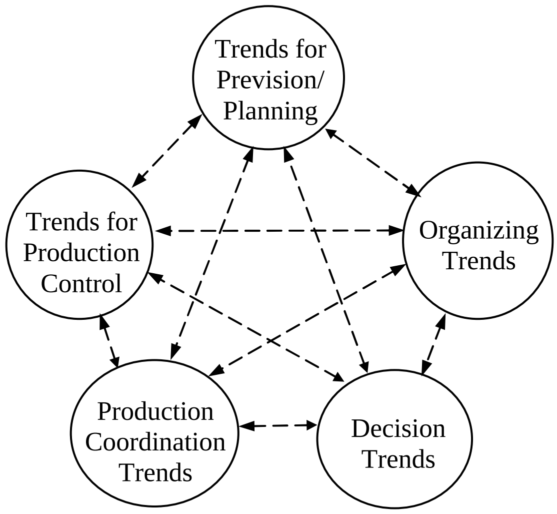

Fig. 1. Trends and interconnections for managerial functions in production

Also, from the management roles concept [5] there should be trends in ten roles for managers and entrepreneurs who should be adapted to a longer period of time and it is difficult from the point of view of SMEs. These roles are: figurehead, leader, liaison, monitor, disseminator, spokesperson, entrepreneur, disturbance handler, resource allocator, and negotiator. From the 10 roles we can consider to be very important, when dealing with future and far in the future, the following roles: leader, monitor, and entrepreneur.

From the point of view of executive function of the small and medium enterprises, forecast should be focusing mainly on production and commercial functions, because other functions may be at minimum level or externalized (such as personnel, financial and accountability, research and development). But of course, without R&D almost no company will survive for a long time, and you can't make strategies without considering innovation a a factor for future success.

2. TIME MANAGEMENT

Time management refers to a range of skills, tools, and techniques used to manage time when accomplishing specific tasks, projects and goals [6]. This set encompasses a wide scope of activities, and these include planning, allocating, setting goals, delegation, analysis of time spent, monitoring, organizing, scheduling, and prioritizing. Initially time management referred to just business or work activities, but eventually the term broadened to include personal activities as well. A time management system is a designed combination of processes, tools and techniques.

Some authors (such as Stephen R. Covey [7]) offered a categorization scheme for the hundreds of time management approaches that they reviewed

- First generation: reminders based on clocks and watches, but with computer implementation possible; can be used to alert a person when a task is to be done.
- Second generation: planning and preparation based on calendar and appointment books; includes setting goals.
- Third generation: planning, prioritizing, controlling (using a personal organizer, other paper-based objects, or computer or PDA-based systems) activities on a daily basis. This approach implies spending some time in clarifying values and priorities.
- Fourth generation: being efficient and proactive using any of the above tools; places goals and roles as the controlling element of the system and favors importance over urgency.

We should look for the fifth generation that should include tool for time crises and strategic planning for very long time planning.

3. VERY LONG TIME PRODUCTION PLANNING

The activity of most of the small and medium size firms being developed under the circumstances of a free market economy, in an environment that is continuously changing in all directions (economically, politically, technologically etc), a changing that takes place in an ever accelerated rhythm, these firms meet with the above described situations, cover, most of the times, periods of accelerated increase followed by stoppage and rapid decline [4].

Within this context there appears the need to resort to a certain new approach, to use certain new models to foreseen the right way of company development [8].

The attention has to be focused on the customer, because any firm's target is its success through the satisfaction of the customer.

Thus, the model of strategic planning should directly contribute to the reaching of the most important objective: improvement of the competitiveness level of by winning new customers [4] [9].

But also, customers not always know what they want in the future, not even in the near future, nonetheless far into the future.

3.1. Forecasting

Forecasting is the process of making statements about events whose actual

outcomes (typically) have not yet been observed.
Risk and uncertainty are central to forecasting and prediction; it is generally considered good practice to indicate the degree of uncertainty attaching to forecasts. The discipline of demand planning, also sometimes referred to as supply chain forecasting, embraces both statistical forecasting and a consensus process. An important and often ignored aspect of forecasting is the relationship with planning. Forecasting can be described as predicting what the future *will* look like, whereas planning predicts what the future *should* look like [10]. There is no single right forecasting method to use. Selection of a method should be based on objectives and conditions (data etc.). A good place to find a method is by using the Selection Tree Method.
The field of forecasting is concerned with approaches to determining what the future holds. It is also concerned with the proper use of forecasts. The terms "forecast," "prediction," "projection," and "prognosis" are typically used interchangeably.
The firms would usually start by planning. The planning process produces a plan that is, along with indicators about the environment, an input to the forecasting process. If the organization does not like the forecasts generated by the forecasting process, it can generate other plans until a plan is found that leads to forecasts of acceptable outcomes. Of course, many organizations take a shortcut and merely change the forecast.

3.2. Forecasting methods

Forecasting methods can be classified first as either subjective or objective. Subjective (judgmental) methods are widely used for important forecasts. Objective methods include extrapolation (such as moving averages, linear regression against time, or exponential smoothing) and econometric methods typically using regression techniques to estimate the effects of causal variables).
There are many good special-purpose forecasting software programs. Some programs help the user to conduct validations of ex ante forecasts by making it easy to use successive updating and by providing a variety of error measures. Some programs incorporate more forecasting principles than others.

3.3. Principles in forecasting

The principles of "engagement" supposed that there should be a certain logic in choosing the right period of time for company's forecast. The forecast must cover a future period of time needed to fulfill as better as possible of the engagements/decisions adopted today.
The implication of this principle is that long term forecast doesn't mean a forecast for future decision, but forecast for the future impact of actual decisions, decisions that are the basis for prevision. Actually, studies and analysis comes before the decisions, and a prevision doesn't exist until there is a decision taken.
This principle must be considered in the light of forecast "flexibility" principle. The forecast must be flexible because there are uncertainties and errors even in the case of best forecasts. Forecast flexibility means the capacity to change when you are forced to do it by the unexpected events, and this change must be done without unjustified used of resources, especially costs.
If the plans must be change to satisfy future requirements that wasn't or couldn't been forecast, then the period of forecast can be shorter, and vice versa.
Flexibility is possible in certain limits. A decision can't be always delayed to the extent then we are sure that it is the right decision. On the other hand, flexibility incorporation in forecast can be so expensive (regarding resources) that the benefits can be below the costs (that means without any benefits and advantages).
Unlike the flexibility principle, the "pilotage" principle refers to the flexibility of the forecast process. The incorporated flexibility doesn't suppose automatically

revisions of plans. Revision means that managers should verify continuously the events and expectations and to revise the plans to maintain an evolution toward the desirable goals and objectives.

3. 4. Using forecasting methods

There are many methods that can be used to forecast. Which are relevant to your situation depends upon your objectives and the conditions you face (such as what types of data are available). To find a method using a framework based on prior research, you can use the Selection Tree. You can use more than one method; in fact, it is best to do so if different methods are likely to provide more accurate forecasts.

In many situations it is useful to be, say, "95% confident" that the actual value will be between X and Y, or that the actual outcome will be Z. Unfortunately, uncertainty over the forecast horizon typically cannot be well estimated from how closely forecasts from a method fit the historical data. In general, the best that can be done is to simulate the forecasting situation as closely as possible. Thus, to determine how well one can forecast two years into the future, examine a sample of two-year-ahead ex ante forecasts. "Ex ante" means that you are looking as if "from before" and you do not use knowledge about the situation after the starting point for forecasting. The problems encountered are bigger when we try to do forecast for a longer period of time (decades, centuries), when there are many variables to consider, with the high degree of uncertainty, up to 100%.

3.5. Scenarios analysis

Scenarios analysis implies the description of possible situations in the future [11]. This analysis can be use especially when dealing with a longer period of time, and explore the phenomena far into the future.

There are longitudinal scenarios that show how the present will be projected in the future, and transversals scenarios that describe how will be the realities at a future moment in time. We can use here especially quality techniques but also quantity techniques can be use.

Thus, we should use these techniques in the process of planning to minimize and take the minimum risk.

4. TRENDS

There is known that there are some steps up to the fulfillment of the objectives of a company that involve deliverables, opportunities and trends (see figure 2). This is known as "TO DO" (Trends, Opportunities, Deliverables, Objectives) brainstorm model for change and innovation [12]. This model helps as a strategic tool for surviving for a long time.

Fig. 2. Trends and objectives

When searching for relevant global or local trends that might influence the added value of the products and services, a company can find what kind of changes can be observed in the environment.

After gathering the trends by wandering around and reading reports the next step is to translate these trends into opportunities.

The step of transforming the opportunities into deliverables is most crucial. These deliverables can be innovative products, services and even innovative processes that do support the opportunities. Always do check whether your innovative products, services or processes do actually meet the trends and opportunities as determined in the first two steps. This ensures that your innovative approach will actually be appreciated by your customers.

The final step is the setting of goals and targets. What are your objectives? When will it be satisfied? How will you involve employees, customers and stakeholders to realize your long-time plan?

5. CASE STUDIES

For a long time, man has been trying to predict the future, only to find that their vision – being too detailed – encounters problems when faced with reality. In order to achieve commercial success it is often sufficient to sketch future scenarios with a certain amount of deviation.

Companies use new products, services and processes as a response to market demand. It' is a challenge to recognise new trends in every line of business. This challenge is even bigger when dealing with megatrends and gigatrends.

Published in 1990, Megatrends 2000 [2] describes what was beginning to shape the 21st century, including the dawn of the Age of Biology, The Triumph of the Individual, the emergence of the Free Market Socialism, a Religion Revival.

In "The Next 100 Years" [3], George Friedman turns his eye on the future, offering a lucid, highly readable forecast of the megachanges we can expect during the twenty-first century. Here are some trends:

• China will undergo a major extended internal crisis, and Mexico will emerge as an important world power.

• A new global war will unfold toward the middle of the century between the United States and an unexpected coalition from Eastern Europe, Eurasia, and the Far East.

• Technology will focus on space,.

Richard Lamb sets "Ten Global Giga Trends" as follows [13]: 1. Time-On-Demand, 2. Safety Web, 3. Time for sale, 4. Interactive Society, 5. Twinning, 6. Quality of Life, 7. Pure Communication, 8. More Mobility, 9. Experience Industry, 10. Pull Economy. He considers that changes often occur at the interface of two or more trends. Some trends seems to be conflicting at the firs glance, but successful company find the way of delivering products to meet those trends at the same time.

To give more detailed examples, a prevision for 2025 is that all Europe country will be in Euro Zone [14]; for 2050 the border between human and machine as we known it will no longer exist [15]. Other trends include increased mobility, education, the end of the industrial age, increasing individualization, aging society, globalization, the importance of health.

Trends are viewed as important indicators for companies, as they are an expression of their time. They help to paint a picture of the future. Companies that anticipate trends correctly and adjust accordingly will gain greater market share, and, of course, success. But, how do companies continue to align themselves with mega trends if new trends are consistently formulated? There are researches that point out that if the trend cycle will continue to accelerate and once mega-trend and gigatrend epoch has finished, we may witness the teratrend era [16].

6. CONCLUSIONS

The importance for a country/sector/ enterprise of achieving international competitiveness is widely considered a goal of public policy.

To achieve this, an entity has to try to know 'the future", to anticipate the future's direction of a business/domain. And sometime has to create this future, not being a simply observer/actor.

Trends are important indicators for companies. Companies that anticipate trends correctly and adjust accordingly will gain greater market share, and will have success. Thus, we should use these techniques in the process of planning to minimize and take the minimum risk.

The modern methods of forecasting are based on the same idea: looking for the law that governs the evolution of the phenomenon and find the probabilistic value which that phenomenon will have at the specific moment in the future.

The methods mentions in the paper are based on the statistical time series. These methods are considering the age of the information, in order to avoid tendency extrapolation and/or of the variations which has stop to be characteristic for the real evolution of the time series. And by this it will be retain for extrapolation only the values with the biggest probability of appearance in the future.

By finding these characteristics, it will respond also to the following imperatives:

To relieve the mean of the phenomenon, the trend, the cycle variations around trend (also seasonal trends), the deviations from the law of the phenomenon.

To eliminate unproductive abnormalities.

To take into account the age of information.

To realize a mobile adjustment taking into account the new events that will appear during the evolution of the phenomenon.

To allow forecasting by using the last calculated values without being necessary keeping the whole time series.

To find all significant modifications of the phenomenon in time by using validity forecast tests.

To allow the modification of the leveling indicators in any time, without questioning the validity of the calculus that was done prior to modification.

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LEAN PRODUCT DEVELOPMENT IN ESTONIAN SMEs

Tähemaa, T. Temerbulatova, A. Karjust, K.

Abstract: *Product development is one of the most creative manufacturing processes. Furthermore, it is highly relevant in product price formation. The process is not predictable and the success of the creative work is evaluated only later – from market reaction. In the main position of this process is human – (engineer, inventor, developer ect). One may ask how we can optimize or be leaner in such processes. Late researches have investigated many similar "leans", for example Lean Manufacturing, Lean Office, Lean Enterprise, Lean Supply Chain, Lean Six Sigma, Lean Thinking and now Lean Product Development. This shows us that everything could be leaner. In this paper, the product development processes of both small and medium size Estonian engineering enterprises are under investigation.*

Relations between PLM (Product Lifecycle Management) and LPD (Lean Product Development) are described. Future trends and needs in LPD field are discussed and analyzed as well.

Key words: Lean Product Development, Product Lifecycle Management.

1. INTRODUCTION

In the production and product development phase advanced CAD/CAE/CAM/PLM tools are becoming more effective and useful in small and medium sized companies. The computer-based methods are used to support engineering decision making processes. They allow the integrated use of information about different aspects, such as geometry and functionality of product, manufacturing and development processes, available resources, pricing processes, supplier data etc.

Progress in design search and optimization (DSO) has continued steadily in recent years and formidable range of optimization methods is available to the engineers. In general, design optimization may be defined as the search for a set of inputs that minimizes (or maximizes) objective function under given constraints. The objective function may be expressed as cost, product lead time, product efficiency, and return on investment. It is subject to constraints in accordance with given relationships among variables and parameters and constraints of manufacturing system parameters and resources. [1, 2].

Lean is the search for perfection through the elimination of waste and the insertion of practices that contribute to reduction in cost and schedule while improving performance of products [3]. Product development as an activity is not the most expensive one among the whole production chain. But as it can be seen from Fig 1, it has a strong influence on the price of the product and faults made during this stage are very costly. One can understand from Fig 1. right side why lean production was the most effective and first in the line to be used.

Most Estonian SME-s have cultivated a personal approach to the product development process. Each company, even each individual product development team member has their own methods [4,5]. This fact shows that there is huge potential for accelerating time-to-market through aggressive waste elimination in planning, design control, and interdisciplinary communication. The interest to be more competitive is more critical in bigger production units while smaller production units may count more in flexibility. It is shown in [6,7], that is important to follow certain rules, even in cases where the product development team is small. Radeka. K and Sutton. T [8] believe that there are five particularly important questions in Lean Product Development (LPD).

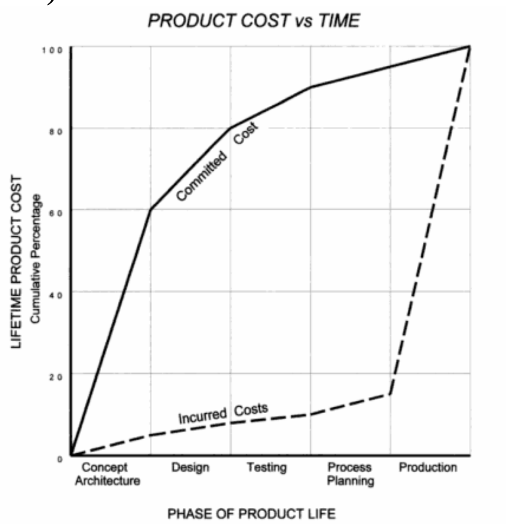

Fig.1. Incurred cost distribution during different production phases

First, get a good handle on customer value. How well do you know your end users? Next, take a good, hard look at your product development process. Then think about program leadership: Who in your organization makes the major decisions about product development? Then take a close look at how much effort you exert at the end of the process versus how much you spend at the beginning, when exploration is relatively cheap. Finally, what organizational barriers foster the waste of reinvention?

Those five questions are the best to describe the meaning of LPD and it is clearly understandable that those five questions have importance in both – large and small-medium enterprises.

Of course some of those questions have higher importance when integrated product team (IPT), as a development unit, is used. IPT's are the basis of organizing development personnel to enable Concurrent Engineering, Integrated Product Development (IPD), or Lean Product Development. Such a team is usually empowered to make critical life cycle decisions for the development of a product or system. Because the product or system development activities are changing and evolving constantly, team membership is changing and evolving as well.

Product Lifecycle management (PLM) as a tool is strongly connected and usually integrated into the Integrated Product Team toolbox. To avoid mistakes made in the past, and to take more advantages from successful products, PLM gives us great possibility to copy useful parts and save a remarkable amount of time. The aim of this paper is to store the current situation of the product development styles and levels of Estonian SME's based on a survey on a selection of SME-s. In addition, a roadmap for Estonian SME's to choose an optimal toolbox for LPD is shown.

In the next part of the paper the current situation of product development level is investigated. It is based on IMECC (Innovative Manufacturing Engineering Systems Competence Centre) group production units. Those production units are categorized and their product development process descriptions are displayed. It is pointed out that a systematic approach to problem solving and Product Development helps to control expenses in this early step of pre-production process.

2. PRODUCT DEVELOPMENT IN ESIONIAN SME-S

Five years ago held a seminar called "Modern Product Development in SME-s – problems and possibilities" was held in Tartu Science Park. In those days, LPD was not discussed a as term. However, many tools used in LPD were often mentioned. Lean Production was already acknowledged at that time but "Modern product development" had meaning that specific process steps in product development just should be passed. The reason for this fact is educational on the one hand. On the other hand, it was caused by high levels of subcontract work, where product development had no meaning. Agility in pricing and low cost equipment from the Soviet time, were the basic reasons against “lean” type of thinking.

Based on the data from a research carried out in 2009 about manufacturing SMEs, only a few Estonian production units had their own independent product development team. In most places the “brainwork” was made abroad or leaded from abroad. Large companies represented in Estonia had only a few engineers in Estonian factories and their task was simply to translate orders to the production unit and send feedback to the opposite direction – back to the head office.

One of the tasks of IMECC is to create a set of SAS (Software as Service) tools for SME cluster, for better and leaner product development.

For the evaluation of product development levels in SME’s, product development toolbox consistence was investigated. Required variety of SME input data is described below.

- From the point of view of the number of employers – the almost full range of SME group was presented;
- From the point of view of location – different regions were covered;
- From the point of view of the two sectors of production profile– subcontractors and enterprises with their own product development departments were involved.

In our case those requirements were fulfilled, (20...150 employers, SME-s situated all over the Estonia and both, subcontractors and enterprises with development department are represented).

As it was shown in Fig 2, 78% among SMEs are not using the possibilities offered by the modern product development tools. Drawings are still archived in papers, versioning is mostly manually driven and unsystematic. Feedback information, for example VOC and reclamations are not available to the product development team.

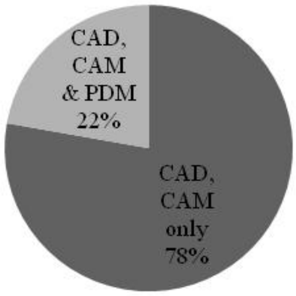

Fig.2. Product Development toolbox elements distribution in Mechanical Engineering SMEs.

As a result of non-systemized archives and an unclear version handling, a lot of time is wasted for the searching of suitable examples from archive. Also product data collecting and systemizing is difficult.

A personal approach to product development process is cultivated in Estonian SMEs and each company and even each product development team member has their own ways to manage. Smallest Product development teams may consist of only one person. Such one-man teams are quite lean by their nature, because there is no need for internal communication. On the other hand, there is a huge risk to lose everything in case of key person’s disappearance.

Companies with bigger product development teams may have already encountered a full variety of problems, Radeka. K and Sutton. T [8]. But mostly they suffer due to the lack of systematic approach.

Larger companies with their sub-production units in Estonia (counted also as Estonian SME) have normally very well organized structures and workflow, but they mostly suffer at communication speed and accuracy.

PLM (PDM) level is in correlation with the employers’ amount but not correlated with the production profile. We can also see that the PLM curve’s highest point in Fig. 3 is only slightly over 50%, which means a

little more than a half of PLM offered modularity is currently used by larger SMEs and only a few modules (mostly CAD and CAM, as it was pointed out in Fig. 2) are currently used in smaller SMEs.
As example, one anonymous SME-s (120 workers in whole) product development team and their work process is shortly described. The design department consists of two types of engineers: electronic engineers and design engineers.

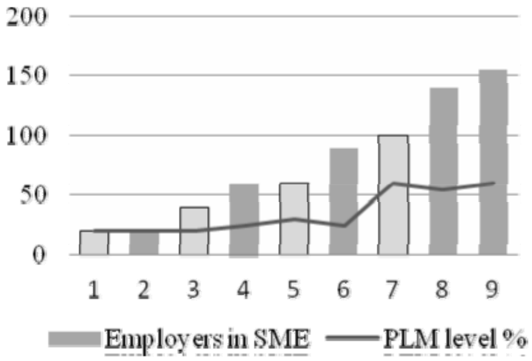

Fig.3. Correlation between employer's amount and PLM systems functionality

The tasks of an electronic engineer are:

1. They start with preparing an electrical scheme according to the client design brief;
2. The Second step is to prepare a list of electronic components;
3. The Third step is to write a program code for frequency converters;
4. The Fourth step is to prepare a testing program;
5. The Fifth step is to write a technical regulation;
6. Finally, when the product is produced, engineers provide the client with exploitation extractions and make the last testing with the client.

The tasks of a designer engineer are:

1. Firstly, the engineer reads the electro scheme and makes clear all of the connections and components;
2. The second step is to prepare the main specifications;
3. The Third step is to find a suitable enclosure;
4. The Fourth step is to prepare technical calculations (cooling, ventilation, stress analysis, etc.);
5. The Fifth step is to do a 3D model of enclosure with all electrical components and details;
6. The Sixth step is to make technical documentation (drawings, specifications, etc.);
7. The Final step is the assembly stage, when engineers control the assembly stage and make corrections in documentation.

In the beginning when new project starts, the manager of design department prepares a plan for future work, in which he mentions designing a team structure. During the project, all serious problems which appear should be solved inside the team. Usually a team consists of 4-5 engineers. The Manager of a design department always controls all of the documentation which has been produced for a project and after corrections, approves it. When the documentation is finished, the design engineer prepares a note, where he/she describes the kind of work should be done next. For example, which drawings should go into work.
There are no any helpful technical tools supporting PLM data collecting and handling. That is why the bureaucracy is very developed there.
In conclusion, it is clear that a roadmap for future activities is more case by case type of instruction than universal rule for all size of organizations.

3. TOOLS AND STYLES IN PRODUCT DEVELOPMENT

For the first step, situation analysis is needed. As every product development team is used to work in their own style and according to their own needs, it would be necessary to find out which tools are already in use and what is needed to add urgently.
Lean product development means different things to different organizations. Some

organizations are "design-to-order", where each customer order requires some amount of design effort. In such companies, customer requirements tend to be well defined, and the design effort typically involves the reuse of existing technologies that will be adapted to meet the needs of specific customers. Other companies engage in longer term "research and development". New technologies must be developed, requiring greater study, testing and time, perhaps years to bring to market. And there are companies that lie somewhere in between.

Regardless, all organizations need to be familiar with the "Lean Development Toolbox". There are numerous tools in the "toolbox". Companies must determine which ones will be most helpful in their particular applications.

Voice of the Customer tools such as Quality Function Deployment (QFD) can help companies get off on the right track at the start of the development process.

Target Costing is a concept that should be initiated at the beginning of a project and followed throughout. Costing models must be developed to monitor projected costs to verify that target costs can be met.

Set Based Concurrent Engineering (SBCE) is a concept that should be put into practice early during the "study" phase of the development process. It is during this phase that different design alternatives are identified and studied.

Design of Experiments (DOE) can help developers learn in more efficient ways during the "study" phase. Methods to help select a "solution" among the alternatives under consideration must be available. Trade-off curves and the Pugh Matrix are two such techniques.

Developers should be familiar with techniques that result in "robust" designs that will be more assured to meet customer expectations. These include Taguchi techniques, including System Design, Parameter Design, Tolerance Design, and Taguchi's Loss Function.

Design Failure Mode Effect & Analysis (DFMEA) can help to insure robustness as well. Here possible failures are considered and countermeasures are proactively included in the design.

Design for Manufacturing & Assembly (DFMA) can insure that manufacturing capabilities are considered while the product is still being designed, as can 3P events. A 3P (Production Preparation Process) event is a kaizen event where a cross-functional team works to develop the details of a design while simultaneously developing the production process. The result is a design that is producible and will be more cost effective when transferred to production.

Project Management techniques are required to manage development projects over time. These techniques go beyond scheduling systems, and establishing "milestones". Effective and efficient communication techniques can be put into practice that will insure success. These include visual management techniques, and methods to capture and share knowledge [9].

One team works for one company, but there are more styles to follow, such as lean product development team for cluster of production organizations or independent product development team working as subcontractor in worldwide on demand style.

This could be even leaner, because sometimes when the production is already running, product development team is underserved. This type of "travelling teams" can do their work in a good lean way in subsystem level and usually in specific fields only (like developing welded frames or molded housings, electronic control systems or power supply units).

There an additional delicate issue – production volumes. It is completely different if in one case one plans production in small numbers or in the other for a long period and mass production. In the first case, it is not so risky to assume to the design phase at once, because of smaller losses of money in the future. But in case of mass production, the product development calculations and DFMA stages should be extremely exhaustive. As mass production is quite rare in Estonia (Norma, Favor, ABB, Ensto, ect) and those factories have high competence levels in product development field, we concentrate more on smaller production volumes.

4. CONCLUSION

The paper demonstrates that the gap between Estonian SME product development level and widely known lean product development methods still exists. It is obvious that a small local market does not generate a large enough pressure to start lean product development activities in SMEs without the help of supporting organizations like IMECC.

From a wider perspective, the deeper experience exchange and wisely organised cooperation in small enterprises product development level improves the overall productivity and Estonia's worldwide competition level. High price level and good quality/functionality relationship of larger PLM and PDM software systems could be an indirect engine for further cluster formation and cooperation.

5. ACKNOWLEDGEMENTS

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RESEARCH ON WELDING OF STAINLESS STEEL VACUUM CHAMBER COMPONENTS

Boiko, I.; Filipov, A.

Abstract: *The goal of this paper is to exam the TIG (Tungsten Inert Gas) welding process for joining of components of vacuum chamber. During welding and cold working the martensitic structure can occur as well as δ- ferrite, both structures are magnetic. This possible structural transformation is one of the significant problems in welding technology elaboration for joining of components of vacuum chamber. A complete investigation from the choice of material of vacuum chamber, design of welds to experimental testing of TIG welding of the elements of vacuum chamber has been performed.*
Key words: vacuum chamber, welding, stainless steel, ferrite content

1. INTRODUCTION

Nowadays for manufacturing of the thin and nano layers on the surface of different materials some deposition methods in the vacuum are used. Generally, deposition of the layer occurs in the vacuum.
In magnetron sputtering technique, which is able to coat any workpiece with a wide range of materials (any solid metal or alloy and a variety of compounds) a vacuum of less than one ten millionth of an atmosphere must be achieved [1]. The working principle of magnetron sputtering deposition techniques is following: the substrate is placed into a vacuum chamber and a small amount of the coating material is vaporized into the chamber (Fig. 1). The molecules or atoms of vapour condense onto the substrate, forming (ideally) a uniform coating of controllable thickness and properties [2].

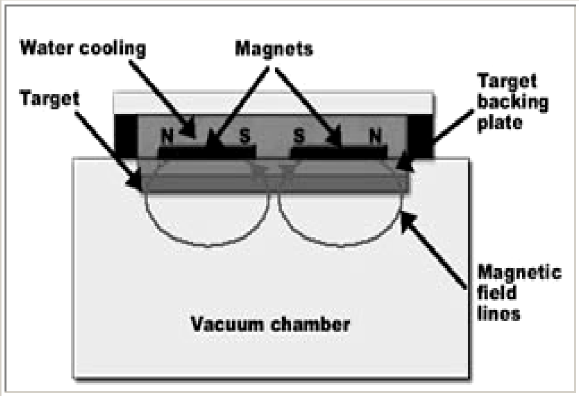

Fig. 1. Scheme of the magnetron spattering process [1]

The deposition process is strongly dependent on magnetic field and plasma parameters such as ion flux, plasma potential, electron temperature and density [3]. Within other process parameters the magnetic field strength and uniformity during deposition have a significant influence on coating properties. Each deviation from the optimal regime leads to rejects. Some deviation could be caused, for example, by deflection of magnetic field due to presence of magnetic structures in welding seams of vacuum chamber. This paper is devoted to examination of the TIG (*Tungsten Inert Gas*) welding process for joining of components of vacuum chamber taking into account prevention of formation of possible magnetic structures in the welds.

2. EXPERIMENTAL

2.1 Materials

According to application different materials for elements of vacuum equipment can be used: stainless steel, aluminum alloy, mild steel, titanium and other.

The material used for the manufacturing of the vacuum chambers must have magnetic permeability of $\mu_{rel} < 1.005$. Grain size and amount of impurities are strictly regulated [4]. To achieve these materials must generally be as follows [5,6]:

- Vacuum chamber walls: austenitic stainless steel sheet/tubes grade AISI 316 LN (another possible materials are 304, 304L, 316 and 316L);
- Vacuum chamber flanges/blanking flanges: AISI 316LN Electro-slag Re-melted (ESR) forgings;
- Cooling water pipe fittings: stainless steel AISI 316.

Type X2CrNiMo17-12-2 (AISI 316L) stainless steel is suited for vacuum vessel construction because of its machining characteristics, excellent corrosion resistance and overall cost effectiveness. Based on the magnetic measurements of sample materials X2CrNiMo17-12-2 stainless steel underwent no significant changes in magnetic permeability throughout the fabrication processes [7,8]. Without cold working, X2CrNiMo17-12-2 had very low permeability (less than 1.005). Thus, stainless steel X2CrNiMo17-12-2 is recommended for use where low magnetic permeability is requires. The chemical composition of steel X2CrNiMo17-12-2 is shown in *Table 1.*

Chemical element	C	Mn	P	S	Si
Content, %	max 0.030	max 2.0	max 0.045	max 0.030	max 1.0

Chemical element	Cr	Ni	Mo	Ti
Content, %	16.0..18.0	10.0..14.0	2.0..3.0	max 0.5

Table 1. Chemical composition of stainless steel X2CrNiMo17-12-2 (AISI 316L) (%)

But during stainless steel X2CrNiMo17-12-2 welding the martensitic structure can occur as well as δ- ferrite, both structures are magnetic. This possible structural transformation is one of the problems in welding technology elaboration. Hence the possibility to use these steel for welded vacuum chamber elements have to be proved.

2.2 Weld joint design

When designing or constructing a vacuum system, the following points need to be observed [9]:

- Full penetration welds should be utilized wherever possible to avoid pockets where volumes of gas or contaminants can be trapped;
- Utilize single pass welds if possible to avoid trapped volumes that could be generated with multi-pass welds;
- Welds should always be made on the vacuum side of the joint;
- If for structural reasons double welds are required, allow for an easy path to flow gas from the joint. This could be in the form of a machined hole between the two welds, or a discontinuous weld on the non-vacuum side.

Correct and incorrect practices of weld butt joints commonly used in vacuum chamber construction are shown in Figure 2.

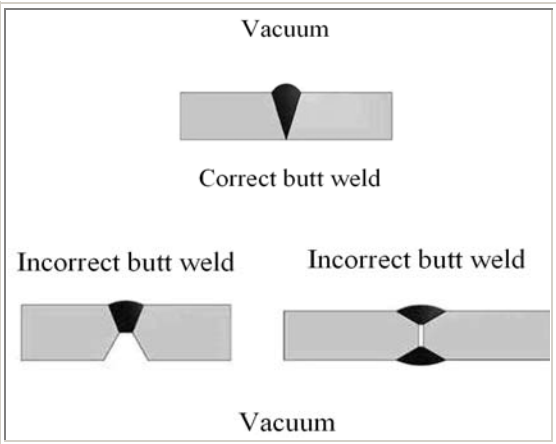

Fig. 2. Examples of the correct and incorrect butt weld joint's design for the vacuum chamber [9]

2.3 Methods

Different welding methods are used for stainless steel welding depending on the materials and customers' requirements: Plasma arc welding, Laser welding, Resistance welding, TIG welding, Electron beam welding etc. TIG welding and electron beam welding are the common welding processes for joining of the elements of vacuum chamber. The energy density of electron beam welding is much higher and leads to less chamber deformations compared to TIG welding. Usually all longitudinal vacuum chamber welds are done with electron beam. But cheaper and easier is TIG welding process: manual or automated orbital welding [10].

There are some common recommendations for welding of the elements of vacuum chamber:

- The high purity inert gas (*Ar* - Argon) should be used;
- *Ar* purging gas flow should be used until the part has cooled down to 60°C;
- All parts to be welded must be cleaned prior to welding. Any later brushing or other finish work on the welds is prohibited.

The vacuum chambers must be manufactured so as to have extremely low leak (the leak rate must be lower, for example, than 1.10^{-10} mbar.l/s) and outgassing rate and, due to the potential inconvenience of a failure in service, exhibit a high degree of reliability. These requirements mean that the welding processes must be correctly determined and then controlled during production [6]. So, it is obligatory, that the quality of the weld must be according to the ISO standard ISO 5817, quality level *B*: *Stringent*.

Taking into account mentioned issues the preliminary welding procedures specification (pWPS) was elaborated.

For example, the main TIG welding parameters for stainless steel X2CrNiMo17-12-2 (AISI 316L) welding in the case of butt joint (material thickness is 5,4 mm) are given in Table 2. The weld preparation details and welding sequence are given in Figure 3.

Welding parameters	**Conditions**
Shielding and backing gas	*Ar* (99.999%)
Arc current	80…100 A
Arc voltage	10…14 V
Ar purging gas flow: Shielding Backing	 10…14 l/min 8 …10 l/min
Post flow time	30 sec
Tungsten electrode	2,4 mm

Table 2. TIG welding parameters

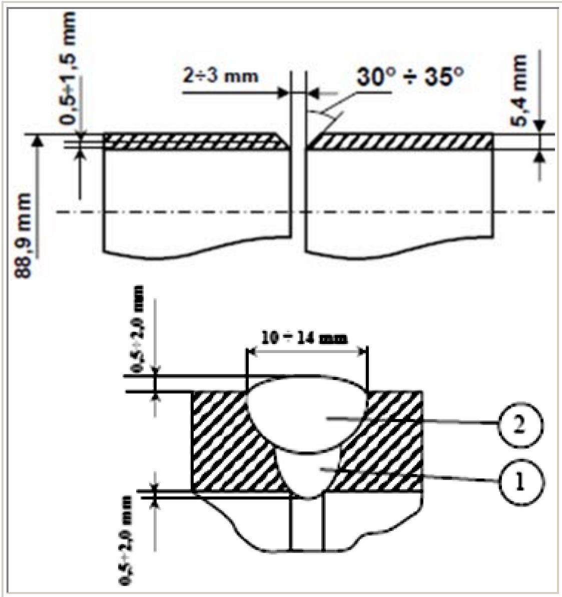

Fig. 3. Skecth of weld preparation details (joint design) and welding sequence of the pipe with outside ∅88.9 mm and thickness 5,4 mm TIG welding: 1 – 1st run, 2 – 2nd run

Filler metal was chosen on purpose of control of the amount of ferrite in the weld metal using Schaeffler-DeLong diagram. Predicted Ferrite Number (FN), using filler material LVS EN ISO 14343 –A-W 19 12 3 LSi was 7 FN (approx. 7% ferrite).

After welding the different types of testing we made: visual test, penetration test and measurement of Ferrite Number. The Ferrite Number after welding was measured using a Feritscope FMP30 (Helmut Fischer GmbH, Germany).

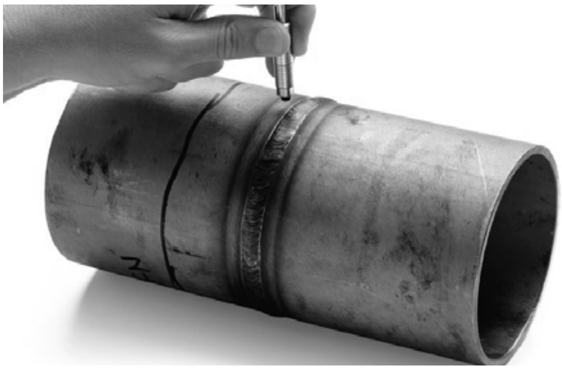

Fig. 3: Test setups for measurement of Ferrite Number using a Feritscope FMP30 [11]

The Feritscope FMP30 measures the ferrite content in austenitic and duplex steel according to the magnetic induction method: a magnetic field generated by a coil begins to interact with the magnetic portions of the specimen. The changes in the magnetic field induce a voltage proportional to the ferrite content in a second coil, which is then evaluated [11].

3. RESULTS AND DISCUSSION

Since the optimal conditions were used the high quality of welds was achieved. It is confirmed by results of visual and penetration testing. The view of welds is given in Figure 4, but penetration view of the weld is shown on the Figure 5.

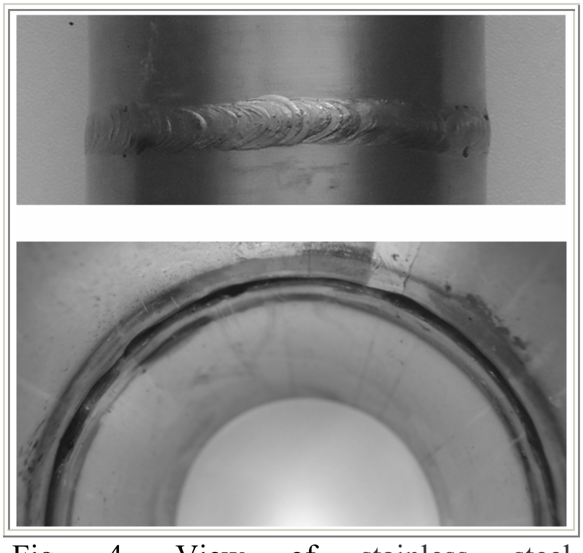

Fig. 4. View of stainless steel X2CrNiMo17-12-2 weld

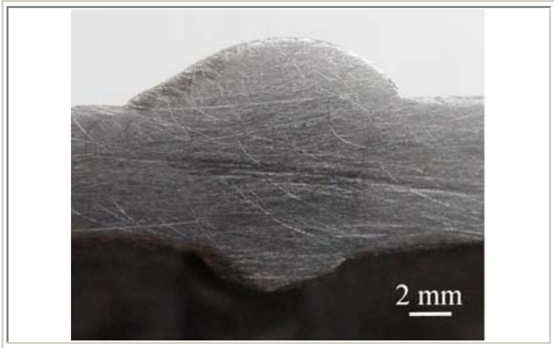

Fig. 5. Penetration view of stainless steel X2CrNiMo17-12-2 weld

It is shown that welds are of good performance full penetration. Ferrite Number measurements after welding are the follows (mean value): 8 FN.
Obtained value non-significantly differs from predicted FN. This difference can be explained by the fact, that using Feritscope FMP30 all magnetizable structure sections are measured i.e., in addition to δ-ferrite also strain-induced martensite, for example, or other ferritic phases [11].
It is well known that the δ-ferrite contents in the austenitic stainless steel welds should be controlled in the range of 3…12 vol.% to prevent hot cracking, reducing of corrosion resistance and weld metal toughness [12]. On the other hand in work [13] for the determination of the ferrite rate the method of measure of the relative magnetic permeability of the weld was used. It was revealed, that the increasing value of welds' relative permeability is due to an increasing in the rate of ferrite. Since an optimum condition can be attained for ferrite contents between 3 and 8 vol. % in the weld deposit [14], especially for vacuum components [15], which assure required low magnetic permeability, we can conclude, that stainless steel X2CrNiMo17-12-2 is the acceptable material for vacuum chamber elements to be welded.

4. CONCLUSION

A complete investigation from the choice of material of vacuum chamber, design of welds to test for the TIG welding of the elements of vacuum chamber has been performed. Elaborated preliminary welding procedure specification (pWPS) for stainless steel TIG welding has provided the high quality welds. It was proved that stainless steel X2CrNiMo17-12-2 (AISI 316L) is acceptable material for vacuum chamber with satisfying weldability and magnetic permeability after welding.

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6. AKNOWLEDGEMENTS

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STUDY OF PROPERTIES OF LEAD-FREE SOLDER TYPE Au-20Sn AT ULTRASOUND ASSISTANCE

Chachula M. & Koleňák R.

Abstract: *The main aim of this work was to determine the soldering, thermal and mechanical properties of joints fabricated by use of Au-20Sn solder.*

Soldered joints were fabricated by application of a flux-free process with assistance of power ultrasound. By acting of power ultrasound, the Au-20Sn solder wets the surface of Cu, Ag and Ni substrates. The contact wetting angle on all substrates varied within 1°≤α≤10° interval.

The melting point of solder was determined using of DSC analysis and soldering temperature was then selected.

The shear strength of soldered joints was determined. The highest shear strength (195 MPa) was observed on Cu substrate and the lowest (20 MPa) was observed on Ni substrate.

It is supposed that this solder may be a suitable substitution for Pb-5Sn solder for higher application temperatures.

Key words: lead- free solder, solderability, EDX analysis, shear strength.

1. INTRODUCTION

The work deals with the study of solders for higher application temperatures. The Sn-Pb alloys have been for a long time the most spread soldering material in electronic industry. However, owing to harmful effect of lead, to be mentioned also in the scientific work of a collective of authors [1], all these soldering materials are gradually substituted by the lead-free solders. But at applications where higher soldering temperature is required, there is still used the Pb-5Sn solder with a high lead content. Fortunately, also alternative soldering alloys exist, which compete with the lead solders by their properties. These may be based on precious metals as Au, but also on the basis of metals as Zn and Bi. The scientific work [2], has dealt with the study of Au and Bi based solders. The Au-20Sn and Bi-11Ag solders, with acceptable soldering temperature were considered for perspective ones. Thermodynamical properties of mentioned solders were studied in work [3].

Based on the results of above mentioned scientific works, but also regarding the other publications [4-7], the primary Au-Sn base was suggested for experiments. It was actually the Au-20Sn solder.

2. EXPERIMENT

2.1 Preparation of specimens

The studied material combination consisted of Cu, Ag and Ni metal substrates. The metal substrates were in the form of rings 15 mm in diameter and 1.5 mm in thickness. The Au-20Sn solder was manufactured by vacuum casting from the mentioned initial elements with 4N purity.

Soldered joints were fabricate by application of power ultrasound from ultrasonic generator type Hanuz UZP2 with an output power of 400 W/ 40 kHz. Description of this soldering equipment was published in work [8]. Ultrasonic soldering meets the requirements for soldering speed and quality of joint fabrication.

After fabrication, the soldered joints were cross cut for metallographic study and the cross sections were prepared by wet grinding.

2.2 Assessment of experiments

Since an experimentally prepared solder was used for soldering, it was necessary to determine the solidus and liquidus temperature. Due that reason the DSC analysis was performed. Based on the results of DSC analysis, the soldering temperature for fabrication of test specimens was suggested.

The transient intermetallic phases were studied on microscope Neophot 32.

Chemical microanalysis of boundary in soldered joints was carried out by EDX analysis. This is a part of electron scanning microscope type JEOL 7600F.

The shear strength was determined on LabTest 5.250SP1-VM equipment at room temperature. For the change in direction of force acting on specimen, a special shearing device was developed. This jig assures a uniform shear loading of specimen in the plane of solder and substrate boundary. The shear gap was selected to 0.1 mm, what corresponds to 2 % of the sheared cross section of the roller formed of solder. The uniform testing rate was 0.5 mm/min.

2.3 Properties of Au-20Sn solder

Eutectic solder Au-20Sn is suitable from the viewpoint of melting temperature, a good thermal and electric conductivity, a high tensile strength and a good wettability. The solder properties mentioned in publication are in Tab. 1 [9].

Tab. 1 Properties of Au-20Sn solder [9]

Melting point	280 °C
Soldering temperature	320 °C
Tensile strength	275 MPa
Density	14.51 g/cm^3
Coef. of therm. expansion	16.10^{-6} °C
Therm. conductivity	57 W/m.K
Specific therm. capacity	388 $J.kg^{-1} K^{-1}$
Young's modulus	68 GPa
Ductility	2 %
Electric resistance	16.10^{-8} Ω.m

3. RESULTS

3.1 DSC analysis

DSC analysis was performed in order to identify the melting point of Au-20Sn solder. Tab. 2 shows the results from DSC analysis measurement.

Tab. 2 The results of DSC measurement

Solder	Au-20Sn
Heating	10 K/min
Temperature range of measurement	22- 450 [°C]
Onset temperature	280.2 [°C]
Peak temperature	294.5 [°C]
End temperature	302.8 [°C]

Fig. 1 shows the DSC curve of Au-20Sn solder. The solder starts to melt at temperature 280.2 °C. The solder is fully molten at 302.8 °C.

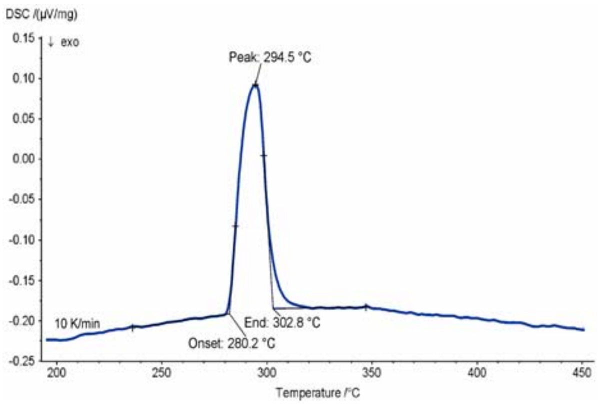

Fig. 1 DSC curve of Au-20Sn solder on heating 10K/min

3.2 EDX analysis of joints fabricated by Au-20Sn solder

The structure of Au-20Sn solder is formed of a eutectic mixture of Au_5Sn and AuSn phases. The lighter phase shown in Figs. 2 and 3 is Au_5Sn phase. EDX analysis has revealed approximate composition of this phase. The phase consist of 11.2 wt. % Sn and 88.8 wt. % Au. The dark phase shown in Figs. 2 and 3 is AuSn phase and consist of 38.4 wt. % Sn and 61.6 wt. % Au. The concentration profiles of Ag, Au, Sn elements determined by EDX analysis are documented in Fig. 2.

By interaction of Au-20Sn solder with the surface of Cu substrate (Fig. 3) a new combined (Au,Cu)Sn phase is formed, which assures the surface wetting by the solder.

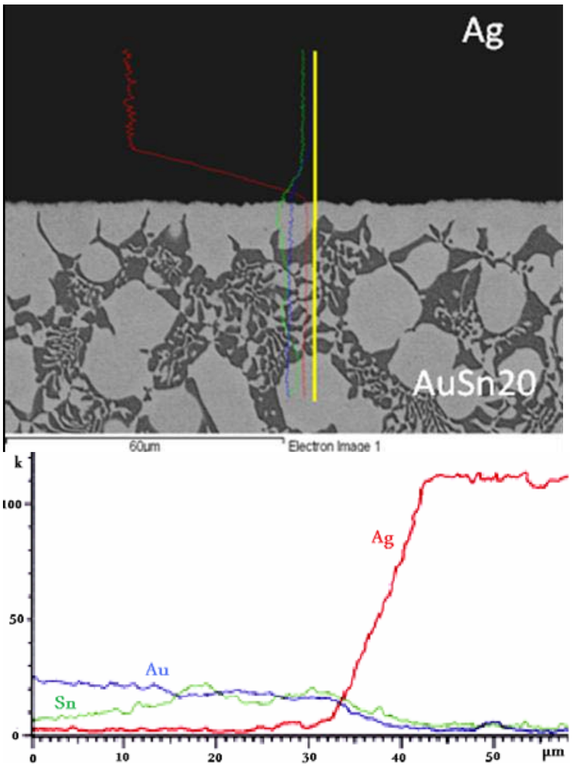

Fig. 2 EDX analysis of Au-20Sn/Ag joint

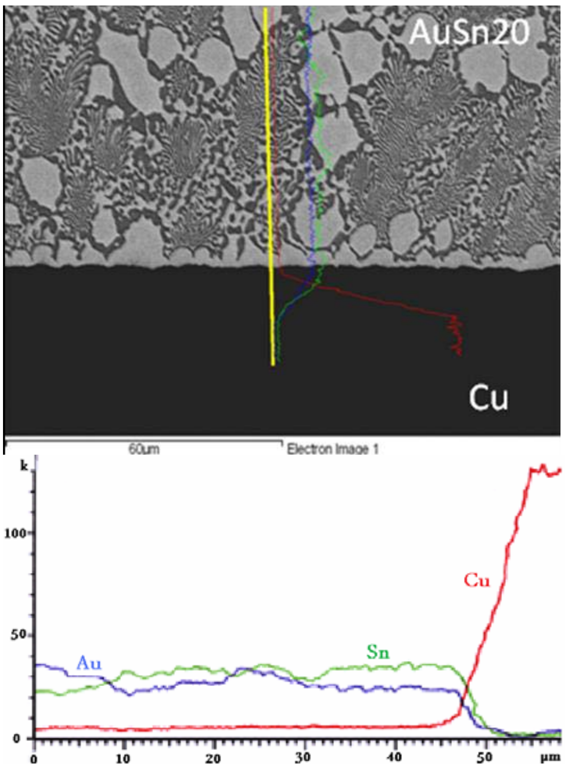

Fig. 3 EDX analysis of Au20-Sn/Cu joint

3.3 Measurement of shear strength of joints

Based on knowledge obtained from the DSC analysis, the test specimens for shear test were fabricated by assistance of power ultrasound. The results of shear strength achieved with Au-20Sn solder on Cu, Ag and Ni substrates are documented in Fig. 4.

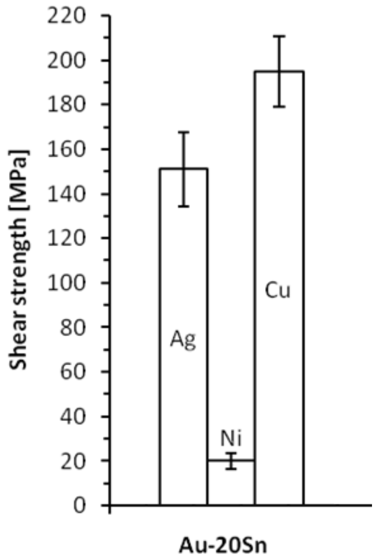

Fig. 4 Shear strength of joints

High shear strength was achieved with the joint fabricated by Au-20Sn solder on Cu substrate, namely up to 195 MPa. Lower value of shear strength, namely 151 MPa, was achieved on Ag substrate. The lowest value of shear strength was observed on Ni substrate, namely 20 MPa in average.

3.4 Fractographic analysis of soldered joints

The morphology was defined by fractographic analyses by use of SEM. Fracture morphology was investigated on the specimen fabricated on Cu substrate with ultrasound assistance. Ductile failure of specimen has occurred. Fig. 5 shows the fractured surface of Au-20Sn solder on intermetallic boundary. In Au-20Sn solder a tearing-off of metallic substrate was observed. The fracture was formed partially in the solder and partially in the Cu substrate.

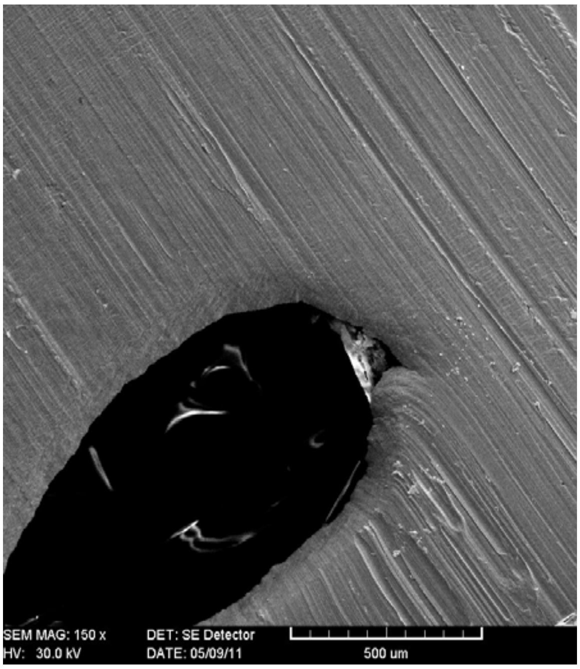

Fig. 5 Fractured surface of Au-20Sn solder with a partial tearing-off of Cu substrate.

4. CONCLUSIONS

The attained results have shown that interaction with joints occurred and surface wetting by Au-20Sn solder took place. The contact wetting angle at soldering with ultrasound attained the value below 10°. The boundaries of soldered joints were smooth and free from defects.

The melting point is very important at selection of a correct alternative substitution. The DSC analysis has proved that the experimental Au-20Sn solder had the melting point of 280.2 °C. This solder temperature approaches to the melting point of PbSn5 solder with a high lead content, which melting point is 298 °C.

The shear test of soldered joints has revealed that the highest shear strength up to 195 MPa was achieved with the joint of Au-20Sn solder on Cu substrate.

The Au-20Sn solder is a suitable substitution for the lead solder type Pb-5Sn for higher application temperatures. However, rather high price of this solder seems to be a certain disadvantage in practical applications.

5. ACKNOWLEDGEMENTS

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Abrasive impact wear of WC-Co and TiC-NiMo cermets

Juhani, K.; Pirso, J.; Viljus, M.; Letunovitš, S.; Tarraste, M.

Abstract: *Present paper is focused on abrasive impact wear of tungsten and titanium carbide based cermets with different binder contents. A series of samples of different cermets was tested in experimental impact wear tester DESI using different amounts of granite abrasive to study the wear kinetics. The wear resistance of TiC–NiMo and WC-Co cermets was compared. The volume wear of the cermets decreases with the increase of carbide content in the composites, which corresponds to an increase in the bulk hardness. The volume abrasive impact wear of the cermets increases approximately linearly with the increase in abrasive content. The wear tracks of the worn compositions were analysed by scanning electron microscopy (SEM) to study the abrasive impact wear mechanism.*

Key words: WC-Co, TiC-NiMo, abrasive impact wear, wear mechanism

1. INTRODUCTION

WC–Co hardmetals are materials well known for their high wear resistance [1–4]. They are used in metal cutting and rock drilling tools and wear parts in various applications.

TiC-based cermets also show high abrasive wear resistance [5–8]. They offer an attractive combination of high wear resistance and specific mechanical properties, such as strength/density, because of their relatively low density. They show a great potential as a substitute for the commonly used WC–Co-based hardmetals.

The impact wear behaviour of different materials and coatings is investigated in [9 – 11]. The abrasive impact wear of chromium carbide based cermets is investigated in [12]. In impact wear conditions multiphase materials exhibited the optimal wear resistance. Multiphase materials as cermets combined softer matrix dispersed with extremely hard grains.

The aim of present paper is to investigate the abrasive impact wear properties of WC-Co and TiC-NiMo cermets with different binder contents and to clarify the abrasive impact wear mechanism.

2. MATERIALS AND EXPERIMENTAL DETAILS

All investigated cermets were produced in Tallinn University of Technology with conventional powder metallurgy technique, i.e. form pressing followed by sintering, using optimal sintering parameters. In Fig. 1 is shown the typical microstructures of tested materials.

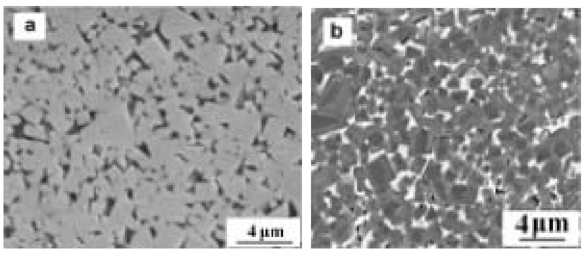

Fig.1. Microstructure of WC-15%Co (a) and TiC-20%NiMo (NiMo 4:1) (b) cermets

The binder content of tested WC-Co cermets was 6, 10, 15 and 20 wt% Co; TiC-NiMo cermets were with binder contents 20, 30, 40, 50 and 60 wt% NiMo. The calculated (initial before sintering) weight ratio of Ni:Mo in the binder of TiC-NiMo cermets took a value of 1:1, 2:1 and 4:1. Mean carbide grain size for WC–Co and TiC–NiMo cermets was 0.9 . . . 2.2 μm. Additionally coarse grained WC-20%Co with mean grain size 7.4 μm was tested. The chemical composition, density and hardness of investigated materials is exhibited in table 1.

Table 1. Chemical composition, density and hardness of investigated materials

WC	TiC	Co	Ni	Density	Hardness
		wt%	wt%	ρ, g/cm^3	HV_{10}
94		6		14,8	1974
90		10		14,4	1521
85		15		13,9	1303
80		20		13,4	1189
80		20K*		13,4	806
	80		16	5,47	1400
	80		13	5,5	1515
	80		10	5,54	1650
	70		24	5,74	1300
	70		20	5,77	1415
	70		15	5,68	1590
	60		32	6,04	1170
	60		26	6,02	1270
	60		20	6,03	1360
	50		40	6,4	990
	50		34	6,42	1150
	50		25	6,54	1340
	40		48	6,5	810
	40		40	6,54	950
	40		30	6,62	1180

20K* – coarse grained WC-20%Co

Impact wear tests were carried out in experimental impact wear tester DESI, described in [13]. Principal scheme of impact wear tester is exhibited in Fig.2. 15 kg of granite abrasive was used in tests; the granite abrasive fraction was 4–5 mm. the hardness of granite abrasive is approximately 1075HV. To investigate the wear kinetics, tests with abrasive contents 3, 6, 9, 12 and 15 kg were carried out. The tests were carried out at the velocity of about 60 m/s and the estimated impact angles were about 90°. The blocks were finished to a surface roughness of about 1 μm prior to each test. Each specimen was weighed before and after testing with an accuracy of 0.1 mg. Weight loss was converted into the volumetric wear rate. The worn surfaces were observed with scanning electron microscope JEOL JSM 840A to investigate the impact wear mechanism.

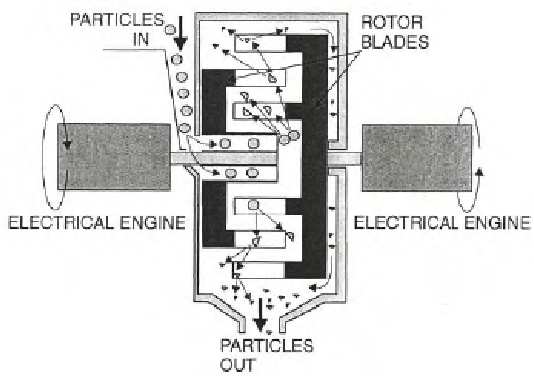

Fig.2. Principal scheme of impact wear test device [13]

3. RESULTS AND DISCUSSION

3.1. Wear Rate

In Fig.3 is exhibited the volume loss of WC-Co cermets depending on binder content. Volume loss increases in increase of binder content, due to the decrease of the bulk hardness of materials. The coarse grained WC-20%Co material exhibits higher wear rate compared to fine grained material, coarse grained WC-20%Co has lower hardness compared with fine grained material and although in case of coarse grained materials the brittle cracking of coarser carbide grains takes place during wear process.

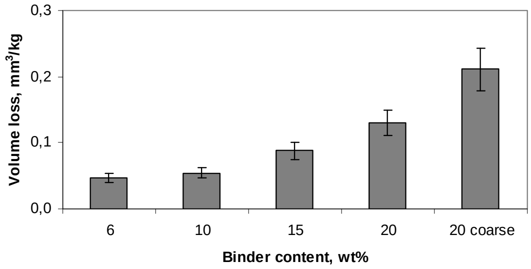

Fig.3. Volume loss of WC-Co cermets vs. binder content

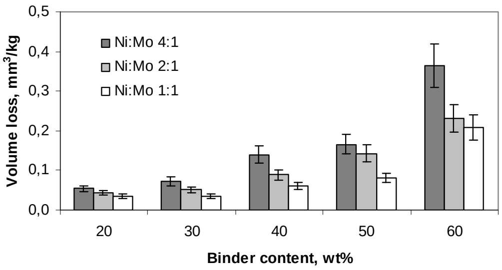

Fig.4. Volume loss of TiC-NiMo cermets vs. binder content and Ni:Mo ratio

In Fig.4 is shown the volume loss of TiC-NiMo cermets depending on binder content and Ni:Mo ratio. The volume loss depends on binder content, when binder content increase the volume wear although increase, materials with higher amount of molybdenum in microstructure exhibit higher wear resistance due to the higher bulk hardness.

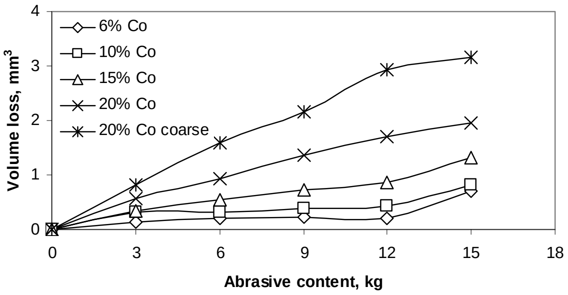

Fig.5. Volume loss of WC-Co cermets depending on binder content and the amount of abrasive used in test

The volume loss of WC-Co cermets in case of higher binder content increases approximately linearly depending on increase in the amount of abrasive (Fig.5). In case of lower binder contents the volume loss at first stays stabile and increase rapidly after 12 kg of abrasive used in test.

In case of TiC-NiMo cermets the volume loss increase approximately linearly for all tested carbide grades (Fig.6).

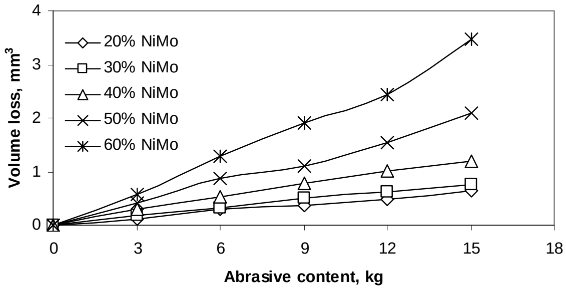

Fig.6. Volume loss of TiC-NiMo (NiMo: 2:1) cermets depending on binder content and the amount of abrasive used in test

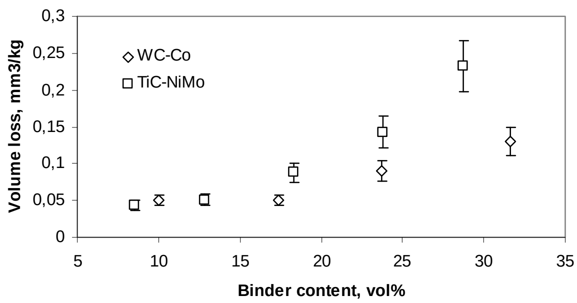

Fig.7. Volume loss of WC-Co and TiC-NiMo (Ni:Mo 2:1) cermets depending on binder content (vol%)

In Fig.7 is compared the volume loss of WC-Co and TiC-NiMo (Ni:Mo 2:1) cermets; the binder content is calculated into volume percentage to compare materials with similar binder contents. In case of lower binder contents the volume loss of different type of cermets is comparable, when binder content increases WC-Co cermets exhibited higher

wear resistance compared to TiC-NiMo cermets, due to their higher hardness.
As seen in Fig.8 the volume loss of investigated materials depends on the bulk hardness of the composites, the volume loss decreases with the increase of the bulk hardness of tested cermets.

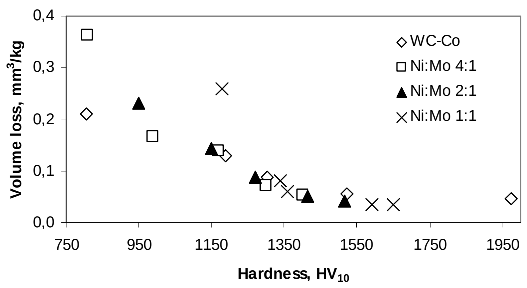

Fig.8. Volume loss vs. bulk hardness of the tested carbide grades

3.2. Wear Mechanism

The wear mechanism of investigated materials was studied by analysing SEM images of worn surfaces. Worn surface of investigated materials are exhibited in Fig.9 and Fig.10. Surface of the material is covered with tracks, where the abrasive particles have hit the material, abrasive material penetrate into the material, deform plastically the binder phase and at the same time crush carbide grains and carbide network. Carbide network is crushed; some of the carbide grains are fractured or removed from the surface (Fig.9 b,d; Fig.10 b,d). In case of WC-Co cermets with lower binder content the plastic deformation of binder content is not obvious, the dominant wear mechanism is the crushing of carbide grains and carbide network (Fig.9 a,b). Some of the granite abrasive is crushed during wear process and the granite dust is formed, it damages the material surface locally. The wear mechanism of TiC-NiMo cermets is similar for low and high binder content materials (figure 10), consisting of the plastic deformation of the binder phase and crushing and removing of carbide network and carbide grains.

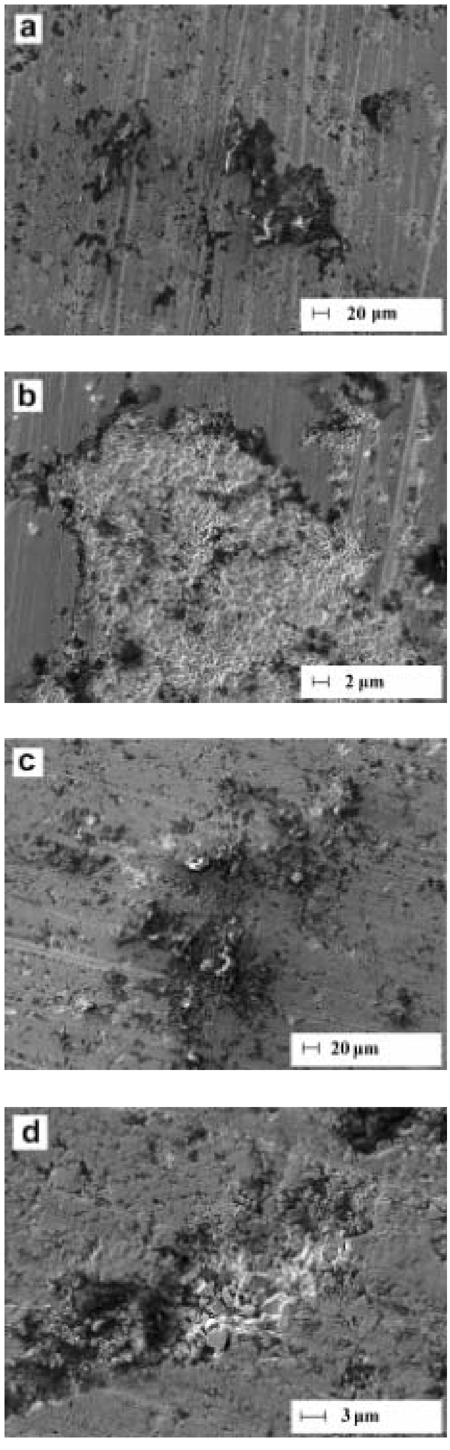

Fig.9. Abrasive impact wear mechanism of WC-Co cermets
a, b – WC-5%Co; c.d – WC-15%Co

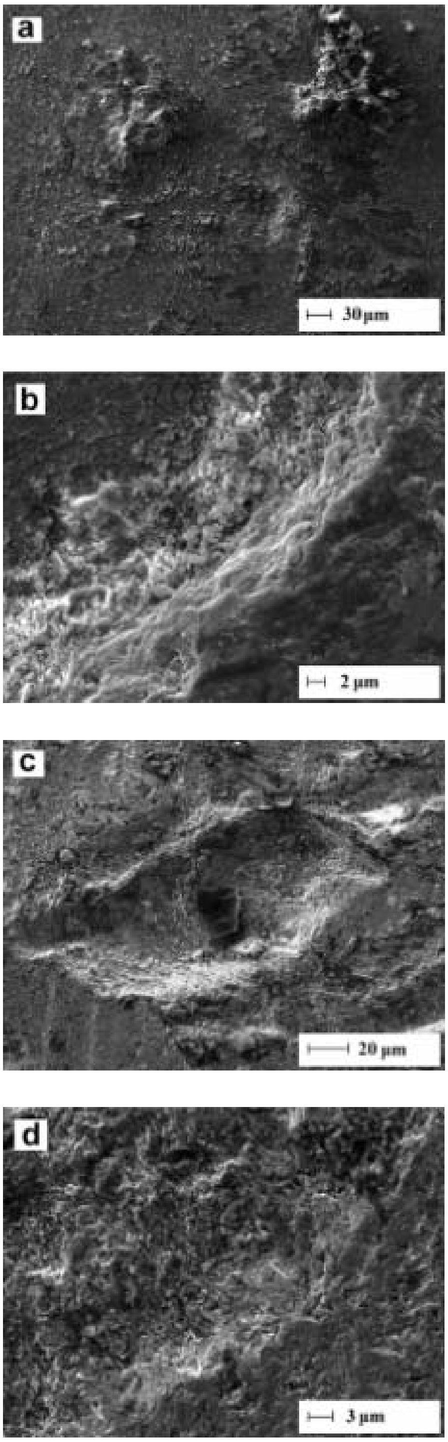

Fig.10. Abrasive impact wear mechanism of TiC-NiMo cermets
a,b – TiC-20%NiMo; c,d – TiC60%NiMo

CONCLUSIONS

1. The abrasive impact wear properties of WC-Co and TiC-NiMo were investigated;
2. Abrasive impact wear resistance of investigated cermets depend on the bulk hardness of material for both types of cermets; materials with lower binder content with higher hardness exhibited higher wear resistance compared to materials with higher binder content;
3. Coarse grained WC-Co composites exhibited lower wear resistance compared to fine grained materials;
4. Abrasive impact wear resistance of TiC-NiMo cermets depends also on NiMo ratio; higher wear resistance exhibited materials with higher molybdenum content due to their higher hardness;
5. The wear mechanism of investigated materials consisted of plastic deformation of binder phase and brittle cracking of carbide grains and carbide network; in case of WC-Co materials with lower binder content the brittle cracking of carbide grains are the dominant wear reason.

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DEVELOPMENT OF EMULSION AND IMPREGNATION TECHNOLOGY FOR WOOD BIOPROTECTION

T. Kaps, R. Reiska , U. Kallavus, Ü. Luga & J. Kers

Abstract: *The timber used in impregnation and leachability experiments was vacuum dried pinewood (Pinus silvestris). Impregnating emulsion joins the benefits of both water solutions and oil.*
The new impregnation emulsion was tested against the emulsion prepared from widely used "Tanalith E" wood preservative.
The obtained results demonstrated that a new penetration agent ensures effective protection against wood rotting fungi and discolouring fungi. Bio testing at Latvian State Institute of Wood Chemistry (EN113) revealed that a new penetration agent ensures effective protection against wood rotting fungi (mass loss less than 3%) and discolouring fungi (mould). Key words: Pine-wood, rapeseed oil-based wood preservatives, protection against wood rotting

1. INTRODUCTION

Pinewood is most common material to be used in building and construction as well in furniture industry. For use in outdoor conditions it is important to protect pinewood against rotting fungi.
When impregnated wood is exposed to surface water during its service life, toxic substances in wood preservatives like chromium and arsenic can leach and harm the environment [[1]]. After the use of chromium and arsenic containing preservatives (CCA) was restricted due to environmental concerns, other systems were introduced. Nonbiocidal techniques for wood protection have become more and more important in the last few years. One of the possible treatments to enhance wood durability is use of water repellents [[2]].
Former studies show that CCA bounds copper most effectively and the element is not that strongly bound in other preservatives [[2-3]]. Solutions of Wolmanit CX-8 and Tanalith were used for impregnation procedure [[4]].
Therefore copper consisting protecting agents are under observation as well.
Some alternative preservative systems for pine wood are developed in papers [[5]].
In water environment inorganic constituent chemicals diffuse into wood cell wall regions and protect wood against aggressive decay. Drying vegetable oil – in this case rapeseed oil – forms on the internal surfaces of wood cell and inside microcapillaries hydrophobic polymerised film what decreases the washing-out of active ingredients.
To compare the impregnation results of rapeseed oil and boron based emulsion, the commonly used copper consisting water-based impregnation solutions Tanalith-E was used.
Leaching is influenced by the conditions where the wood is placed into, water pH and flow, also by site, species and preservatives, extractive content in wood etc. [[6-7]]. The leaching of boron from spruce wood impregnated with preservative solutions based on boric acid can be significantly reduced [[8]].
The main objective of the current research work was to develop new environmentally friendly impregnation emulsion for effective protection of pine wood against rotting fungi. The new impregnation emulsion was tested against the emulsion

prepared from widely used “Tanalith E” wood preservative.

2. EXPERIMENTAL STUDY

2.1 Material

The round wood and sawn timber of Scots pine (*Pinus silvestris*) were selected for impregnation experiments. The samples of pine roundwood stem were with outside dimensions 1000mm in length and about 200 mm of diameter

The density of used Estonian pinewood was in the range of 410...480 kg/m^3 and about 5…8 rings per 1cm.

To prevent the liquid flow in the longitudinal direction, cross sections of the samples were sealed with nitrolaquer.

To ensure the more effective penetration of impregnation agent the vacuum drying process was used.

After vacuum drying the resin canals in pinewood are easier permeable compared to other drying methods.

2.2 Development of emulsion

The developed impregnating emulsion is based on rapeseed oil in water emulsion. The optimal concentration of rapeseed oil in water emulsion was determined experimentally.

Active ingredients for emulsion were chosen among Boron compounds – borax, boric acid and quaternary ammonium salts QUATS (here dioctylmethyl ammonium chloride). Boron compounds ensure the potential bio protection against wood rotting fungi and QUATS against discolouring fungi.

To stabilize the emulsion oleic acid and the by-product of the rapeseed oil production (partially de-esterificated rapeseed oil, so-called acid oil) was used.

Emulsification was carried out in a TUT developed specific pulsating emulsifier apparatus. During the emulsion preparation experiments two pulse frequencies of 900 and 1800 Hz were used. The viscosity and stability of emulsions were analysed.

2.3 Impregnation technology

For wood impregnation two main types of technological processes are in use non-pressure and – pressure based processes. In non-pressure based passive-impregnation methods the preservatives are applied by means of brushing or spraying, dipping, soaking, steeping or by means of hot and cold bath [8]. The most common wood protection processes are based on treatments in closed cylindrical vessels, where deeper and more uniform penetration and a higher absorption of preservative can be achieved by applied vacuum or pressure conditions [9].

To perform the impregnation tests with rapeseed oil based emulsion and Tanalith E new autoclave with 1m^3 capacity and 16 bar maximum pressure was designed and built in laboratory of TUT Woodworking Chair (see Fig. 3).

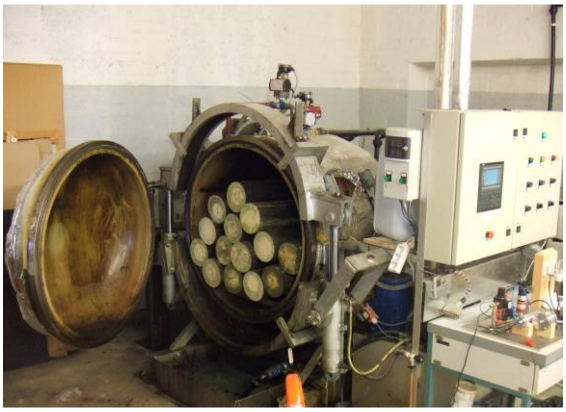

Fig. 3. Autoclave used in pinewood impregnation process

In impregnation experiments the water-based pressure impregnation treatment in pressure autoclave was used.

2.4 Leaching test

To assess leachability of emulsions two methods were worked out M1 and M2. Method M1 is based on analyzing copper and boron content after 24h leaching in 20-22 °C water. Firstly, the specimens were cut from impregnated roundwood in radial direction with dimensions 40x25x25 mm. Then the specimens were dried and all sections were covered with polyvinyl acetate glue, only outside tangential surface was not covered. Then the specimens were soaked in 20-22 °C water about 24 hours.

Leaching method M2 was based on imitation of rainy conditions to the impregnated wood. The specimens were cut from impregnated roundwood in stem direction with dimensions 60x30x30 mm. Then the specimens were dried and all sections were covered with polyvinyl acetate glue, only outside tangential surface was not covered. Then the specimens were tested under burette with 100ml water and test speed was about 8-12 drops per minute. The content of copper and boron was analyzed in collected leaching water. The copper content in leaching water was analyzed by atomic absorption spectroscopy (AAS).

The boron content in leached-out water was analysed via ICP (Inductively Coupled Plasma) technique.

2.5 Decay test

Bio testing was performed in Latvian State Institute of Wood Chemistry according to standard EN 113. Scots pine (*Pinus sylvestris* L.) sapwood blocks (25 × 25 × 50 mm) were cut out from impregnated sapwood. Wood specimens were sterilized and conditioned. The specimens were exposed to fungi according to the EN113 (1996) using brown-rot fungies *Coniophora puteana, Gleophyllum trabeum, Poria Placenta.*

3. RESULTS AND DISCUSSION

3.1 Developed emulsion

Emulsification technology tests were made with pulsating emulsifier with two different frequencies 900, 1800 Hz (see Table 1). Change of pulsating frequencies did not change the viscosity remarkably and after repetition of emulsification experiments particles size was still in the same range and emulsion stability was good (see Figs 1 and 2). Obtained emulsion is stable for 24 hours but for the assurance of higher dispersion rate of the emulsion it is advisable to use emulsion during first 8 hours. Working emulsion is reusable in impregnation process.

Emul-sion mark	Emulsi-fication technology	Properties of emulsion	
	Pulsation frequency, Hz	Particles size, µm	Visco-sity, s
T24	900	2-4	11.8
	1800	3-4	11.7
T27	900	3-4	11.5
	1800	2-5	11.6
U25	900	2-3	11.0
	1800	2-4	11.1

Table 1. Properties of emulsions

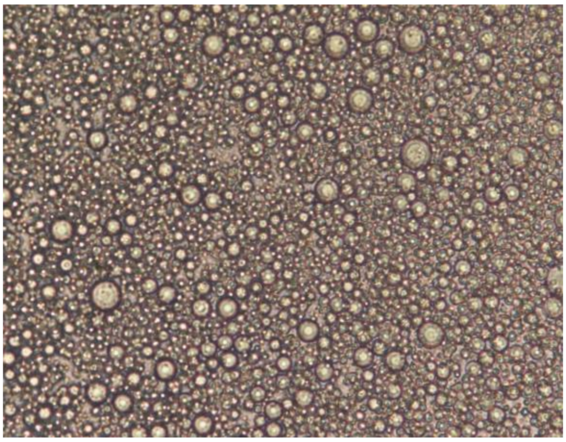

Fig. 1. Emulsion U25 2%, Boron-compounds, Rapeseed oil 3%, Acid oil 3%

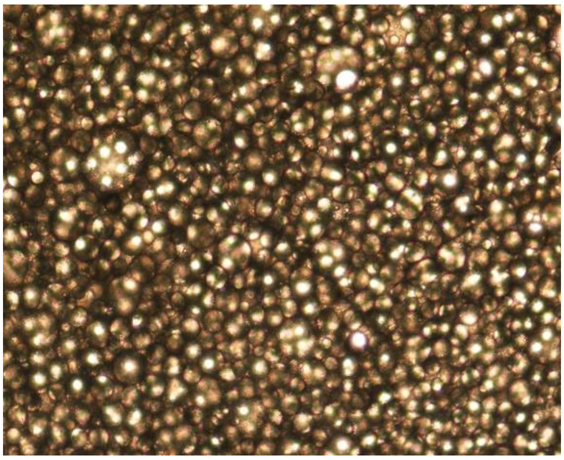

Fig. 2. Emulsion T27: Tanalith E 2%, Rapeseed oil 3%, Acid oil 3%.

3.2 Developed impregnation technology

The impregnating agent was carried in the wood in one technological step. The developed technological regime for the penetration was as following:

- preliminary vacuum treatment at 100 mbar for 0.5 hours;
- pressure impregnation at 12.5 bar for 1 hour;
- final vacuum treatment was executed 100 mbar for 0.5 hours.

To evaluate the penetration efficiency absorption rate of the agent (standard load 200 kg/m^3), average depth of penetration, leaching-out of active components and bio resistivity was carried out.

After the impregnation tests the colour characteristics of a wood impregnated with new agent are similar to those of untreated wood (see Figs 4-5).
To compare the leaching test results with aqueous solutions and emulsions, the leach ability of active agent reduced for Tanalith E based emulsions about 2.3 times and for emulsion with rapeseed oil and boron-compounds about 1.7 times.
Washing–out of active components in the rapeseed oil based penetration agent with minimal oil content (2%) is 1.5 times less than with water solutions (see Table 2).
The absorption of emulsion in pine sapwood was in similar range with oil based and water based emulsions.

Emulsion marking	Wood properties			Impregnation test results				
	Density kg/m^3	Rings no/cm	Humidity %	Absorb-tion of emulsion kg/m^3	Average impreg - nation depth mm	Stat. deviation Δmm	Leach ability. Cu or B*, mg M1	M2
T24	448	6	27.2	223	23	15	18.5	4.8
T27	427	5.5	26.3	215	22	16	17.3	4.5
TVL	448	6	28.0	260	24	14	30.3	13.2
U25	455	7	29.0	208	22	12	200*	28*
UVL	455	7	29.5	236	22	15	352*	47*

Table 2. Results of the impregnation tests

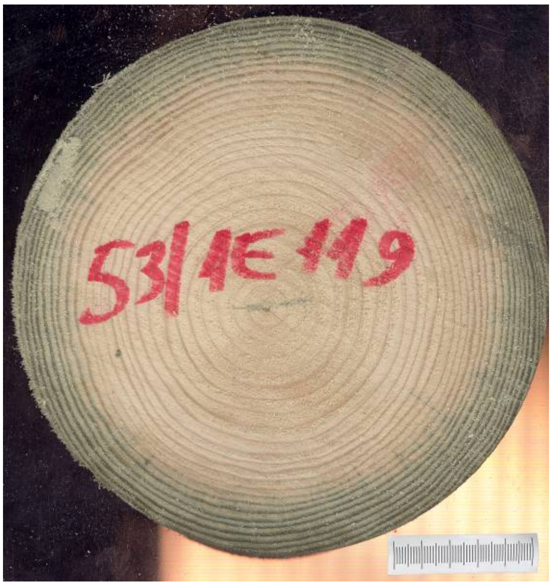

Fig. 4. Results of impregnation tests of pine roundwood with Tanalith-E agent

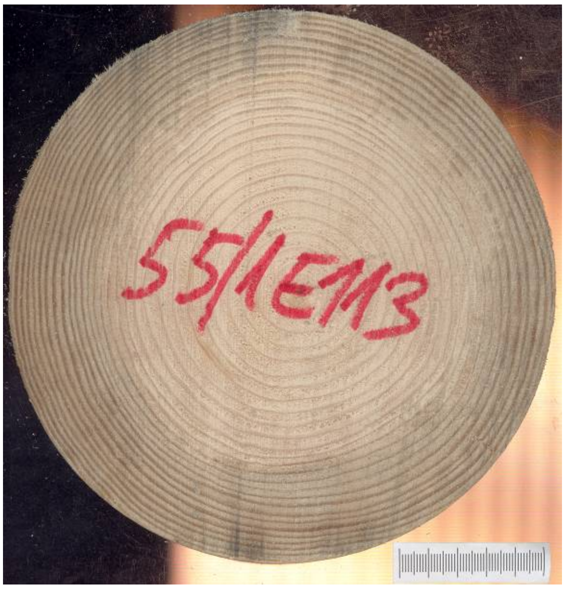

Fig. 5. Results of impregnation tests of pine roundwood with Rape-seed oil based emulsion

In impregnation tests two additional emulsions (TVL – Tanalith E aqueous solution and UVL – Aqueous solution of boron compounds) were compared with developed oil in water emulsions.

The best absorption results gave oil in water emulsion where the maximum concentration of the rapeseed oil concentration was 4 % of the emulsion. In the case of higher concentrations of oil the permeability of the sapwood decreased even when the effect of hydrophobisation was increased. The results of impregnation process showed that the sawn timber of pinewood could be penetrated more effectively than that of pine roundwood. This effect is explained with the greater specific surface area of sawn timber. Used impregnation regime allows penetrating sapwood up to 95-100%

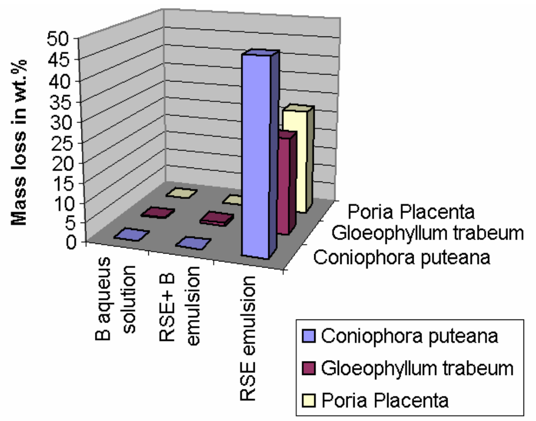

Fig. 6. Mass loss of different treated and untreated wood samples

4. CONCLUSION

Effective rapeseed oil and boron-compounds based emulsion was worked out.

Leachability of active components in the penetration agent with minimal oil content (2%) is 1.5 times less than with only water based solutions. With increasing the oil content in emulsion composition it can be presumed that leachability of wood preservatives decreases even more.

The obtained results demonstrated that the new penetration emulsion ensures effective protection against wood rotting fungi and discolouring fungi (see Fig. 6). The most effective emulsion against wood rotting fungi penetration agent had the composition of 3.5% boron compounds, 2% rapeseed oil, 2% acid oil. Mass-loss caused by fungal decay was after leaching less than 3% (according to EN113).

On the basis of this scientific research an utility model ”Method of preservation of pinewood”has been received (EE0068641).

5. ACKNOWLEDGEMENTS

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ADHESION MEASURING METHOD OPTIMIZATION IN REINFORCED COMPOSITES

Karjust, K.; Pohlak, M. & Majak, J.

Abstract: *The objective of the current study is to analyze and modify the adhesion processes between the glass-fiber reinforcement layer and acrylic sheet and to find out the optimal adhesion measuring methods depending on the bending strength, reinforcement layer concentrations and plastic composite material parameters (dimensions, wall angles, edge radiuses and connection methods). The experimental tests with different glass-fiber reinforcement concentrations, testing part design and acrylic material heating temperatures have been performed. Different well known methods have been analyzed for finding out the optimal adhesion measuring method. For optimal selection of the adhesion measuring process and the adhesion area the optimization model has been proposed. There have been tried to find out the max Tensile Force, optimal adhesion area and testing part design to minimize acrylic sheet brokering. The Finite Element Analysis simulation has performed with optimal adhesion area values to verify the prediction accuracy of a surrogate model.*
Keywords: adhesion processes, large composite plastic products, glass-fiber reinforced composites, finite element analysis.

1. INTRODUCTION

The increasing competitiveness in markets highlights the importance of rapid product development, high quality products, productivity, optimal price levels, multi-company collaboration and predictability. The manufacturers have to update and improve their product development, production process and product quality to maintain their places in the market. To improve their ability to innovate, get products to the market faster than the competitors and reduce errors [1,2].

In different industries like whirlpool, aerospace, plastic boat, composite barrel and car body component building industries the final product quality depends on the composite plastic parts. In those fields the large composite plastic parts are visible and because of that they will determine the final product sales success in large extent [3,4].

There have been analyzed a large composite plastic bathtub (dimensions 2300 mm in length, 900 mm in width and 800 mm in depth). The production of the bathtub has been made in two main stages. The first stage is vacuum forming of the inner shell acrylite FF0013 Plexiglas. The second stage is applying the reinforcement layer to the vacuum formed shell. The reinforcement consists of polyester resin with randomly oriented short glass fibers. Concentration of curing agent Methyl Ethyl Ketone Peroxide (MEKP) 0.8%, the epoxy resin 64.1% and glass-fiber 35.1%. There was developed a surrogate model consisting of finite element method (FEM) and artificial neural network (ANN) to find out the optimal wall thickness distribution for a thermoformed and glass-fiber polyester reinforced part [5,6,7].

There could be some abnormalities in the reinforcement process, depending on the weak adhesion between the reinforcement layer and the acrylic sheet. There could be some open spaces between those two layers depending on the vacuum forming temperatures, product parameters (wall angle, edge radiuses, etc), reinforcement layer concentrations, material thicknesses, glass-fiber orientations and concentrations [8,9]. Some samples of the weak adhesion are brought out in Fig. 1 and Fig. 2.

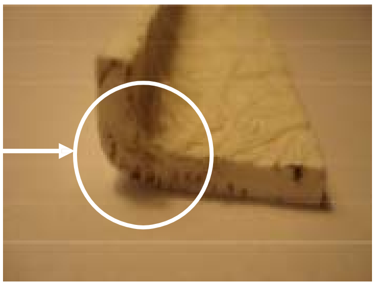


Fig. 1. The sample of the open space in corner

Because of the weak adhesion between two layers there could be defects in final products. In Fig. 3. is brought out defective bathtub. After cleaning the bathtub acrylics sheet broke down, because there were open space between two material layers.

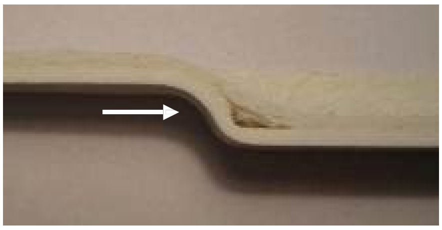


Fig.2. The sample of the weak adhesion

To avoid those issues brought out in Fig.1-Fig.3. it is very important that we can manage the adhesions processes between different composite layers. Thus it is important to find out suitable adhesion measuring method.

Fig.3. Broken bathtub

2. ADHESION MEASURING METHOD OPTIMIZATION

Different adhesion measuring methods can be divided into two categories: destructive and nondestructive. More is used destructive class, where a loading force is applied to the coating in some specified manner and the resulting damage is subsequently observed. Nondestructive methods typically apply a pulse of energy to the coating system and then try to identify a specific portion of the energy that can be assigned to losses occurring because of mechanisms operating only at the interface. In destructive test class there are many different types of well known test methods like tensile test, peel test, tape peel test, indentation bonding test, self loading test, scratch test, blister test, beam bending test etc [10,11].

To find out optimal adhesion measuring method we have to analyze different well known methods and find out the effective one. After the analysis of different methods tensile testing was selected. The main issue was to find out the optimal design of the test part, optimal thickness for the glass-fiber reinforcement layer, optimal adhesion area and to avoid additional bending strengths and stresses to get the reliable results.

In the beginning we tried to find out the optimal test part design and adhesion area, depending on the materials conditions and parameters. The selection of the adhesion area parameters are crucial. Firstly when the area is too big, then the acrylic material will break down and we can’t measure the correct force. Secondly when the area is too small then glass-fiber reinforcement layer will be removed too quickly and we will measure too low force and wrong adhesion. Because of that it is important to find out the optimal adhesion area to get the reliable measurement data. There have been simulated and tested different shapes of test parts [12] and some of the samples are brought out in Fig.4.

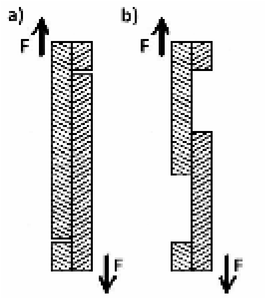


Fig. 4. The samples of the test part

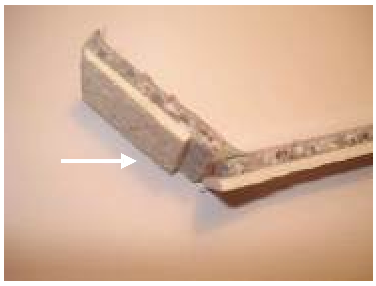


Fig. 5. The acrylic material break down

There have been milled two grooves into the acrylic sheet and reinforcement layer to separate those two layers. Several tests have been made, but the result was the same – acrylic material broke down. This was caused by too strong connection, too large adhesion area and properties of the materials. Some samples of the test results are brought out in Fig.5.

To optimize the adhesion area and testing part design the optimization model has been developed using FEM software HyperWorks. The optimal adhesion area has been determined and the results were validated against experimental test to control the reliability of the existing model. The first step of the tensile strength FEM simulation is shown in Fig.6 (the stress parameters are given in MPa).

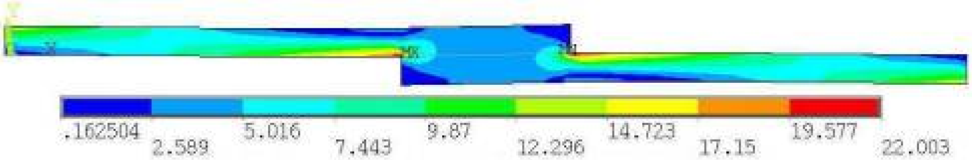
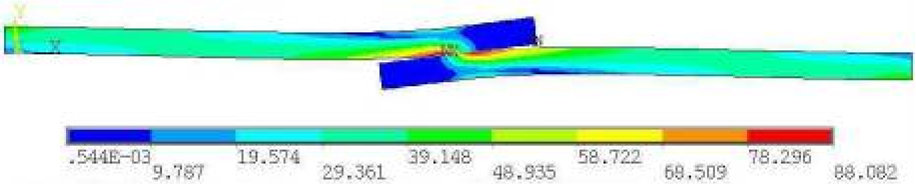
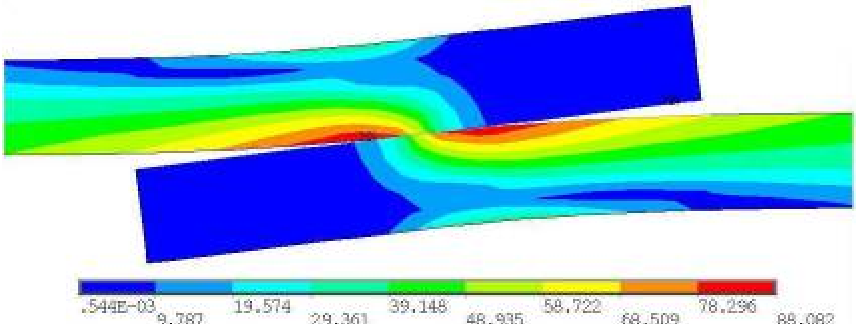


Fig. 6. First step of the loading (equivalent stress plot)



(a)



(b)

Fig.7. Final step of the equivalent stress plot (a) and detailed view (b).

The final step in tensile test (a) and more detailed view (b) of the equivalent stress plot is shown in the Fig. 7. This was the final step, when the tensile test continued then in the next step the materials were disjointed completely. Modified testing part is brought out in Fig.8.

In the FEM optimization there was found out the critical bending stresses during the test process. To avoid the additional bending different test part design and connection methods were developed.

Fig. 8. Modified testing part

In Fig. 9 are brought out some types of the testing parts. Streaked details are additional supporting bars, which help to avoid the additional bending. To test the reliability of the testing part with additional bars different FEM simulations were done. In Fig. 10 is brought out the deformation plot in the final stage with mm. In Fig.11. is brought out removed parts after the test.

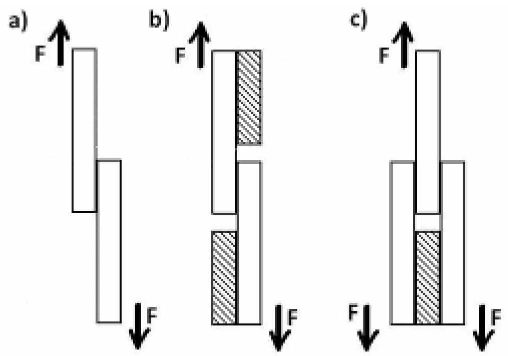


Fig. 9. Different design of the testing part

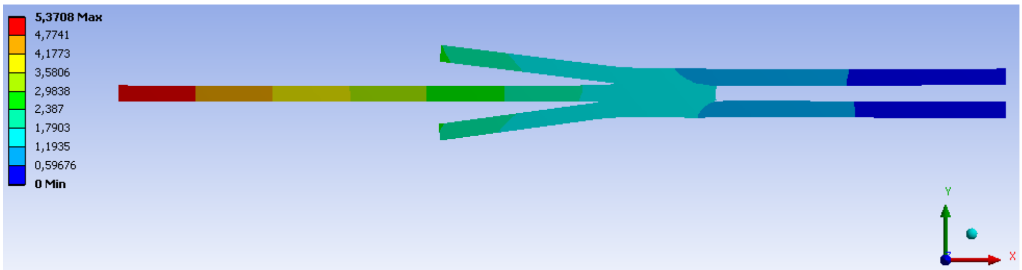


Fig. 10. Deformations in the final stage

Fig. 11. Removed parts after test

3. ANALYSIS OF MEASUREMENT RESULTS

For measuring the glass-fiber reinforcement layer and the acrylic sheet adhesion lot of different experimental tests have been done. The ratio of the polyester resin and fibers is kept constant, but the concentration of Methyl Ethyl Ketone Peroxide (MEKP) is varied from 0.8% up to 2%. Evidently, the ratio of the polyester resin and MEKP has significant influence on curing time and also on mechanical properties (e.g. modulus of elasticity, tensile strength) of the composite [12]. There were also varied the glass-fiber concentration and lengths in the reinforcement layer and tested three different group (in group A length of the glass-fiber is 5 mm, B – 10 mm and C- 15 mm) also similar concentration change between the groups) of tested parts. Some results of the measurements are brought out in Table 1 and Fig.12. In Fig. 13 is brought out summarized Max Force in three group.

In Table 1 and Fig. 12 are brought out some sample results of the experimental tests. Those test are made with three groups of materials (A, B and C), which are different of the glass-fiber concentrations and length. Values which are brought out are the mean values of the different tested groups. There were also made different test wher varied: the MEKP concentration, acrylic material was heated or not, reinforcement layer with and without of the glass-fibers, reinforcement layer thickness and etc [12].

From the experimental test, there were found out that there are connection between glass-fiber concentration and length to the adhesion between the glass-fiber reinforcement layer and the acrylic sheet.

Specimen	Thickness	Width	Yield	Yield Force	Elong at Yield	Max Force	Tensile strength	Elonga-tion
	mm	**mm**	**MPa**	**N**	**%**	**N**	**MPa**	**%**
A_11	18	6x2	36,67	1760	16,2	1760	36,67	16,2
A_21	18	7x2	34,58	1660	12,9	1660	34,58	12,9
A_51	18	6x2	33,42	1604	14,3	1604	33,42	14,3
A_61	18	6x2	33,83	1624	12,3	1624	33,83	12,3
B_11	18	7x2	40,50	1944	16,5	1944	40,50	16,5
B_31	18	7x2	36,79	1766	13,8	1766	36,79	13,8
B_51	18	7x2	41,77	2005	13,1	2005	41,77	13,1
B_61	18	7x2	44,11	2118	16,3	2118	44,11	16,3
C_11	18	6x2	46,51	2233	13,5	2233	46,51	13,5
C_21	18	6x2	51,20	2458	14,8	2458	51,20	14,8
C_41	18	7x2	42,86	2058	14,7	2058	42,86	14,7
C_71	18	7x2	54,08	2596	19,6	2596	54,08	19,6

Table 1. Results of the experimental test

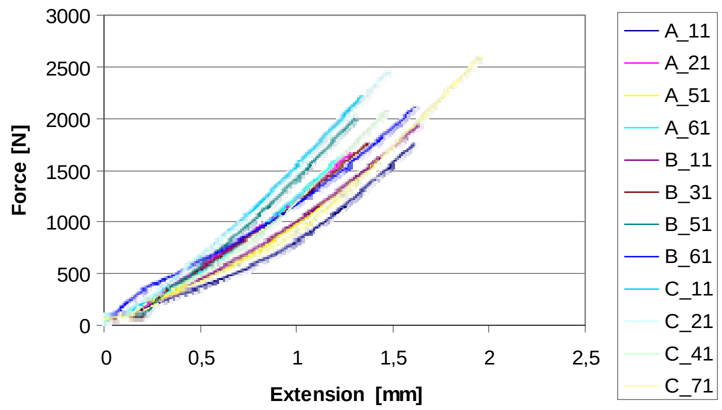


Fig. 12. Force extension graph

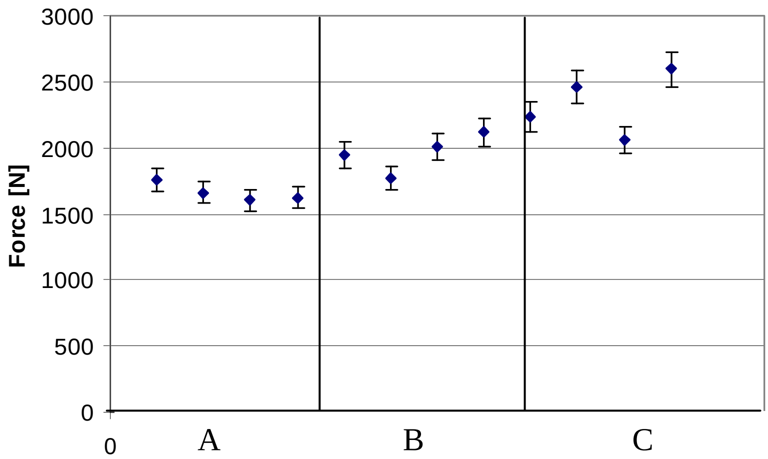


Fig. 13. Summarized Max Force in groups

4. CONCLUSIONS

The adhesion processes between the glass-fiber reinforcement layer and acrylic sheet were analyzed, the optimal adhesion measuring methods were selected.

The optimization model has been developed for determining optimal adhesion area and testing part design. This procedure includes design of experiment, FEM simulation and experimental validation of reliability of the model.

A number of experimental tests have been made with different glass-fiber reinforcement concentrations, acrylic sheet heating temperatures and adhesion area parameter variations.

The results of the experimental tests can be used as the base for the future glass-fiber reinforcement layer and acrylic sheet adhesion optimization processes.

5. ACKNOWLEDGEMENTS

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WEAR PROTECTION OF HIGHLY LOADED COMPONENTS: ADVANTAGES OF PLASMA TRANSFERRED ARC WELDING AS HARDFACING TECHNOLOGY

Katsich, C.; Zikin, A.; Badisch, E.

Abstract: *Hardfacing is one of the most economical surface treatment technologies to improve service life and durability of metal parts subjected to wear. The application of hardfacings is technically feasible with different welding technologies. In this work, the plasma transferred arc (PTA) process was used for deposition of different hardfacings. For a better understanding of the correlation of PTA processing and wear behaviour, two different alloys were investigated under various deposition parameters. The influence of cooling conditions was studied by temperature controlling of the substrate.*

Key words: tribology, hardfacing, plasma transferred arc, wear protection

1. INTRODUCTION

Plasma transferred arc (PTA) welding is an increasingly used technology to protect highly stressed components with a wear resistant thick coating. In different industrial applications e.g. mining, recycling industry and agricultural machinery, hardfacings are used for wear protection to increase lifespan and support component efficiency [1,2].

The hardfacing process normally uses materials consisting of a metallic matrix material and hard particles as reinforcement. The metallic matrix acts as a binder for the hard particles where iron, nickel and cobalt are used. An essential condition for embedding the hard particles is their ability of wetting [3].

Furthermore, the wear mechanism has a significant role in the selection of material composition. Investigations showed under abrasive conditions that an increase of hard phase content in the metallic matrix is beneficial. Furthermore, the metallic matrix can be modified too. A softer and more ductile matrix is more insensitive to impact wear than a brittle matrix with high hardness. For reducing material loss due to wear, it is necessary to find a compound of material properties related to the major wear regime [4].

Applying PTA technology, a coating with excellent wear resistance can be deposited on a cheap bulk material. The wear behaviour of this hardfacing is mainly influenced by many different factors and process parameters. The challenge is to find the optimised adjustment of hardfacing parameters to reach the claimed wear behaviour. For this goal, a fundamental knowledge of each parameter effect on the properties of the compound is necessary [5,6]. It is possible to homogenise the microstructure and resulting wear behaviour of hardfacing by modulating the welding parameters [7].

Within this work, a NiCrBSi based hardfacing reinforced with coarse tungsten carbides is investigated and show clearly the effect of working parameters during the hardfacing process on the microstructure and wear behaviour, respectively. Furthermore, a FeCrVC based material with homogenous dispersed hard phase precipitations is deposited under various cooling conditions. Optimised wear behaviour under abrasion conditions and at the same time low wear rates under combined impact/abrasion should be achieved by selection of adjusted processing parameters.

2. EXPERIMENTAL

2.1 Testing material and hardfacing

A Ni-based matrix alloy with enhanced B, Si and Cr content was used to manufacture testing samples to investigate the effect of welding current modulation. This matrix was reinforced by coarse tungsten carbide (WC/W_2C, fused & crushed) with particle diameter distribution between 75 µm and 150 µm at a fraction of 40 % and 60 % mass, respectively (samples N1 to N3). Mild steel 1.0037 with 8 mm thickness was used.

To investigation the influence of cooling conditions, an iron based alloy with Cr, V and C content was used. The hard particle content is formed by precipitations of vanadium and carbon. Mild steel 1.0037 substrate (samples FM) and austenite substrate 1.4301 (samples FA) with 5 mm thickness were used. The chemical compositions of alloys are given in Table 1.

PTA welding was done with a EuTronic® Gap 3001 DC at AC2T research GmbH (see Fig. 1). Hardfacing parameters including welding current, oscillation and welding speed, substrate, powder feed rate, nozzle distance to substrate, carrier, shielding and plasma gas flow rates are optimised based on practical welding procedures. Hardfacing parameters are given in Table 2.

[mass-%]	C	Si	Mn	Cr	Ni	Mo	V	B	Fe
NiCrBSi	0.2	2.5	-	4.0	base	-	-	1.0	-
Fe-VC	2.8	0.7	1.1	5.7	-	1.7	12.5	-	base

Table 1. Chemical composition of alloys

	N1	N2	N3	FM	FA
current [A]	85	110	93	80	75
pulsing time [ms]	-	8-4	8-4	-	-
velocity [mm/s]	1.15	1.15	1.15	0.9	1.15
osc. velocity [mm/s]	25	25	25	28	25
osc. width [mm]	20	20	20	20	20
WC/W_2C content [%]	60	60	40	-	-
substrate thickness [mm]	8	8	8	5 (mild steel)	5 (austenite)

Table 2. Hardfacing parameters

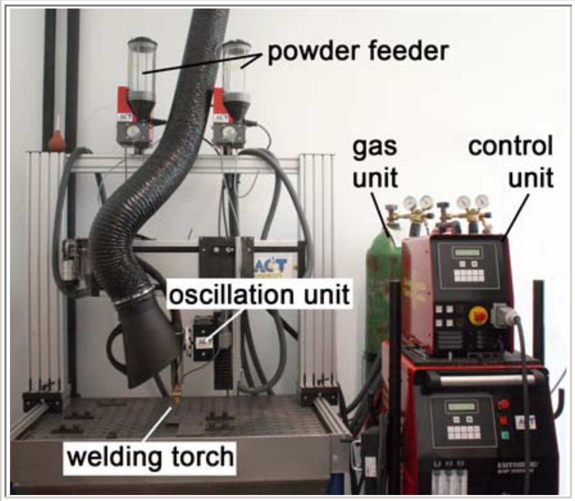

Fig. 1. PTA welding station at AC²T research GmbH

To describe the pulsing cycle, the modulation of welding current was given as pulsing time “8-4”. This means that after 8 ms of nominal current, a pause of 4 ms followed. This schematic is given in Fig. 2a. As result of the “on-off” switching of the current a sawtooth-shaped current profile can be measured (Fig. 2b). It was not possible to reach a deactivation of current due to upkeeping of the welding plasma by the pilot current (15 A).

Testing specimens were prepared by waterjet cutting to avoid heating up of substrate and hardfacing.

For measuring the cooling time during the hardfacing process, thermocouple type K was used by sticking in the liquid melt pool and the temperature/time values was recorded with a thermocouple measuring board National Instruments NI 9213.

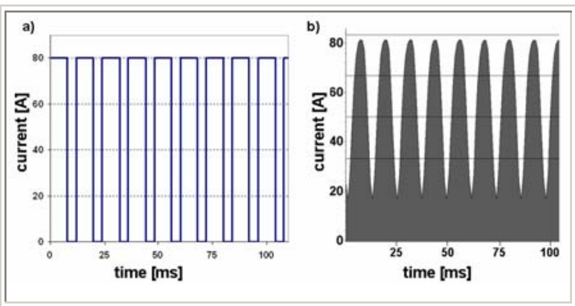

Fig. 2. Current/time diagram a) schematic b) measured

2.2 Wear investigation

Abrasion tests on a dry-sand rubber-wheel tester according to ASTM G65 Procedure A were performed simulating conditions of 3-body abrasion under low stress. Testing parameters were conducted at a rotational speed of 200 rpm, a normal load of 130 N, a sliding distance of 4309 m, and with Ottawa silica sand grain size of 212–300 µm. Each test was repeated three times for statistical calculation. Wear characterisation was done by mass loss of specimens during wear testing.

Wear tests under combined impact/abrasion were performed on a specially designed impeller-tumbler apparatus (CIAT). The device consists of a slowly rotating outer tumbler and a fast rotating inner impeller, where the testing specimens were mounted and spun at rotation speeds of 60 and 650 rpm respectively. The tumbler was filled with a defined amount of abrasive, and controlled the flow of abrasive particles hitting the fast moving testing specimens (see Fig. 3a and b). Due to the kinematical motion, the particles contact the specimen (surface exposed to abrasive particles, 25×10 mm) at an impact velocity of approximately 10 m/s. The abrasive material was 1 kg of corundum particles (5–10 mm). Each run lasted 20 min, and each test was repeated 3 times for statistic calculation. Wear characterisation has been done by gravimetric mass loss of the testing specimen during wear testing.

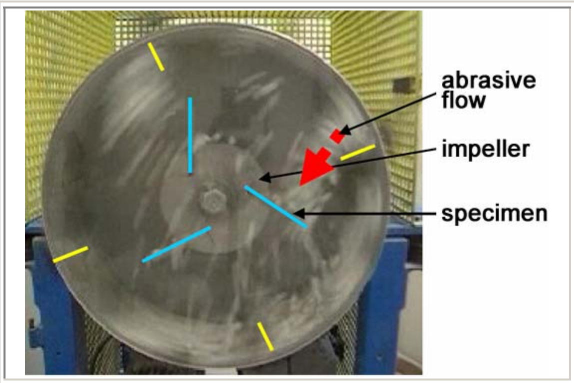

Fig. 3. Combined impact/abrasion test device - Principle of particle flow.

3. RESULTS AND DISCUSSION

3.1 Modulation of current by pulsing

As result of the pulse modulation of the welding current (see Table 2) the effect on the carbide reinforced Ni-matrix is clearly shown in Fig. 4. Note that the dilution process of the hard particles is significantly reduced (N2) in comparison to the standard welding (N1). The decrease of heat input reduces the formation of the matrix-carbide interphase zone and helps to maintain the volume fraction of the origin hard particles which is required for abrasion resistance. In the pulsed sample, the amount of secondary precipitations is also reduced due to less solved WC/W_2C (Fig. 4c, d).

The difference in dissolution can be observed in hardness level of the compound too. The comparison of investigated hardfacing conditions (see Tab. 2) shows no difference in hardness of the metallic matrix. This means that the Ni-alloy is not significantly modified in the chemical composition by the dissolution process. On the other side, the macro hardness of the pulsed sample N2 is increased in comparison with the standard sample N1 and is a result of the increased area content of origin hard particles. The reduction of hard particle content from 60 to 40 weight-% leads to a decrease in macro hardness as expected.

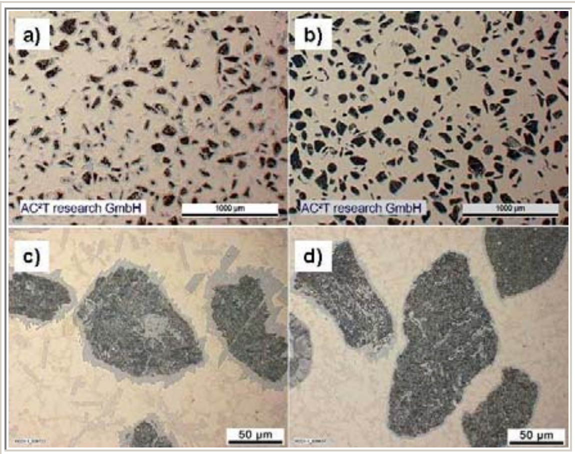

Fig. 4. Optical image of surface microstructure a) sample N1 (without pulsing) b) sample N2 (with pulsing) c) detail sample N1 d) detail sample N2

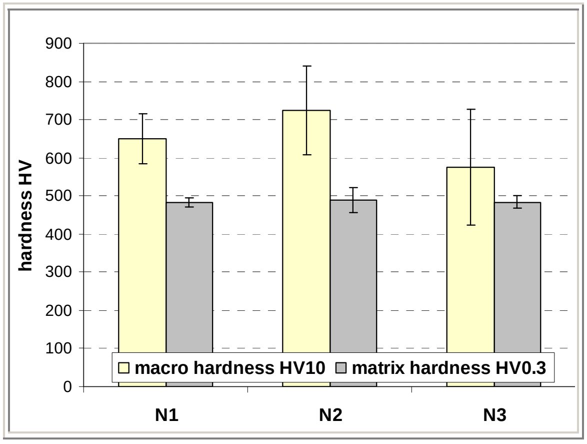

Fig. 5. Hardness of WC/W_2C reinforced NiCrBSi matrix

The wear behaviour under 3-body conditions is given in Fig. 6. Standard sample N1 shows a relatively good abrasion resistance with a wear rate of 0.0026 mm³/m in comparison to industrial deposited hardfacings with similar composition (~ 0.0038 mm³/m). The gap in the wear rate is a consequence of the different focus of the welding process, whereas the industrial parameters are dominated by increased heat input for high deposition rates.
With pulse modulation of the welding current, the wear rate of sample N2 decreases by nearly 20 % down to 0.002 mm³/m despite the fact the current is increased to 110 A. This increase is necessary to ensure the dissolution of the metallic matrix and keeps it liquid for homogenous distribution of hard particles to form a connection between the hardfacing and the substrate material.
A reduction of the hard particle content in pulsed sample N3 comes to a reduction of wear resistance and the wear rate increases up to 0.004 mm³/m. This doubling of wear rate illustrates a significant loss of wear resistance; however, the wear rate is still on a low level for this type of hardfacing. It shows clearly the effect of reduced hard particle content and distance between the particles, respectively. However, the amount of expensive carbide content and the density of the hardfacing can be reduced.

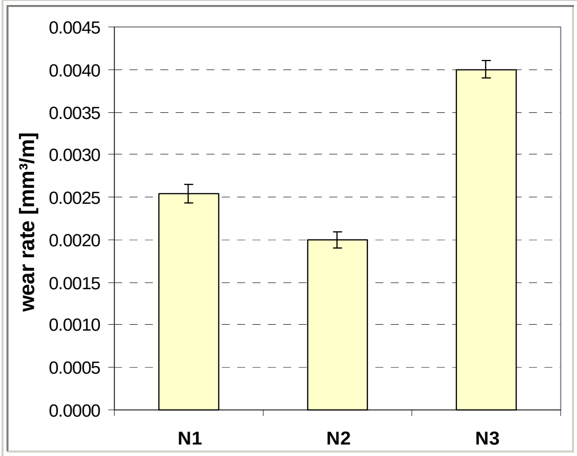

Fig. 6. 3-body abrasion wear rate (ASTM G65) of WC/W_2C reinforced NiCrBSi matrix

3.2 Effect of cooling conditions

To substitute expensive hardfacing compounds, like WC/W_2C reinforced NiCrBSi alloys, iron based hardfacing alloys has become very popular in the last few years. In this work, a common iron based hardfacing powder with high content of vanadium and carbon (Table 1) is used for investigations of cooling effects during the deposition process.
The microstructure of the Fe-VC type consists of primary precipitated hard phases, which are homogenously distributed in the matrix (Fig. 7).

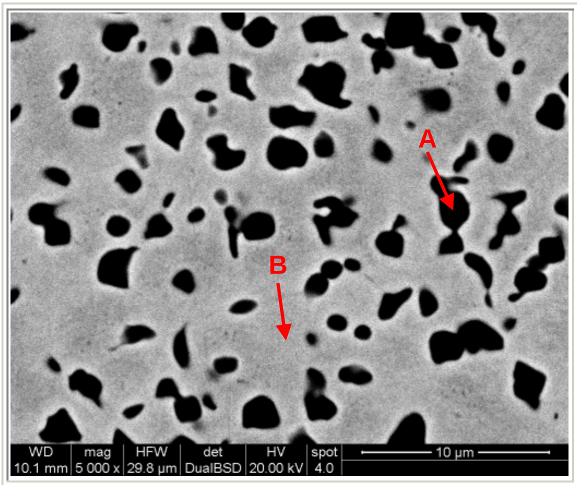

Fig. 7. SEM image of Fe-VC type hardfacing microstructure

	FM1	FM2	FM3	FA1	FA2	FA3
dilution [-]	0.058	0.061	0.107	0.151	0.136	0.163
cooling time t8/5 [s]	47.4	44.8	45.2	35.2	42.1	66.4
hardness [HV10]	655±3	730±4	680±16	590±38	645±13	611±3

Table 3. Dilution, cooling time and hardness of Fe-VC samples

The spherical shaped carbides (black phase A) are small with diameters between 2 and 5 µm in comparison with the WC/W_2C reinforcements above. The precipitations consists not only of vanadium and carbon, but iron can be also found in the carbide phase (A) that comes to a vanadium rich mono carbide type of (Fe,V)C. The metallic matrix is martensitic (Phase B in Fig. 7).

For the realisation of different cooling conditions, the substrate is passively cooled with a water cooled copper plate down to 10 °C (attachment "1" in sample name), is set in with room temperature (attachment "2") and is pre-heated to 100 °C (attachment "3"). The different welding parameters for mild steel and austenite substrate are necessary to receive a usable hardfacing bead and can be explained by the different thermal conductivity of these alloys.

After hardfacing process microstructural properties (dilution and hardness) are determined and compared with the cooling time between 800 °C and 500 °C ($t_{8/5}$); data is given in Table 3. For the mild steel substrate, low dilution can be achieved, increasing with the substrate temperature (TM1-3). Remarkably, the cooling time $t_{8/5}$ does not change significantly at a moderate level of 45 s. However, an effect on the hardness can be observed, where FM2 shows the highest hardness level, which is not expected. A change in substrate composition to austenite material diversifies the values for dilution and hardness. The welding current has to be regulated down to 75 A as consequence of the decreased thermal conductivity and comes to an increase of cooling time from 35 s (FA1) up to 66 s (FA3). The hardness level of FM series cannot be reached due to the higher dilution with the substrate. This leads to a modified composition with enhanced content of Cr and Ni from the austenitic substrate.

To correlate the abrasion resistance with the impact/abrasion behaviour of the different cooled samples, a wear map can be compiled and is given in Fig. 8. This figure helps to identify the fields of application for materials in mineral wear regime.

The passively cooled sample deposited on the mild steel shows the best wear resistance under both conditions. With increasing, the substrate temperature abrasion wear rate is increased and maintains a constant level, whereas the impact/abrasion wear resistance decreases significantly. The loss of alloying elements in the hardfacing due to higher dilution with the mild steel substrate and the fast cooling time leads to a more brittle matrix on a high hardness level.

Hardfacing samples on the austenitic substrate (FA) show less abrasion resistance than sample series FM with a maximum factor of 2. This can be explained by the higher dilution with the substrate, which leads to an enrichment of Cr and Ni in the hardfacing composition. Due to decreasing carbon content in the hardfacing, the formation of carbide precipitations is reduced, leading to lower hard particle content. However, the combined impact/abrasion resistance is still excellent, independent of cooling performance. Again, the same mechanism in microstructure is responsible for this effect. The reduced hard phase content helps to dissipate the impact energy and reduces the wear rate. The moderate cooling rate of sample FA2 with relatively low dilution shows the best performance considering 3-body abrasion resistance.

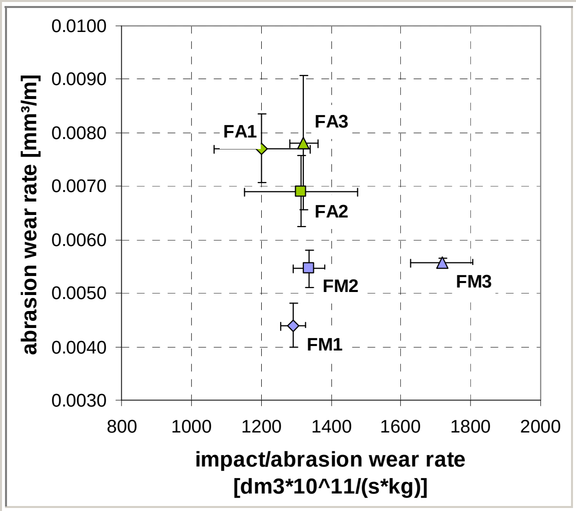

Fig. 8. Wear map of Fe-VC samples deposited under different cooling conditions

4. CONCLUSION

Based on the study within this work, the following conclusions can be drawn:

1. Reduced energy input by current modulation shows a reduced dissolution of origin hard particle and reduced content of secondary precipitations in the Ni-matrix.
2. Pulsing current successfully optimises micro-structure of WC/W_2C reinforced Ni-matrix under 3-body abrasion conditions.
3. WC/W_2C content can be reduced to 40 weight-% for low level abrasion wear rates.
4. Fe-VC alloy system can act as all-round hardfacing under abrasive and impact/abrasive wear conditions.
5. Cooling and substrate conditions have a significant influence on wear behaviour at Fe-VC system.
6. Hardness is not the major parameter for wear behaviour evaluation.
7. Dilution, thermal conductivity and substrate composition have to be considered for practical application of Fe-VC hardfacing systems.

5. ACKNOWLEDGEMENT

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DESIGN OF SUPERHARD c-BC_2N-PRECIPITATES IN B_4C/Al-COMPOSITES THROUGH SHS AND HEAT TREATMENT

Kommel, L.; Metsvahi, R.; Viljus, M.; Kimmari, E.; Kolju, K. & Traksmaa, R.

Abstract: This *report introduces the synthesis of diamondlike superhard cubic boron-carbon nitride (c-BC_2N) precipitations in multi-phase binder of light-weight boroncarbide aluminum composite. Mentioned B-C-N-phase was designed viaself-propagating high temperature synthesis and followed by heat treatment in nitrogen atmosphere under pressure at high temperatures. X-raydiffraction revealed that as result of solid state chemical reactions new refractory ceramic phases were formed which changed the mechanical properties of composites. As determined by nanoindentation the Vickers hardness of cubic boron-carbon-nitride precipitations was ~95 GPa and elastic modulus ~600 GPa like that of diamond. The maximum value of the experimentally determined thermal stability of BC_2N up to 1450 °C and that is higher than that of diamond.*

Key words: Cubic BC_2N, Hardness, Elastic modulus, Elastic recovery parameter.

1. INTRODUCTION

It is well known that carbon (C) is a key element in the technologically useful ultra-strength materials such as diamond, fullerenes, graphene, carbon nanotubes (CNT), boron carbide (B_4C), tungsten carbide (WC), etc. These carbon based materials with high values of hardness and elastic modulus will be used in electronic and engineering industries. The superhard diamond like pseudo cubic boron-carbon nitride (c-BC_2N) at firstly was predicted at 1981 by D.A. Zhogolev et al. [1]. Recently the structural and mechanical properties of ternary B-C-N compounds through first principles of calculation via cluster expansion technique and systematically explored by Monte Carlo simulations was predicted by K. Yuge [2, 3], S. Chen et al. [4], L. Xiaoguang et al. [5], etc. Theoretical Vickers hardness of this mechanical mixture highly dispersed diamond and cubic boron nitride has been investigated by X. Guo and coworkers [6] using the microscopic hardness model. Results lie between 70 and 72 GPa and it is consistent with the experimental value of 76 GPa [7]. This new pseudodiamond c-BC_2N compound is harder than c-BN, but retains the thermal and chemical stability of c-BN. The theoretical and experimental investigations of this superhard compound also gave contradictory results. Based on first-principle calculations by mapping the distribution of the formation energy, Vickers hardness, Young's modulus and ductility were studied in the ternary B-C-N phase diagram by X. Jiang et al. [8]. It is shown, that depending on composition of B-C-N phase the formation energy distributes symmetrically along the C-BN isoelectronic line. Most of the experimentally synthesized B-C-N compositions located in (B: 15-35, C: 30-55 and N: 15-35 at. %) area had excellent hardness (45-50 GPa), elastic modulus (670-730 GPa) and good ductility (1.04-1.24) at low formation energy (— 0.01-0.09 eV/atom). This material shows ductile behavior at increased C-content.

There are different methods to form B-C-N ternary compound which are elaborated here. For example the BC_2N thin films are being made using the radio frequency magnetron sputtering [9], dual gun sputtering [10], reactive laser ablation [11] or remote plasma-assisted chemical-vapor deposition [12, 13] techniques. Also it is possible to synthesize the cubic BC_2N compound in MgO capsule from graphite-like BC_2N under high-pressure of 18-25 GPa and at temperatures higher than 2200 K [14]. In that case the c-BC_2N has Vickers hardness of 76 GPa, nanohardness of 75 GPa, shear modulus of 447 GPa and bulk modulus of 282 GPa, which is lower than those of diamond [15, 16]. It is mentioned in [7, 15, 16] that the c-BN has Vickers hardness of 62 GPa and diamond of 115 GPa.

The first B_4C/Al-based metal matrix composites (MMC) for light-weight defence components in military aviation were produced via self-propagating high temperature synthesis (SHS) technigue [17]. The green defence elements were heat treated in ZrO_2 flux during long exposure time and at high temperatures. Later, in [18, 19] the formation of a new hard refractory phases forming via solid state phases transformation in vacuum at high temperatures and their influence on the tribological properties of the composites were studied. It is well known that SHS method was invated by A.G. Merzhanov [20] 45 years ago in the last century.

The aim of this present report is to study the superhard BC_2N-precipitates forming in B_4C/Al-composites during SHS and followed heat treatment in nitrogen (N_2) under relatively low pressures. The microstructure, chemical composition and mechanical properties of the composites and also the hardness and elastic modulus of formed precipitations through nanoindentation were studied, respectively.

2. EXPERIMENTAL

The raw composites based on B4C/Al were produced via low cost capsule technigue of self-propagating high temperature synthesis (SHS) [17-20]. The followed heat treatment was conducted in nitrogen (N_2) atmosphere under pressure, forming different refractory carbide and nitride based phases. The powders (H8) of industrial boron carbide (B_4C) with grain size in range of 4.2-74.7 μm (average 17.3 μm) and aluminum powder PA-4 (GOST 6058-73) containing 0.35 at.% Fe, 0.4 at.% Si, and 0.02 at. % Cu impurities were used as inlet powders. The powder contents were ball-milled during 20 h. Depending on B_4C amount (50, 60, 70 and 80 wt.%) in the powder mixture the content of WC-Co in composite (as result of wear during ball milling) was increased from 3.6, 5.3, 8.7 and 11.2 wt.%, respectively. Such increasing of WC-Co content in powders mixture was determined by simple balance of powder before and after ball-milling and compared by X-ray investigation. The balls and mill were manufactured from WC-Co (Co=8 wt.%) hard metal. So that the powder mixture has different chemical content, which contans main components like B_4C and Al with the WC-Co and in small amount (≤5 wt.%) of copper (Cu) to increase the B4C crystallites wetting with Al binder during processing.

The mixed powders compositions were put into a steel container for furnace heating. For SHS process initiation the steel capsules were heated from 600 °C to 800 °C with low heating rate of 1 °C/min in furnce to start the exothermic reaction of powder mixture. For better densification of heated compacts by SHS reaction the subsequent pressing with pressure stress of ~120 MPa was conducted immediately. After compaction the green samples were removed from the steel container by cutting it open. Heat treatment was conducted in vacuum furnace (RED DEVIL vacuum furnace WEBB 107, USA). The main parameters of the regimes were the temperature increase rate of 2 °C/min, low flow noitrogen (N_2) surrounding atmosphere under chamber pressure of +3PSI, and duration at maximal temperature was about two hours with followed cooldown time of ~17 h. The temperatures of heat treatment were from 650, 800, 1000, 1150 and 1450 °C, respectively. These temperatures were combined with new refractory carbides forming temperatures avilable from scientific literature. Because the heating rate was constant, the duration of heat treatment was increased for higest temperatures, respectively. The microstructural studies of composites (for each step of processing) were performed. For this the light optical (Nikon CX) and scanning electron microscopes (Zeiss EVO MA-15, Ultra 55 and Geminy LEO Supra-35) were used. X-ray diffraction technique (Bruker AXS, D5005) was used to analyze forming states of the hard refractory compounds depending on processing steps, from initial powders chemistry, SHS processed green products, and after heat treatment of samples at different sintering temperatures. The micromechanical properties like Vickers (nano) hardness and elastic modulus of the constituents of composites were characterized using the nanoindentation device of NanoTest NTX testing centre (Micro Materials Ltd.). A trigonal Berkovich diamond tip with a three-side pyramid apex angle of 142.3° and radius of 100 nm was used for measurements. According to Oliver-Pharr method the mechanical properties were automatically calculated from the load-displacement curves. The elastic recovery parameter was determined from the final depth of the contact indent after unloading and the indenter displacement at the peak load [21]. Nanioindentation was conducted in diamond polished surfaces under load of 20, 100 and 500 mN for 100 indents with step of 10 and 15 μm on one sample, respectively (Fig. 1). The phases at the indents sites were identified in SEM pictures. For comparison the Vickers microhardness for the main phases were carried out at loads of 0.01 and 0.05 kg by Micromet-2001. The hight (over diamond grinded surface of composite) of new superhard phase was measured by Mahr Pertohometer PGK 120 Concept 7.21 use.

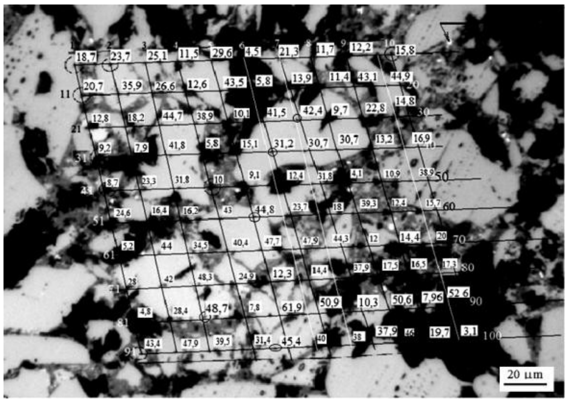

Fig. 1. Optical picture of composite nanoindentation region with test points and nanohardness value demonstrate.

3. RESULTS AND DISCUSSION

The appraised nanohardness, elastic modulus and elastic recovery parameter of cubic boron-carbon nitride (c-BC_2N) (as well as other phases) is difficalt to obtain, because the tested oval-shaped phase grains are small (15-30 nm) [7] and exhibit mechanical properties comparable with the trigonal Berkovich diamond indenter. The others hard phases (which are detected in SHS processed and heat treated comosites) are c-BN, c-$B_{13}C_2$, c-B_4C, Al_3BC, W_2B_5, $CuAl_2$, AlN, AlB_2, Al_4C_3, Al, etc. which have lower hardness (Fig. 2) then c-BC_2N. In this work the main parameters (measured by nanoindentation technique) are nanohardness, elastic modulus and elastic recovery parameter (Fig. 3).

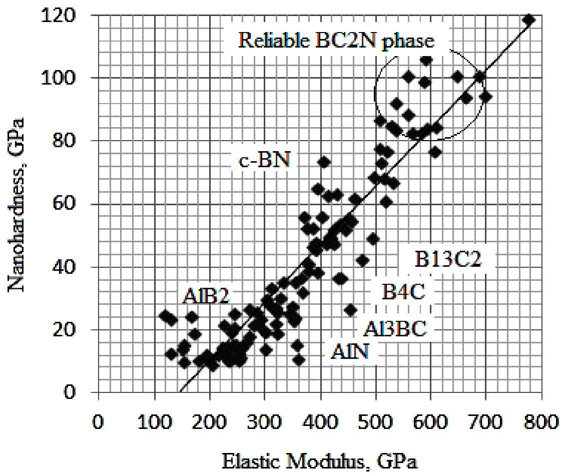

Fig. 2. Reliable values of tested phases.

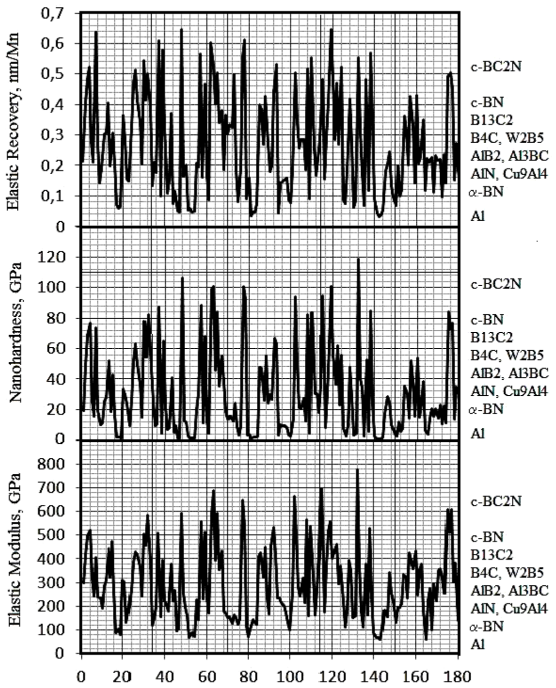

Fig. 3. The measured elastic recovery parameter (a), nanohardness (b) and elastic modulus (c) distribution of composite.

These values dependence are presented in Fig. 2 for detected phases. As is shown the nanohardness and elastic modules of phases have approximately linear relationship. The phase transformation in B_4C crystallites takes place and the boron carbon or icosahedral boron subcarbide ($B_{13}C_2$) [22] phase was formed. The reliable values of new designed superhard (pseudo)cubic boron-carbon nitride (c-BC_2N) phase (Fig.2, 3) are: nanohardness (95 ± 15 GPa) and elastic modulus (600 ± 100 GPa). This new pseudodiamond c-BC_2N compound was formed at ~1150 °C as the Co as catalyst was used. This new phase is harder than c-BN, but retains the thermal and chemical stability of c-BN [15]. Unfortunately, studied by Sun and co-workers in [22] about the pseudopotential density functional method for all the possible structures starting from an eight-atom zinc-blende-structured cubic unit cell conclude that these c-BC_2N compound structures are expected to be metastable. The c-BC_2N structures have bulk module slightly higher than those of c-BN. The scanning electron microscopy (SEM) shows that the composite microstructure does not contain porosity and investigation on the light optical microscopy (OM) show that the different new phases in Al-based binder were formed. Unfortunately, the B_4C crystallites contain micrometric measures porosity on the diamond grinded surface. The superhard BC_2N crystallites were detected as small tubercles in diamond grinded surfaces of composite as they hardness as well as wear resistance were comparable to that of diamond. The roughness investigation results show that this hardest compound is higher about 0.7-1.4 μm over the diamond grinded surface of composite. The width (diameter) of these protuberances is about 10-17 μm.

The X-ray investigation was conducted for samples with increased content of B_4C from 50 to 80 wt. % and for samples which were SHS-processed, heat treated at 650, 800, 1000, 1150 and 1450 °C, respectively. The XRD diagram and calculation of the samples after heat treatment at 800 °C of composite with 60 wt. % of B_4C shows (Fig. 4) that after SHS it consists mainly of Al-18.6, B_4C-17.2, $B_{13}C_2$-43.7, Al_3BC-8.3, AlN-2 and C-3.7 wt.%, respectively. The composite with 80 wt.% of B_4C after SHS and heat treatment at 650 °C shows 10.8 wt.% of orthorhombic BC_2N and does not contain free Al, but the 17.4 wt.% AlN was formed because of the use of nitrogen gas (Fig. 5). As result of phase transformation in the boron carbide crystallites were formed in large amount of boron carbon (c-$B_{13}C_2$) layers. The very stabile phase of boron aluminum carbide (Al_3BC) was formed on base of Al and B_4C at 800 °C of heat treatment in nitrogen. Boron tungsten (W_2B_5) forming starts from 800 °C and the contents in binder phase increase to 8.4 wt. % in composite with 80 wt. % of B_4C at 1450 °C. The deleterious aluminium carbide (Al_4C_3) was formed in composite with 50 wt. % of B_4C at temperatures since ~1000 °C and for 80 wt. % of B4C at 1450° C (Fig.6). The BC_2N phase with lattice parameters is shown in Fig. 6.

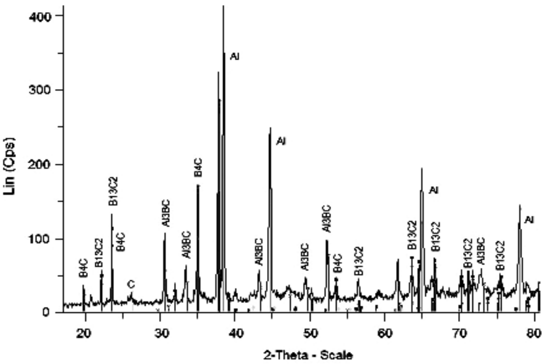

Fig. 4. X-ray diagram of B_4C-60 wt. % composite phase's content after SHS and heat treatment in N_2 at 650 °C.

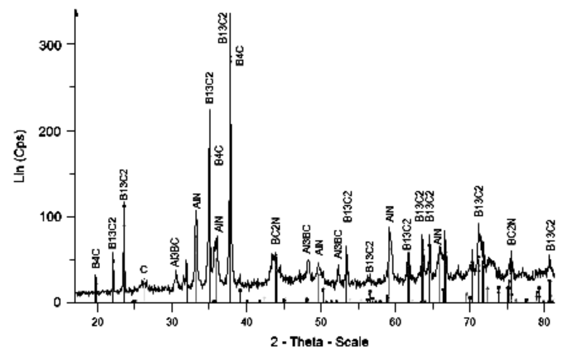

Fig. 5. X-ray diagram of B_4C-80 wt. % composite after SHS and heat treatment in N_2 at 650 °C.

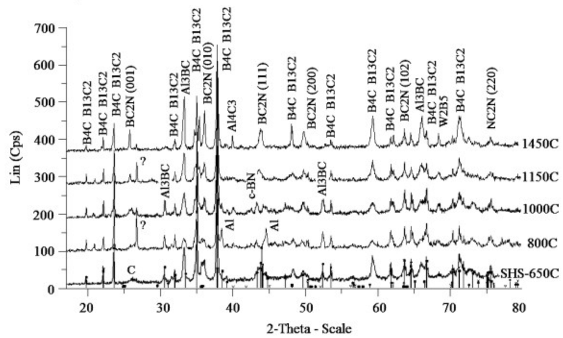

Fig. 6. XRD diagrams of phases forming and transformation during heat treatment under nitrogen pressure.

The B_4C content was maximal and $B_{13}C_2$ content minimal after heat treatment at 1000 °C for samples with 80 wt. % of B_4C. Since this temperature leads to decrease of B_4C a content in composite, furthermore the Al and C contents were decreased from 800 °C. For all of the samples the AlN content increased with heat treatment in N_2 surrounding from 800 °C. The maximal concentration of Al_3BC and c-BN was conducted at 1000 °C and c-BC_2N at 1450 °C for all samples.

Such large amount of phases (with very different hardness, elastic modulus and elastic recovery parameter) lead to forming of composites with homogenized medium (from 100 tests and include surface defects, see Fig. 1) nanohardness from 20 to 54 GPa.

4. CONCLUSIONS

This paper describes the superhard diamond like c-BC_2N phase (compound) as one of the phases in multi-phase binder of light-weight B_4C/Al composite. This chemical compound firstly was successfully synthesized via SHS reaction and heat treatment under N_2 gas pressure.

As determined by nanoindentation the Vickers hardness of cubic boron-carbon-nitride (c-BC_2N) precipitations was ~95 GPa (in the range of 80-110 GPa) and elastic modulus ~600 GPa (in range from 500 up to 700 GPa) like that of diamond. The Vickers hardness and elastic modulus are applicable with theoretically calculated results.

The controlled thermal stability of BC_2N is 1450 °C and it is higher than that of diamond.

We propose that the c-BC_2N is an extremely effective reinforcement for composite for defence elements due to its high hardness and elastic modulus.

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PRODUCTION TECHNOLOGY ELABORATION AND CHARACTERIZATION OF Al-MWCNT, Al-fullerenes and Al-B4C COMPOSITES

Kommel, L.; Metsvahi, R. & Mihhaltsenkov, M.

Abstract: *The effects of production technology parameters on the microstructure and mechanical properties of aluminium based composites filled with CNT, B_4C and fullerenes was studied in this work. Aluminium with different content of mentioned reinforcements were mechanically alloyed, compacted by equal-channel angular pressing, and heat-treated at high temperatures. The results show that the concentrations of chemical elements, cumulative strain of compaction, heat-treatment environment and temperature have significant effects of improving composites microstructure and mechanical properties. It was established, that the adding of CNT-s into Al matrix with high energy ball milling does not have any meaningful influence in increasing the strength of a material. Composite hardness increased mainly during heat treatment as a result of a new phases formation.*
Key words: Metal matrix composites, Aluminum, MWCNT, B4C, Hardness.

1. INTRODUCTION

It is well known, that historical development and current impact of severe plastic deformation (SPD) techniques are considered methods for production of ultrafine grained (UFG) and nanocrystalline or nanostructured (NC) bulk metals and alloys [1]. It is well established that SPD processing like equal-channel angular pressing (ECAP) [2] is capable for producing bulk metals and alloys in large samples with grain sizes within the submicrometer (100-1000 nm), referred to as ultrafine grained (UFG) materials and in the nanoscale (less than 100 nm) via high pressure torsion (HPT) method [3]. Such bulk solid metallic nanomaterials having fairly homogeneus microstructures with no porosity and exellent mechanical properties are comparable to the coarse grained polycristalline metals manufactured by common routes.

Over the past decade the literature data shows a significant strengthening effect by adding of CNTs [4-5] and carbides [6-7] into metallic or into the polymer [8] matrix. The addition of these reinforcements into powder metallic matrix via mixing in planetary mills or by high energy ball milling and compacted by different SPD processes can improve mechanical properties compared to conventional engineering materials. There are different methods developed for compaction of powderes via SPD techniques. The main methods are conventional extrusion [9], equal channel angular pressing with back-pressure [10], high-pressure torsion (HPT) [4], reciprocating extrusion (CEC) [11] etc. In the works [4] by Li H. and coworkers, they suggest that reinforcement of pure copper powder with CNT-s by high energy attrition milling (ball to powder ratio was 10:1 and the milling time was up to 5 h), subsequently isostatically compacted under pressure of 500 MPa and consolidation by HPT technique under 6 GPa for 5 revolutions at room temperature has low effects for increasing the mechanical properties of Cu-CNT composite. It is shown in this work that during ball milling and HPT the grain size decreased for Cu-CNT to 22 nm and for Cu to 29 nm, respectively. As a result of CNT addition, the microhardness during HPT processing increased only ~16 %, from ~3 GPa to ~3.5 GPa, respectively. The influence of CNT-s morphology and diameter on the processing of CNT-reinforced aluminum composites is studied by Esawi and coworkers in [12]. According to Hi the CNT-s shortened during ball milling. By Nayan and coworkers in [13] they explain that during attrition high-energy ball-milling (up to 48 h) the CNT-s get embedded and cold-welded between the Al particles. Also fractured detrimental aluminum carbide (Al4C3) forms as the CNTs react with Al and Al4C3 formation takes place before melting of Al. To eliminate the mentioned problems, composites after ball milling were subsequently hot consolidated by hot extrusion. It is well known [5], that CNT-s have high specific strength (~55 GPR) and high specific modulus (~555 GPa), which makes them ideal reinforcements in metal and polymer based composites. Usually the CNT-s are agglomerated and for better dispersion within the metal powder the ball-milling are expected to be sufficient [12]. Unfortunately, the increase of ball-milling time has adverse effect on the quality and properties of final composite [14]. Before mixing with metal powder the agglomerated CNT-s were initially dispersed in ethanol by using an ultrasonic shaker and then metal powders were added into the CNT-ethanol dispersion [5]. After that, the dried mixture was ball-milled at different periods (12, 24, 48 and 72 h) [15]. Depending on the powder content during attrition ball-milling, different processes take place. These processes are pure Al powder agglomeration [15], shortening of CNT-s and damages of carbon walls [14], formation of aluminum carbide (Al4C3) [13], dissolving, cold-welding and fracturing of CNT-s [15]. At a very low milling time (30 min) the homogenous dispersion of CNTs within the aluminum matrix takes place [14]. In addition, there is poor wettability between CNT and Al, because the CNT and aluminium surface energies differ greatly [5]. Considering all of this, the reinforcement of metal matrix composites (MMC) with fullerenes and carbides has number of differences. When we increase the milling time during attrition, the reinforcements grain size decreases which has a positive effect on the composite mechanical properties

In this case the elaboration of efficient production technologies for practical solutions using Al reinforcemed CNT-s, carbides and fullerenes via SPD techniques is an essential task.

2. EXPERIMENTAL AND MATERIALS

Here, we present a study of the MMC composites production technology for compacting powder mixtures via SPD techniques like equal-channel angular pressing (ECAP) and there modification of multi-pass angular pressing (MPAP). According to this method the die has three channels, which cross-sections are decreasing stepwise along the route. The back-pressure is formed automatically when the preheated powder compact is being pressed through the channels. The ECAP die has right angle and MPAP die has two 110º angles of crossing channels. The attrition milled powder compacts were enclosed in a metal (Cu, Al) capsules, preheated in furnace up to 350 °C for 1.5 h and extruded as a bulk metal via crossed channels of ECAP and MPAP die. Compared to conventional ECAP the von Mises strain increased up to two at one pass. Hydraulic press of 1000 kN capacity was used for compaction. The commercial aluminum powder PA-4 (GOST 6058-73) contains impurities Fe 0.35, Si 0.4 and Cu 0.1 wt.% and has grain sizes between 100-140 μm. Different amounts of CNT = 0.6 - 6 wt.% (Baytubes C150P, MW CNT), fullerenes = 3 wt.% and B4C = 1 - 50 wt.%

(H8, average grain size 17.3 μm) were added into Al powder (PA-4, GOST 6058-73) and attrition milled at different times, rotating speeds and ball-to-powder ratios of milling. These initial powders (Al and B4C) were mixed in proportions: Al-100, 90, 85, 75 and 50 wt.%, respectively. The attrition mixed (with metanol) powder compacts were then compacted by vibration in cylindrical containers with diameter of 14 mm and length of 120 mm. The heating of containers under compaction was conducted at a temperature of 350 °C for 1.5 h. The pressing value varied and the maximal number by Bc route of ECAP as well as collected Von Mieses strain was up to ten. The microstructure was investigated using optical (Nikon CX) and scanning electron microscope (SEM, Zeiss EVO Ma-15). For hardness measurements the Mikromet-2001, and nanoindentation device of NanoTest NTX testing centre were used. Nanoindentation was conducted in diamond grinded surface under load of 5, 10, 20 and 300 mN, respectively.

3. RESULTS AND DISCUSSION

Results show that depending on the cumulative strain increase in MPAP die (Fig. 1) the binder phase grain size decreased and microhardness increased which leads to the increase of the composite mechanical properties. At the distance of 40 mm and over the powder compacts microhardnes was decreased due to decrease of back pressure [10]. It will be mentoined, that pure bulk metals like Al and Cu microhardness increases significantly with compared to composites. As is shown in (Fig. 2) the microhardness of composites that are reinforched with CNT increase by cumulative strain increase and it depends on the heat treatment temperature as well (Fig. 3).

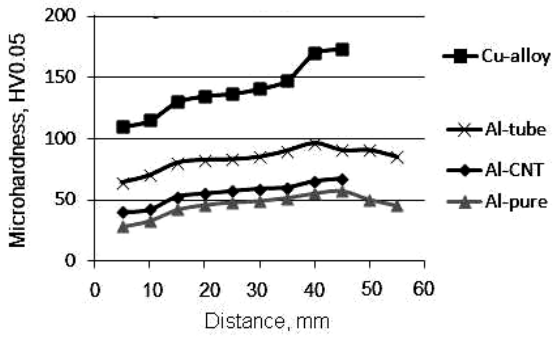

Fig. 1. Composites metallic binder and bulk Cu and Al microhardness depending on cumulative strain increase in MPAP die.

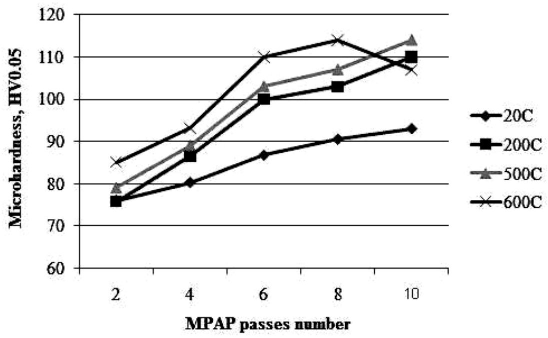

Fig. 2. Influence of the number of passes of MPAP on microhardness increase for heat treated samples.

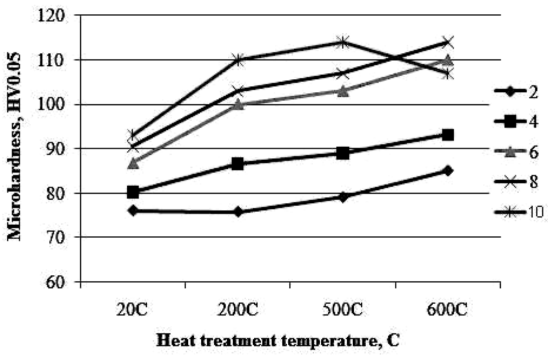

Fig. 3. Influence of heat treatment temperature on the microhardness of CNTs reinforced Al-based composite.

Microhardness of samples that were heat treated at 600 ºC with 10 passes, the fine grained microstructure was decreased as the stress softening take place, this parameter depends on the grain size. It is well known, that nanostructured materials have low properties of thermostability [1-

3] and the softening takes place at lower temeratures compared to coarsegrained counterparts.

Composites reinforced with CNT-s (Fig. 4) and compacted by ECAP by route A influenced CNT-s orientation along sample axis and the properties (tensile stress, elongation, UTS) at tensions increased slightly compared to samples after B_c route. B_c route of ECAP followed by attrition milling, the CNT-s were fractured and the reinforcement effect was minimal. In this case the hardness increased as a result of CNTs fracturing and the increase of graphite content.

Compared to CNT-s reinforced composites the carbon fullerenes filled (via attrition milling at 840 rpm for 6 h and compacted by ECAP) B4C/Al composites microhardness increased significantly during heat treatment at 650 °C for 1.5 h in vacuum (Fig. 5). The composites mean nanohardness enhanced with increasing of B4C content and heat treatment temperature.

The nanohardness of composite (Fig. 6) was measured for 100 indents in ECAP compacted and heat treated composite, respectively. As is shown (Fig. 7) the nanohardness and contact compliance parameters have approximately identical distribution. The homogenized medium parameters of composites with fullerene reinforcements and attrition milled mechanical properties are presented in Tab. 1.

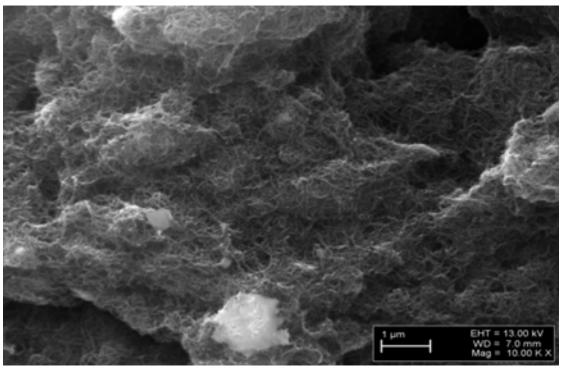

Fig. 4. SEM picture of CNT-s in fractured surface of composite.

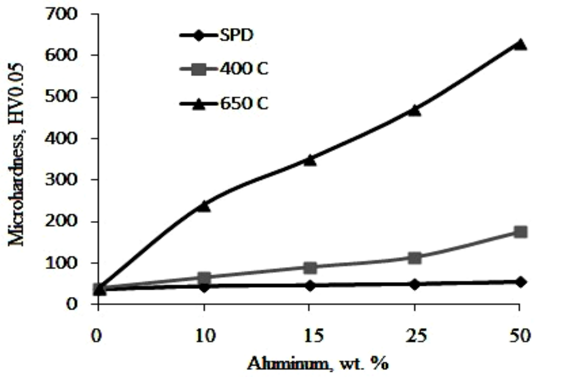

Fig. 5. Influence of B4C content increase and heat treatment temperature increase on microhardness of ECAP processed Al/B4C (reinforced with carbon fullerenes and attrition milled powder) composite.

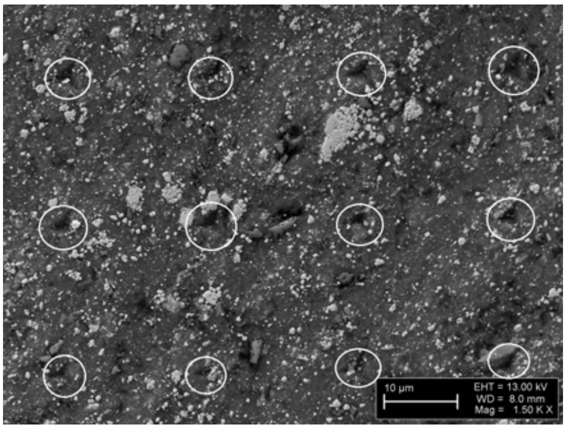

Fig. 6. Test points of nanoindentation in SEM picture of heterogeneous microstructure of composite is shown.

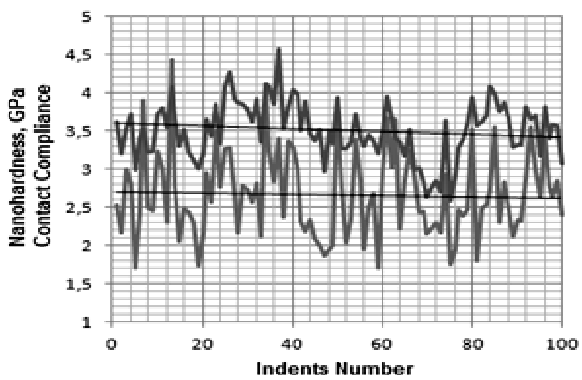

Fig. 7. Nanohardness and contact compliance parameters values for 100 indents of nanoindentation of composite, compacted by MPAP technique.

Tab. 1. Micromechanical properties of attrition milled composite.

	Max. Depth	Pl. Depth	Nano-hardness	Er	ERP	Cont. Compl.	Pl. work	El. work	Fit MSE
	nm	nm	GPa	GPa	nm/Mn		nJ	nJ	
ECAP	601.5	548.6	2.66	91.8	0.098	3.51	3.89	1.04	2.061
650°C	392.6	345.8	5.75	152.7	0.135	3.1	2.15	0.96	0.181

It will be mentioned, that the nanohardness increased over two times during heat treatment. The B4C crystals were embedded and uniformly distributed in relatively soft aluminum matrix (see Fig. 6). The microhardness enhancement depends on the binder phase hardness. The X-ray investigatin shows that small precipitations of boron aluminum carbide (Al_3BC) were formed at 650 ºC in Al based binder.

4. CONCLUSIONS

We have presented analysis of the hardness and microstructure of aluminium based composite reinforced with MWCNT, fullerenes and B4C.

Due to the large difference in CNT and Al surface energies the CNT-s wetting with pure Al during attrition ball milling depend on milling time.

Reinforcement of pure aluminum and Al/B4C based composites with CNT and attrition milling times over 12 h show low effect on mechanical properties.

During attrition high-energy ball-milling CNT-s were embedded, cold-welded between the Al particles and fractured. Also the detrimental aluminum carbide (Al4C3) was formed as the CNTs reacted with Al and Al4C3 formation took place before melting of Al.

Composites reinforced with CNT-s and compacted by ECAP by route A influenced CNT-s orientation along sample axis and properties (tensile stress, elongation, UTS) at the increased tensions. By route Bc of ECAP the CNT-s were fractured and the effect of the reinforcement was minimal, similar to the effect of graphite. Preliminarily attrition milled B4C with grain sizes below 1 μm (UFG microstructure) significantly increased the composites microhardness.

Powder compaction in two action MPAP die is favorable.

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FIBER CONCRETE PROPERTIES CONTROL BY FIBERS MOTION INVESTIGATION IN FRESH CONCRETE DURING CASTING

Krasnikovs, A.; Zaharevskis, V.; Kononova, O.; Lusis, V.; Galushchak, A. & Zaleskis, E.

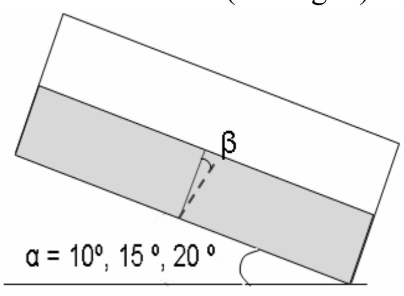
Abstract: *Short steel fiber concrete (SF) tensile strength is dependent on fibers distributions and orientations inside the material. In the present investigation numerically are simulating (using FEM) all fibers motions in fresh concrete during the process of filling the mold by SF. Flow modeling was executed for Newton's and viscous Bingham's liquids. Potential weakest internal zone (is the place with undesirable fibers orientations and spatial distributions –the place of future macro-crack), from the point of view future load bearing capacity under four point bending conditions was recognized. Structural SF fracture model was created; material fracture process was modeled, based on single fiber pull-out laws, which were determined experimentally (for straight fibers, fibers with end hooks, and corrugated fibers).*
Key words: fibers, orientation, high strength concrete, flow.

1. INTRODUCTION

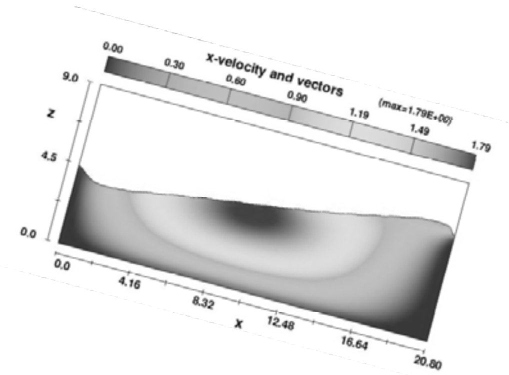
Commercially produced 0.6 to 6 cm long, with various types of geometrical and crossection's forms steel fibers are widely used nowadays as a concrete disperse reinforcement in civil engineering applications. Steel fiber reinforced concrete (SFRC) can perform high flexural and tensile strength, impact resistance as well as a quasi ductile post cracking behavior. At the same time SFRC tensile (as well as bending) strength and post cracking behavior is highly dependent on the number of fibers crossing the weakest crack (is bridged by fibers) and their orientation to particular crack surface [1-4]. Filling the mould by SFRC, fibers are moving and rotating with the concrete matrix till the end of motion in every concrete body internal point. Filling the same mould from the different locations SFRC samples with the different internal structures (and different strength) can be obtained. With the goal to achieve greater mechanical properties and to make material more cost effective (due to optimal use of material ingredients) is necessary to recognize potential internal zones in material with undesirable fiber orientation which can be obtained using traditional casting technologies without additional fiber placing and orientation control in material. This task can be solved in opposite way- creating internal structure (fibers distribution and orientation (see [3, 4]) in SFRC during the casting procedure and after it optimally admitting internal stretching stresses in material. In the present investigation SFRC casting was modeled as filling the mould by viscous flow. Simultaneously single steel fiber rotation and motion in the flow with internal velocity gradients were investigated experimentally and numerically (using FEM). And finally crack opening process in SFRC prism was modeled and was investigated experimentally.

2. FIBRE ROTATION IN VISCOUS FLOW WITH VELOCITY GRADIENT

Single fiber motion in viscous flow with velocity gradient was simulated experimentally (using model liquid with known viscosity parameters - potato-starch fluid) and numerically (using FEM code FLOW 3D). The potato-starch liquid with known viscosity coefficient was poured into the transparent container. Two groups of experiments were executed: a) with short (see Fig. 1) container (208mm long, 90mm high and 100 mm wide) and b) with long container (2400mm long, 200mm high and 200 mm wide (see Fig. 2).



a)



b)

Fig. 1. a) experiment with short container; b) viscous fluid flow velocity (along the container) modeling result (FEM code Flow 3D simulation).

a)

b)

Fig. 2. Experimental equipment (a) long container) for fibers motion investigation in viscous flow; b) fibers in the flow.

2.1 Experiments with short container

Single steel (or polymer) fiber was inserted in the container middle part (with fluid) under the different starting angle to vertical axis. In initial position the container is placed fully horizontally. Then container's one side was lifted up from the horizontal position for required angle and test started. Movement of fiber in our fluid was observed and measured, influenced by the movement of fluid fiber starts to decline to flows direction. Fiber is turning because of movement of fluid and gravitational forces. After declination process stops time and fiber declination angle β were measured. Three experimental angles α - 10°, 15°, 20° were observed.

Above mentioned experiment was numerically simulated using FEM software FLOW-3D. Sample of calculations results is shown in Fig.1 right picture. For simplicity in the model was assumed that container stays in horizontal position and vertical and horizontal axes of gravity components are changing the angle [5]. For angle 10 degrees components of gravitational acceleration was g_x=170,35 cm/s^2, g_z=-966,10 cm/s^2, for 15 degrees g_x=253,90 cm/s^2, g_z=-947,57 cm/s^2, for 20 degrees g_x=335,52 cm/s^2, g_z=-921,84 cm/s^2. Container parameters(the same as in the experiment): length l=20,8 cm, height h=9 cm, and the height of viscous fluid in container 5 cm. The viscosity coefficient

was η=486.14 g/cm·s (was measured), and potato-starch liquid density was used the same as a density of water ρ=1 g/cm^3.
When we know viscous parameters of our fluid and can approve them with numerical calculations then it was possible to go to the next step of calculations – fiber rotation calculation due to velocities variation in liquid flow. Observing forces acting on the fiber in the flow with velocity gradient is possible to conclude that the gradient of horizontal speed (1) between our observed fiber endpoints is the parameter which will establish fiber orientation (and rotation speed) in the flow:

$$grad\ v_x = \frac{v_1 - v_2}{l} \qquad (1).$$

Here v_1 is the horizontal speed of fiber top end, v_2 is the horizontal speed of fiber lower endpoint and l is the length of fiber.

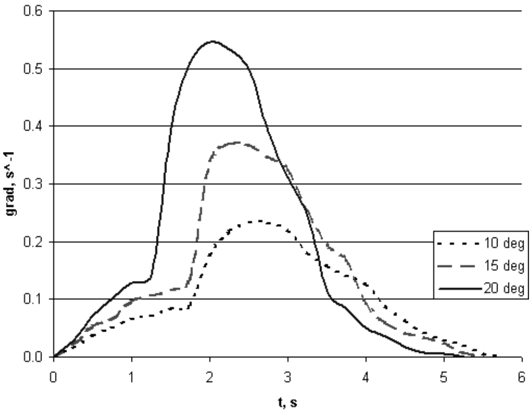


Fig. 3. Speed gradient change in the time after container was placed with declinations for 10°, 15°, 20° degrees.

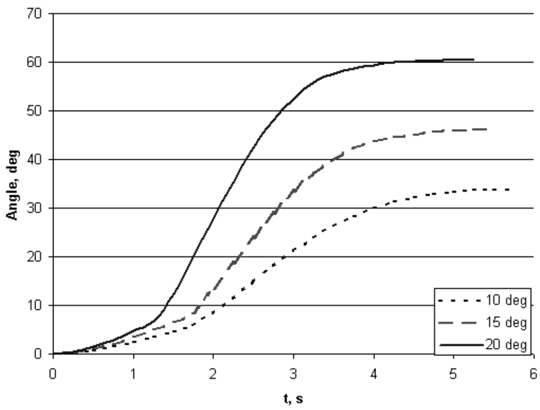
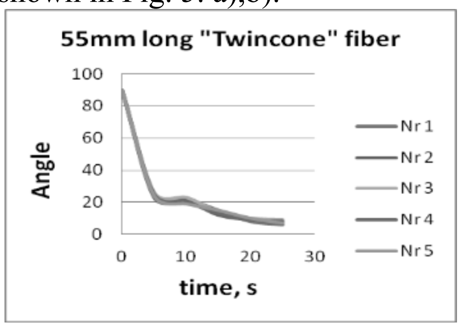


Fig. 4. Fiber angle change after declinations of container for 10°, 15°, 20° degrees.

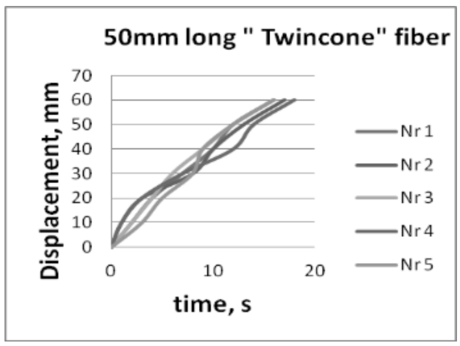
Is possible to presume speed v_2 staying equal to zero (liquid bottom layer is sticking to the container surface). Numerically calculated gradient values for our experiments were shown in Fig. 3, corresponding fiber declination history in Fig. 4.

2.2 Experiments with long container

Few steel (or polymer) fibers were inserted vertically into container middle part (with fluid) (see Fig. 2. b)). In initial position the container is placed fully horizontally. Then container's one side was lifted up from the horizontal position for required angle, simultaneously a valve on the lower end of the container was opened and test started. Movements of fibers in the fluid were observed visually and by video-camera and measured. Each fiber lower end motion distance and declination angle β was measured and was documented depending on the current time. For 50mm long 1mm thick "Twincone" steel fiber dependence are shown in Fig. 5. a),b).



a)



b)

Fig. 5. middle fiber a) declination angle and b) displacement dependence on experiment time.

2.3 Velocity gradients determination during SFRC casting

Filling the mould by SFRC, fibers are moving and rotating in the concrete flow till the end of motion in every concrete body internal point. The mould parameters was 15x15x60 cm, hole for casting (or falling flow cross-section dimensions) was 20x15 cm. The 2D and 3D modeling were performed (FLOW3D code was used). Newtonian fluid 2D flow modeling results are shown in Fig. 6. Mould is filling by SFRC flow falling at the middle of the mould.

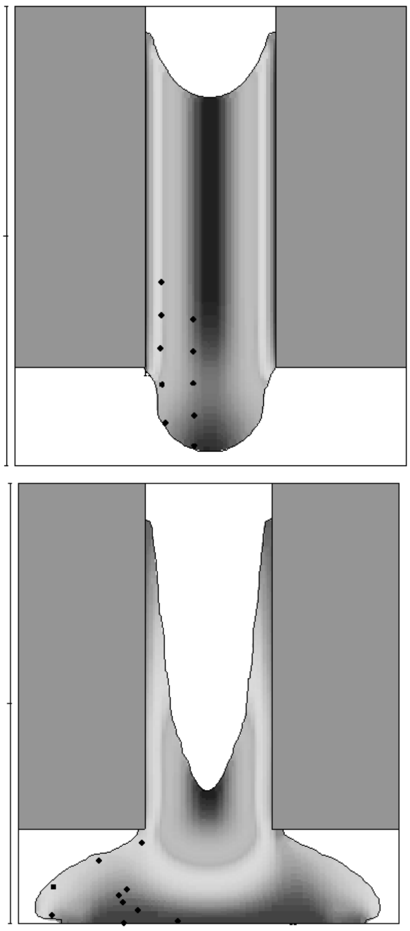


Fig. 6. FEM concrete casting process modeling. Marked points (fibers midpoints) motion in concrete during casting.

The viscosity coefficient was η=5000 GPa·s, liquid density - ρ=2400 kg/m^3. Point markers were placed into the fluid for all flow process visualization (every marker can be observed as the particular single fibers midpoint path in concrete body during the casting (see Fig. 6). In Fig. 7 are shown five marked points trajectories in concrete during filling the mould (till the concrete flow stops in every point). According to symmetry of the process only one half of the mould (and falling SFRC flow) is shown, horizontal coordinate x=0 corresponds to left border of the mould, vertical coordinate y=0 corresponds to the bottom of the mould. Numerical simulations were performed changing the place were external flow is falling to the mould.

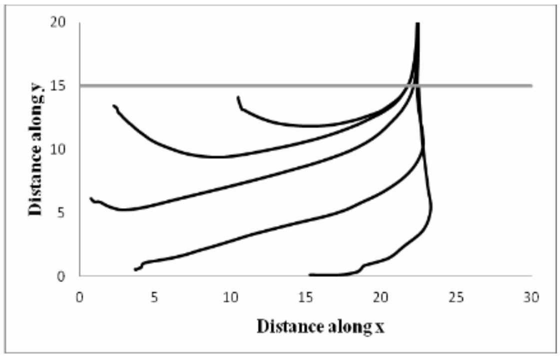


Fig. 7. Trajectories of marked points in the concrete flow during filling the mould.

Calculated vertical velocity gradients in the SFRC filling the mould were obtained and were analyzed (velocity gradient picture is shown in Fig. 8), critical zones in the concrete prism body with high velocity gradients obtained during mould casting were recognized.

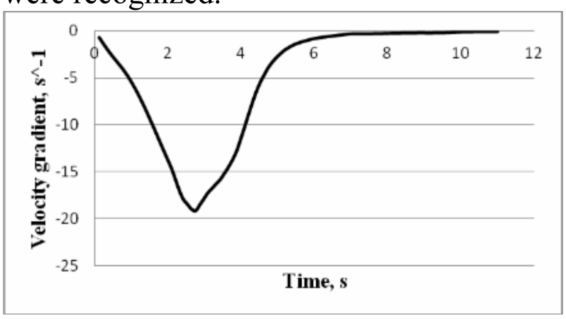


Fig. 8. Velocity gradient in the concrete flow during filling the mould (20<x<25 cm, y=7.5 cm).

3. DESCRIPTION OF THE MODEL

A SFRC beam with chaotic fibre orientation subjected to four point bending was modelled. The geometry (length, form and diameter) and amount of each fibre type is included in fibre-cocktail mix is given. A random distribution function is applied to assign location of each fibre. Fibers orientation function was used depending on velocity gradients were realized in every material internal place. Fibers spatial orientation function was highly different from random (oriented along fibers flow) in critical zones. Orientation parameter was introduced. Monte-Carlo simulations were performed to obtain fibre distribution in every particular SFRC prism. After that, weakest (critical) cross-section was recognized as the cross-section with the smallest amount of fibers crossing it. The crack starts to open. Data from the database file which contains all information from the single fibre pull-out experiments (were obtained earlier) were applied. Performing numerical simulation of above mentioned crack opening process theoretical applied load - CMOD curve was obtained. Modelling result comparison with four point notched prism bending test is shown in Fig. 9.

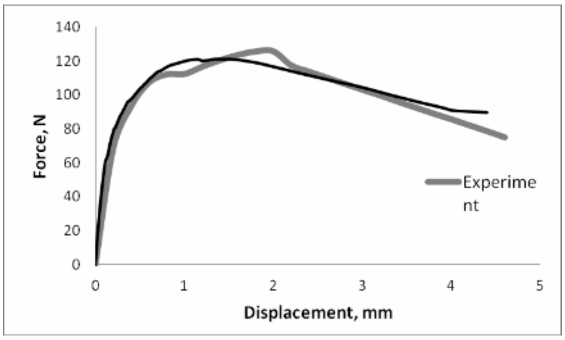


Fig. 9. Load – crack mouth opening displacement (CMOD) diagram for 4 point bending test, SFRC with fiber amount 320 kg/m^3 (Tabix 50).

Fracture surfaces analysis shown high amount of fibers oriented under large angles to crack surface. Ruptured prisms crack surfaces were visually investigated. Pulled out fibers distributions according to orientation (to crack surface) and pulled out length were obtained in every case. Fibers orientations distribution is shown in Fig. 10.

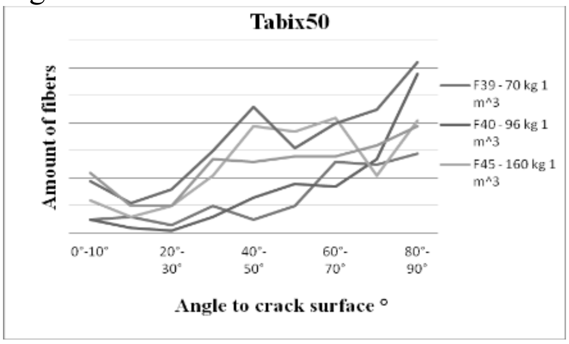


Fig. 10. Pulled out fiber end distribution according to angles to crack surface, depending on fibers Tabix50 amount in concrete.

In Fig. 11 is shown X-ray picture of the prism were potential crack place can be recognized. Place is characterized by non-homogeneous oriented fibers distribution.

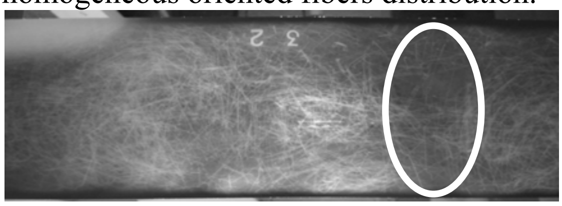


Fig. 11. SFRC prism X-ray picture. View from the flank.

4. CONCLUSIONS

Detailed internal structure formation in SFRC structural elements was performed. Fiberconcrete flow was simulated and investigated numerically in the casting process with the goal to recognize zones in obtained SFRC structural elements with oriented fibers. Experimentally were shown that zones with oriented fibers are the paces of potential macro-crack formation.

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LEACHABILITY OF WOOD PROTECTION AGENTS FROM IMPREGNATED PINE WOOD

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Abstract: *Scots pine (Pinus sylvestris L.) trees were harvested from three different sites. Sapwood was cut to samples (20 × 20 × 50 mm) in as many layers as the dimension in radial direction allowed. It is possible to trace every sample back to its original position in the stem. Wood material was impregnated with commonly used copper-based preservatives, Wolmanit CX-8 and Tanalith. Samples were conditioned and leached according to EN84. Copper and boron content in water samples was determined by an ICP (Inductively Coupled Plasma) technique. The variation in leachability within trees and between different stands was studied.*
Key words: Scots pine, copper-based wood preservatives, EN84, leaching.

1. INTRODUCTION

Wood is relatively light and strong, hence a desirable construction material. Since being a natural material, it is influenced by environment and in order to prolong its usage, needs to be protected from insects and fungi. Impregnation is a widely spread process for protecting wood and to make it durable against termites and environmental conditions. Impregnation has been studied from the viewpoint of penetrability, in order to examine sufficient sapwood penetration and ensure better economic process conditions. [1] [2] [3] Besides the efficiency of the process, the safety of the end product is of interest as well. When treated wood is exposed to rain or surface water during its service life, toxic components can leach and harm the surrounding nature. [4]

After the use of chromium and arsenic containing preservatives (CCA) was restricted due to environmental concerns, other systems were introduced. [5] [6]

In this study copper consisting water-based impregnation solutions were used. Copper occurs in the nature and is a micronutrient for plants and animals at low concentrations. [7] Elevated concentrations become toxic to aquatic life forms. Previous studies have shown that CCA bounds copper most effectively and the element is not that strongly bound in other preservative systems. [8] [9] Therefore copper consisting protecting agents are under observation as well. [6]

Leaching is influenced by the conditions the wood is exposed to, water pH and flow rate, also by growing conditions, wood species and the type of preservatives, extractive content in wood etc. [10] [11]

The main objective of this study was to assess the dependence of leachability of impregnation agents on different wood properties of Scots pine. The same material has been used in studies about permeability, indicating the effect of growing location and origin of the sample in the stem on the treatability. [1] [3]

2. MATERIALS AND METHODS

2.1 Material

Three Scots pine stands were chosen for this study, two from Norway and one from Denmark. Nine trees were harvested from each site, 27 trees in total. After cutting off the top of the tree, 5 sections of 60 cm were taken from 0, 25, 50, 75 and 100 % of remained tree height. From each of the section a block of 75 mm in width was sawn with north-south orientation. Blocks were split exactly through the pith. The two halves of each block were either "air dried" or "kiln dried". Drying method for the north and south side was randomly selected.

Only sapwood was chosen for this study, heartwood was removed. Samples with dimensions of approximately 20 × 20 × 50 mm were cut out in as many layers as the radial size allowed. In total – 893 samples were tested.

After cutting, samples were conditioned at 65 % RH and 20 °C until equilibrium moisture content was reached. To prevent the liquid flow in the longitudinal direction, cross sections of the samples were sealed with a two component sealer (Pyrotect-2K-Aussen-Schutzlack 1720-7100-302, Dreisol coatings GmbH, Germany).

This set of samples was impregnated with Wolmanit CX-8 and Tanalith, which are commonly used water-based copper containing wood protection solutions.

456 samples were treated with Wolmanit CX-8, which is a chromium free, copper- and boron-based wood preservative consisting of 2.8 % Bis-(N-cyclohexyldiazeniumdioxy)-copper (Cu-HDO), 13.04 % Copper hydroxide carbonate and 4 % boric acid.

437 samples were impregnated with Tanalith, which is a water-borne wood preservative based on copper and co-biocides consisting of 22.5 % Copper Carbonate, <45 % 2-AminoethanolCarbonate, 0.49 % Tebuconazole, 4.9 % Boric Acid and <5 % Di-2-ethylhexylphthalate.

2.2 Impregnation

To correlate permeability to leaching, samples were not impregnated to full amount to observe the difference in treatability. Impregnation schedule of 6 Bar for 10 min was used. Pre-trials to develop the scheme was conducted by Larnøy et al. [2]

Samples were weighed before and immediately after impregnation to calculate respective uptake values.

Permeability in this study is calculated with ratio of filling (RoF) which expresses the ratio of actual liquid amount in the wood to the potential filling if the void volume was completely filled. Level of treatment is often determined by retention of preservatives which is related to permeability and density of wood. Larger void volume occurs in less dense wood, which therefore can retain more preservative. In this case, since the impregnation conditions were kept constant, only permeability limits the flow into the sample. High permeability stimulates fast liquid flow and results in high RoF. [2]

$$V_{void} = V_{12\%} - V_{cellwall} - V_{water} + V_{swell} \quad (1)$$

$$RoF = V_{uptake} / V_{void} \times 100\ [\%] \quad (2)$$

where V_{void} is the void volume in wood

$V_{12\,\%}$ is the volume of the sample at 12 % MC

$V_{cellwall}$ is the volume of the cell wall material

V_{water} is the volume of water at 12 % MC

V_{swell} is the potential increase in volume due to swelling

V_{uptake} is the volume of the treating liquid

2.3 Leaching

Prior leaching samples were conditioned in the same manner as after cutting (65 % RH and 20 °C until equilibrium moisture content). Conditioned samples were leached according to EN84 [12], water was changed ten times in fourteen days. Before every change 5 ml of leaching water was gathered from each vessel, all ten collected water samples were pooled and chemically analysed.

2.4 Chemical and data analysis

The leached water was analysed via ICP (Inductively Coupled Plasma) technique. Elements of interest in the leaching water were copper and boron. Water samples were neutralised with hydrochloric acid (HCl) for ICP.

To discover the sources of variance, results of leach-outs were correlated with different physical and anatomical wood properties.

Statistical analyses were executed with JMP Pro 9 by SAS Institute Inc.

3. RESULTS AND DISCUSSION

Raw material has an influence on sapwood permeability, thus leaching can be affected by various wood properties. [1] [2] [3] It has been established that elements are most mobile in the initial phase of leaching, Habicht et al. noted that after first three leaching cycles, copper seems to be fixed and only minimal emission occurs. [8] Similar observations have been reported by Temiz et al., Liibert et al. and Evans. [9] [13] [6]

Besides aforementioned, impregnation and emission are affected by many factors, i.e. time, wood dimensions, wood properties, moisture content, impregnation liquid. In order to fulfil the main objective of the study, most of the factors were kept constant, letting only wood properties influence the leaching of different preservatives.

Leaching in this research can be affected by the mild impregnation scheme, leaving the preservative not enough time to fixate in the wood. With a pre-test, it was confirmed that between impregnation and leaching test EN84 some small amount of preservative leaches out.

Some samples (both Wolmanit CX-8 and Tanalith treated pieces) were regarded as outliers according to Mahalanobis and Jackknife distances and, therefore, excluded from the analysis.

Table 1 shows that both treatment solutions are distributed equally, 13-39 % of whole void volume is filled. Correlating permeability to leaching, no strong relation occurs, for Cu R^2~0.1 and for B R^2~0.4. The weak correlation in Cu case indicated that wood properties have an influence on leaching. For B, the correlation is stronger, displaying that the more boron goes into the wood, the more leaches out. According to literature boron is very soluble in water and the current research backs this argument as most of the test samples lost impregnated boron almost completely, in both Wolmanit CX-8 and Tanalith case, making it hard to evaluate the raw material's influence. [14] [15]

Screening on possible variables to determine what affects leaching did not give any moderate correlations (R^2>0.01) or significant differences (95 % confidence level) for density, latewood amount,

Treatment	Variable	Dimension	N	Mean	Std dev	min	max
Wolmanit CX-8	uptake	kg m^{-3}	456	209	38	114	312
Tanalith	uptake	kg m^{-3}	437	210	32	109	290
Wolmanit CX-8	RoF	%	456	26	5	13	39
Tanalith	RoF	%	437	26	5	13	39
Wolmanit CX-8	Cu leaching	mg L^{-1}	456	0.57	0.16	0.33	1.14
Tanalith	Cu leaching	mg L^{-1}	437	0.74	0.24	0.33	1.43
Wolmanit CX-8	B leaching	mg L^{-1}	456	0.56	0.14	0.28	0.93
Tanalith	B leaching	mg L^{-1}	437	0.43	0.11	0.16	0.78

Table 1. Overview of outcomes

exposure side, sample age, horizontal position and dominance class. Potential influences by Tukey-Kramer test are impregnation liquid, latitude, vertical position of the sample and drying method.
Wolmanit CX-8 treated samples tend to leach out slightly less of impregnated copper than Tanalith treated pieces. Humar et al. discovered that larger amount of boron in preservative can increase copper leaching, that including boric acid which is present in both Wolmanit CX-8 and Tanalith solutions. In Tanalith boron is represented in slightly larger percentage, which can influence the amount of unfixed Cu in the samples. [16] Evans, who used the same preservatives for his study, recorded difference in leaching from the different solutions, but does not disclose which product is more susceptible to copper emission. According to his work copper leaching can be reduced by treating wood surface with wood oils. [6] Treu et al. and Liibert et al. who studied combined impregnation process found out that copper emission can be reduced by treating wood in a combination process with hot oil. [17] [13]
Tukey-Kramer test reveals differences in the way preservatives act during leaching – latitude plays role in Tanalith leaching but does not affect Wolmanit CX-8 leaching. Trees from Denmark, from the southern stand, are more prone to emit the former preservative.
In both cases, vertical position has an effect, indicating that samples from the lowest part of the tree fixate less preservative than those from the upper parts.
Wolmanit CX-8 was also influenced by drying method, indicating that naturally dried timber leached out more preservative than kiln dried.
The same variables were found to affect permeability, i.e. ratio of filling, in the same manner as leaching – samples from the southern stand, the lowest part of the kiln dried tree were easiest to treat. [1] [2] [3] In this project, although leaching is stronger from naturally dried wood, the drying method shows no effect on RoF.

4. CONCLUSIONS

The study shows the influence of the harvesting site and wood variables on the leaching behaviour of copper-based preservatives. Significant difference was found between impregnation liquids. A significant correlation between vertical stem position of the samples and the emission of Cu from preservatives was exhibited. Preservatives leached more from the lowest part of the stem. Naturally dried wood emitted more copper than kiln dried and southern latitudes could not fixate preservatives as properly as northern latitudes.

5. ACKNOWLEDGEMENTS

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BEHAVIOR OF TI-15-3 ALLOY AT A WIDE RANGE OF STRAIN RATES AND TEMPERATURES

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Abstract: *Increasing number of practical applications, such as many high-rate manufacturing processes, involve large plastic deformations at high strain rates and at the same time at elevated temperatures. Therefore, future designs and improvements in the existing technological processes and applications are difficult without proper understanding of the material response to high-rate loadings at different temperatures. In addition, development of improved material models and validation of FE simulation results using these models require reliable experimental data at these conditions. This paper presents a computer controlled system for compression testing at high strain rates and high temperatures. The mechanical behavior of Ti-15-3 alloy was studied using this setup at wide ranges of strain rates and temperatures. Also, the Johnson-Cook plasticity model was used to simulate the material behavior.*

Key words: strain rate, high temperature, Split Hopkinson Pressure Bar, Ti-15V-3Al-3Sn-3Cr.

1. INTRODUCTION

Today there is an increasing number of applications where high rate deformations occur. Good examples are high-speed material forming and cutting operations, car crashes, vibrations of structures and buildings during earthquakes, and various aerospace applications. Especially in these kind of applications, the dependence of material properties on strain rate must be known to justify materials selection and to facilitate modeling and simulation of the material behavior.

Titanium alloy Ti-15V3Cr3Al3Sn, commercially known as 15-3, is a metastable beta-titanium alloy, first introduced in 1978 by American company USAF. Beta-titanium alloys like Ti15-3 show a unique combination of high strength, high ductility, and low density. The most important industries using these alloys are the aerospace, power generation, and chemical industries. Continuous demand for higher safety and lower CO_2 emissions make titanium alloys attractive for automotive industry as well, but so far their use has been rather limited due to the high cost of the material [1, 2]. The relatively high price of titanium alloys, compared to other construction materials, has two principal reasons: 1) the production costs of the raw material and 2) the costs related to the manufacturing of the components. In some instances, up to 50% of the material has to be removed with different machining processes [3], which can be very time consuming and therefore expensive due to the generally poor machinability of titanium alloys. Automated high speed machining of Ti-15-3 is hampered by two key factors: first, the continuous chip production, due to which the operator must continuously interfere with the process to remove the chips manually, and second, the accelerated wear of the cutting tools due to the adiabatic heating and poor heat conductivity of the metal, which in turn causes insufficient geometrical and surface tolerances of the workpiece [3].

The machinability of titanium alloys can be improved by developing so-called free machining alloys with better chip formation properties, by developing better tools, and by enhancing machining procedures, which can be greatly assisted by proper modeling of the material behavior and simulation of the machining process.

1.1 Deformation and testing at high strain rates and high temperatures

The strain rate dependence of flow stress in crystalline materials at low and intermediate strain rates is explained by the thermally activated dislocation motion, but a steep upturn in the flow stress is often observed at higher strain rates. This rapid increase of strength can be explained by phenomena caused by viscous drag on dislocations at higher dislocation velocities. Also temperature affects the material behavior by changing the available thermal energy and character of the obstacles for the dislocations. Changes in the material temperature can, in turn, happen for both external and internal reasons. During deformation only 5 to 10 % of imparted energy is consumed for restructuring the defect (dislocation) structure of the material, and most of the work is dissipated as heat. When strain rate increases, there simply is not enough time for the heat to escape from the deforming material, and the isothermal conditions of low strain rate deformation change towards more adiabatic during deformation at higher strain rates. As a consequence, the deformation may become highly localized at very narrow regions or adiabatic shear bands.

Split Hopkinson Pressure Bar (SHPB) is the most widely used technique for conducting high strain rate tests in the range of 10^2 to 10^4 s^{-1}. The compression test apparatus consists of two symmetrical slender bars, between which the small cylindrical specimen is sandwiched. The actual test is performed by impacting a striker bar to the free end of the first (incident) bar and by the consequent travel of the elastic stress pulse through the specimen, deforming it at a high rate.

Conducting high strain rate tests at elevated temperatures is rather challenging due to several practical and scientific reasons. The test setups found in the literature can be divided into two basic methods: 1) heating up all or short sections of the incident and transmitted bars together with the specimen, and 2) heating the specimen only while keeping the bars at room temperature throughout the test. The first method involves an inherent problem that limits its usable temperature range: when heating up the bars their physical properties change, which affects the strength of the bars and the speed of the elastic waves distorting the measured stress pulses. The change in the speed of the wave is difficult to account for and the necessary mathematical or mechanical corrections are complicated. Restrictions to the second technique are set by the allowed contact time of the hot specimen with the cold bars before the impact. The contact time can be minimized by a special manipulation system for the bars and the specimen and using, for example, a furnace or a radiation heater outside the axis of the bars. The essence of this method is to bring the hot specimen and the cold bars into contact just a fraction of a second before the impact of the striker on the input bar. Both the control and timing of the specimen heating and the movements of the bars and the specimen are very critical and can only be done using computer controlled systems.

2. DESCRIPTION OF THE HT-SHPB SYSTEM

The following Chapters describe the high temperature Split Hopkinson Pressure Bar device designed and built at the Department of Materials Science of Tampere University of Technology.

2.1 SHPB device

The device typically consists of two 1-2 m long metal bars with a diameter of 10-25 mm, and a striker bar, usually made of the same material and with the same diameter as the stress bars. When the striker bar is shot against the free end of the incident stress bar, the impact generates a stress pulse that propagates in the incident bar towards the specimen, which is sandwiched between the incident and transmitted bars. As the stress pulse reaches the bar-specimen interface, part of the pulse is reflected back as a wave of tension while part of it is transmitted through the specimen into the transmitted bar. The specimen is deformed plastically at a high strain rate as the pulse travels through it. Stress, strain, and strain rate in the specimen can be calculated from the three elastic stress pulses, incident, reflected, and transmitted pulses, measured from the pressure bars using strain gages and recorded with a digital oscilloscope.

The compression SHPB test system built at the Department of Materials Science of Tampere University of Technology (TUT) uses pressure bars made of high strength steel (YS ~ 1100 MPa), Maraging steel (YS ~ 1850 MPa), or high strength aluminium alloy 7075 (YS~500 MPa). Compression behaviour of materials can be studied in a strain rate range of $2 \cdot 10^2 - 10^4 s^{-1}$ by varying the length and the impact velocity of the striker bar and the length of the specimen. For data acquisition, a pair of strain gauges is bonded on both the incident and the transmitted bars. The signals are amplified using a signal conditioner with a bandwidth of 500 kHz and recorded on a 12-bit 10 Msample digital oscilloscope. Test data is downloaded to a PC and processed further with MATLAB based calculation routines.

2.2 High Temperature (HT) System

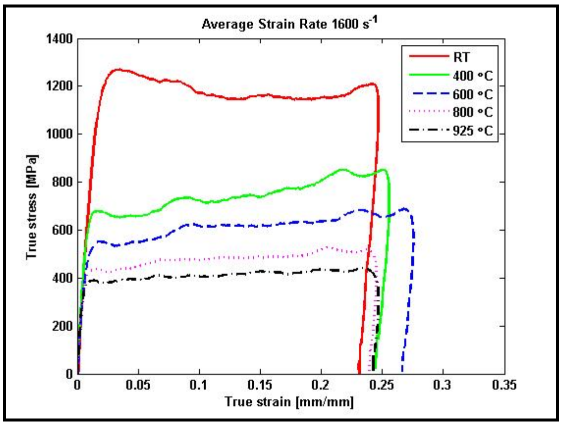
The fully computerized high temperature SHPB (HT-SHPB) system at TUT is constructed using the idea of only heating the specimen and keeping the other components of the testing system at room temperature. The specimen is first placed in a specimen holder using a ceramic wool support ring. The specimen holder is then pushed into the furnace by a pneumatic manipulation system. When the specimen has reached the desired test temperature, the manipulator rapidly retracts the specimen at high speed from the furnace to the centerline of the bars. The striker bar is shot, and just before it hits the incident bar, a transmitted bar manipulator pushes the bars and the specimen together. This way the maximum contact time of less than 50 ms is ensured between the hot specimen and the cold bars. The specimen is heated by a small resistive tube furnace with a maximum temperature of 1000 ºC. Entrance of the furnace is shielded with a special pneumatically controlled shutter to protect the bars from the heat. During heating of the specimen, a flow of inert gas is maintained to prevent the specimen from oxidizing. The specimen temperature is measured directly from the surface of the specimen using a K-type thermocouple touching the surface of the specimen. A summary of the system capabilities is given in Table 1.

Type of loading	Compression
Duration of the loading pulse [s]	50 ... 200 10^{-6}
Strain rate range [s^{-1}]	10^2... 10^4
Load range [kN]	0...250
Temperature range [ºC]	-150...1000
Specimen dimension [mm]	D<22; h~0.5…12

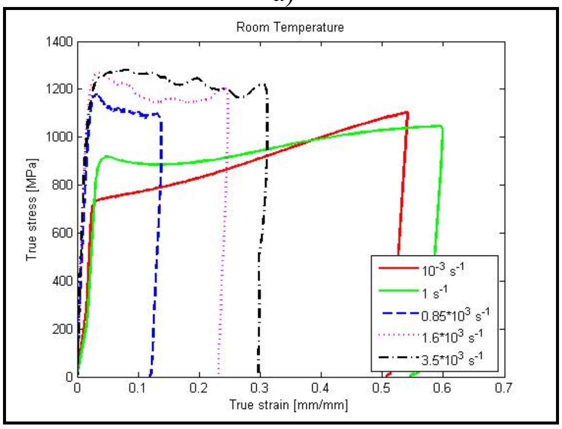
Table 1. SHPB system capabilities at TUT [5, 6].

3. RESULTS

Figure 3 shows true stress-true strain curves for the 15-3 alloy at different temperatures and strain rates. A substantial decrease in the flow stress levels with increasing temperature can be clearly seen in Fig 3a. At the strain rate 1600 s^{-1} at RT (Fig 3a), strain hardening takes place in the beginning of the test, but after a few percent of plastic deformation the material first strain softens and then shows almost ideal plastic deformation behavior. With increasing temperatures the material shows notable strain hardening also at higher strains, especially at 400 ºC, as seen in Fig. 3a.



a)



b)

Fig. 3. Compression true stress – true strain curves for the Ti-15-3 alloy a) at different temperatures at an average strain rate of 1600 s^{-1}, and b) at different strain rates at room temperature.

The strain hardening rate, however, decreases when the temperature is further increased from 400 ºC, and at the highest test temperature of 925 ºC, the work hardening rate is already very low, most likely due to the fast dynamic recovery taking place at high temperatures.

Figure 3b shows the room temperature stress-strain response of the material at different strain rates. The flow stress levels increase notably with increasing strain rate, especially in the low strain regime, but the strain hardening rate clearly decreases at the same time. As can be seen in Fig 3b, at high strains the strength of the material at 10^{-3} s^{-1} even exceeds that at 1 s^{-1}, which is evidently related to the internal (adiabatic) heating of the material.

4. MODELING

One way to numerically describe the plastic deformation of materials is to use mathematical expressions that relate the dependencies of flow stress to variables describing the state of the material and the deformation conditions. Commonly used variables include strain, strain rate, and temperature, and the equations of state can be written in a general form as

$$\sigma = f(\varepsilon, \dot{\varepsilon}, T) \tag{1}$$

A good model should be able to reproduce the real material behavior well enough, be mathematically simple, and to have an optimum (small) number of material parameters. Due to the interdependence of parameters on each other, setting up an ideal model is an extremely hard task. In engineering, compromises are usually needed, and typically somewhat simplified models are used that still provide the needed accuracy.

4.1 Johnson-Cook Model

The most widely used semi-empirical equation is the Johnson-Cook model

$$\sigma(\varepsilon, \dot{\varepsilon}, T) = \left(A + B \cdot \varepsilon^n\right)\left(1 + C \cdot \ln\left[\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{ref}}\right]\right)\left(1 - \left[\frac{T - T_r}{T_m - T_r}\right]^m\right) \tag{2}$$

which describes the flow stress as a multiplication of three terms. The first term represents the dependence of flow stress on strain, the second term on strain rate, and the third on temperature. It includes five material parameters that are to be determined from a set of tests performed at different strain rates and temperatures. The model, however, has a fundamental problem that it assumes the parameters to be independent of each other, which for most materials and deformation conditions is not the case. However, the Johnson-Cook model is still broadly used mostly because of its simplicity and availability of the parameters.

The first three parameters A, B, and n are determined by fitting the Ludwik's equation, the first term in the model, on the reference stress-strain curve (often the curve obtained at room temperature at the strain rate of 1 s^{-1}, where the conditions are still isothermal for most materials). The remaining two parameters are then determined by fitting the model to the data measured at different temperatures and strain rates.

The material studied in this work, Ti-15-3, is a modest heat conductor and heats up considerably during plastic deformation. Because of this, an additional term was introduced into the model to take also the adiabatic heating into account, i.e,

$$\sigma_a(\varepsilon,\dot{\varepsilon},T)=\left(A+B\cdot\varepsilon^n\right)\left(1+C\cdot\ln\left[\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{ref}}\right]\right)\left(1-\left[\frac{T+\Delta T-T_r}{T_m-T_r}\right]^m\right) \quad (3)$$

$$\Delta T=\frac{\beta}{\rho\cdot C_p}\int\sigma\cdot d\varepsilon \quad (4)$$

In this study an attempt was made to find a single set of values for the model parameters over the whole studied range of strain rates and temperatures. The first initial set of values was obtained from room temperature low strain rate tests. Several rounds of iterations were made, during which the initial set was compared to the experimental results obtained at different strain rates and temperatures. As a result of fitting, the model into the compression test data, the following set of material parameters for the Johnson-Cook (J-C) model (Table 2) was found to give the best fit at the strain rate range of 10^{-3}-4×10^{3} s^{-1} and the temperature range of 295-1273 K.

A	B	n	C	m
754	992	1.3	0.02	0.7

Table 2. Parameters for the Johnson-Cook Equation for titanium 15-3 alloy.

Figure 4 shows the comparison of the experimental stress-strain curves and the curves calculated using the Johnson-Cook model (Table 2). The calculated values match extremely well with the measured data at the reference conditions, i.e., room temperature and strain rate of 10^{-3} s^{-1}. However, the model does not predict the material behavior at higher strain rates, and the calculated stresses are clearly underestimated. Furthermore, simply increasing the strain rate sensitivity of the model by increasing the parameter ‘C’ will lead to increasing strain hardening rate as a function of strain rate, which does not agree with the experimental observations in Figure 3, where the strain hardening rate decreases with strain rate. However, the fit is significantly improved if only relatively narrow ranges of strain rate and temperature are used. Therefore it is obvious that separate sets of J-C parameters should be used for different strain rate and temperature regimes.

The main reason for the J-C model not to be capable of reproducing the true stress-strain response of Ti-15-3 is related to the strain hardening behavior of this material that deviates considerably from the shape of the Ludwik equation. Also the general interdependence of the J-C model parameters on each other limits the usability of the model to narrower ranges of strain rates and temperatures. For any positive value of parameter ‘C’, the strain hardening rate predicted by the model increases with strain rate. For the titanium 15-3 alloy this seems not to be the case, as the strong adiabatic heating decreases the strain hardening rate rapidly at strain rates higher than 1 s^{-1}.

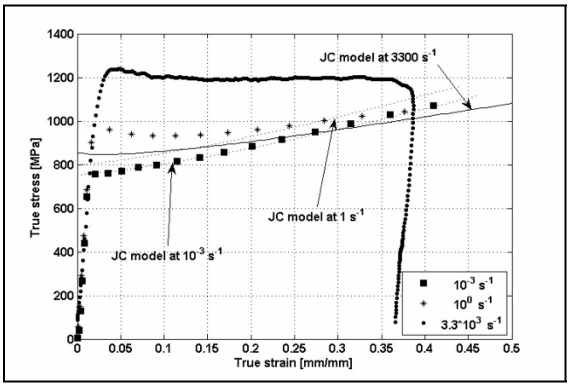


Fig. 4. The comparison of measured and calculated stress strain curves.

5. CONCLUSIONS

In this paper, a computer controlled HT-SHPB testing system is described in details, as well as some example results of the high temperature high strain rate testing of titanium 15-3 alloy. The results of the compression tests for the titanium 15-3 alloy show strong positive strain rate sensitivity at room temperature. Also the strain hardening rate is strongly affected by both the strain rate and temperature. At room temperature the strain hardening rate clearly decreases with increasing strain rate, and even becomes negative at very high strain rates and small strains.

No single set of Johnson-Cook parameter values was found to be able to describe the mechanical behavior of Ti-15-3 over the studied wide range of strain rates and temperatures. Therefore the model parameters have to be defined for narrower regions of strain rate and temperature to yield acceptable fits between the calculated and experimental stress strain curves.

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Behaviour and Modelling of Titanium 15-3 Alloy at a Wide Range of Strain Rates and Temperatures

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POTENTIAL ECO-FRIENDLY WOOD PROTECTION SYSTEMS USED IN ROYAL PROCESS

Liibert, L.[1] Treu, A.[2] Kers, J.[1] & Meier, P.[3]

Abstract: *Royal process is a two stage wood-processing method; firstly the wood is preserved with a copper-based preservative system and then followed by hot oil treatment under vacuum for 3 hours. Royal treated wood products (garden furniture, cladding, terrace etc.) are used for exterior applications due to high dimensional stability and durability. New governmental restrictions, rising environmental and disposal concerns have resulted rapid global shift to copper-based systems. The aim of this study was to investigate potential alternatives for copper-based system used in Royal process. Lab scale experimental equipment for oil treatment was set up.*

Key words: linseed oil, copper, chitosan, tannin propiconazole, scots pine, CX-8

1. INTRODUCTION

Scots pine sapwood samples were impregnated with two different natural polymers and organic biocide – chitosan, tannin and propiconazole and a commercial copper salt preservative Wolmanit CX-8 as a control; afterwards impregnated samples were oil-treated with modified linseed oil. Two different preservative fixation parameters were performed. Preservative, oil retention and moisture content were calculated. The results indicated that 24 hour fixation time is needed. After leaching, specimens were exposed to fungal attack according to EN113. The fungal resistance of samples impregnated with natural polymers (tannin, chitosan) by using Royal process was improved. The results showed that Royal process works well with propiconazole. Eco-friendly improvement in Royal process was developed.

Wood can be considered as one of the most sustainable materials. Wood is natural, renewable, recyclable and biodegradable, but untreated wood in outdoor exposure becomes easily subject to degradation by various causes such as different microorganisms, UV radiation and moisture. To prevent degradation, wood products are treated with different technologies – biocidal or non-biocidal systems. Major biocidal systems are water-borne copper-rich systems that contain complexed copper(II) and an organic cobiocide (e.g. Copper xyligen (CX), alkaline copper quat (ACQ) and copper azole (CA)). Non-biocidal methods include treating wood with various resins, polymers, oils, chemical modification, silanes and heat treatment [1].

Royal process is a wood processing method which combines wood preservation with biocidal system and subsequent non-biocidal treatment. In other words, wood is impregnated with water-borne copper-based preservative and afterwards treated with hot oil [2], [3], [4].

Modern copper-based preservatives are effective against fungi, but have lower fixation rate compared to chromate copper arsenate (CCA) and can easily be leached out during outdoor exposure conditions [5], [6], [7].

Royal process has a great environmental advantage; it significantly reduces the leaching of copper in use [4], [8]. New governmental restrictions and environmental concerns have resulted rapid global shift to metal-based with non-metallic systems. For example, ongoing studies are investigating the use of organic biocides, natural polymers for nontoxic wood preservatives [14], [11].

Propiconazole is a derivate of triazole, an organic biocide, which was developed originally as agrochemical. Propiconazole is highly effective against fungi, leach resistance and biodegradable in the soil [1], [9].

Chitosan is a derivate of chitin, a natural polymer, which is manufactured primarily from waste products of crabs and shrimps. In recent years chitosan has received attention as a potential eco-friendly wood preservative [10], [11], [12].

Tannins are natural phenolic polymers, commercially produced from wood and barks. Several observations have shown fungicidal effect of tannins [13]. It is known that tannins show poor fixation. They accumulate on the wood surface and leach easily [14].

Wood destroying fungus causes serious damage to wood structures. Fungus requires four fundamentals to survive which are oxygen, favourable temperatures, moisture and nutrients. Decay fungi are divided into three types: soft-, white and brown rot.

The aim of this study was to investigate potential alternatives for copper-based system used in Royal process.

2. MATERIAL AND METHODS

2.1. Wood samples

Scots pine sapwood (*Pinus sylvestris* L.) blocks (50 x 25 x 15 mm) were selected, end-sealed and oven-dried at 103 ± 2°C for 24 hours. Absolute dry weight was recorded and samples were conditioned at 20°C and 65% relative humidity before impregnation.

2.2. Wood protection agents

Wood protection agents are presented in **Table 1.** The chitosan solution preparation, determination of the degree of deacetylation (FA) and the molecular weight (Mw) were examined by methods described by Larnøy [11].

Mimosa tannin powder was dissolved with deionized water without any additional chemicals.

Table 1: Overview of used wood protection agents in this research

Solution	Con-cent. [%]	Description	Active agent
Wolmanit CX-8	4.0	Commercial chromium free preservative based on copper and inorganic copper and boron compounds, pH = 9.5	Cu
Scanimp	5.1	Commercial microemulsion based on organic biocides. pH= 3.0	Propicon-azole
Kitoflokk	5.0	Chitosan, natural polymer produced from crabs, pH= 5.3	D-glucos-amine
Tannin	5.0	Water soluble polyphenol produced from mimosa bark, pH= 4.7	
Oil	-	Modified linseed oil produced from flax plant seed, drying oil	

2.3. Royal process

The Royal process includes two steps: impregnation procedure and following oil process.

2.3.1. Impregnation procedure

The impregnation procedure was identical for all solutions by using vacuum of 0.004 MPa for 30 min, and pressure of 0.9 MPa for 1 h. The samples were weighed to determine retention of solutions which was calculated by using the following Eq. 1

$$R = \frac{G \times C}{V} \text{, [kg/m}^3\text{]} \quad (1)$$

where G: (T2–T1) is absorbed solution in sample in kilograms, C is concentration of solution, and V is volume of sample in cubic meters.

2.3.2. Oil process

In the second step the samples were treated with hot oil (modified linseed oil) at temperature 80°C in a vacuum (100 mbar) for 3 hours. Some seconds before the end of the process samples were pulled out from the oil and then air was released in afterwards in order to avoid high oil uptakes of the samples. Three sets of samples were run using 10 specimens for each set: 1) Samples were exposed to hot oil directly after impregnation; 2) Samples were stored 24 hours for fixation; 3) Samples without oil treatment were tested as controls. After the process, samples were dried at a temperature of 55°C and using 20 mbar vacuum until stabilization (7 days) to determine the oil uptake.

2.4. Decay test

The conditioned samples were leached according to the European standard EN84 (1997). After leaching, samples were vacuum dried. The specimens were exposed to fungi according to the EN113 (1996) using brown-rot fungi *Coniophora puteana* (CP) and white-rot fungi *Trametes Versicolor* (TV).The incubation time was 16 weeks at 22° C and 70% RH. After harvesting the samples were dried at 103 ± 2° C for 24 hours. Mass loss were calculated according to Eq.2.

$$Mass\ loss\ (\%) = \left[\frac{m_0 - m_1}{m_0}\right] \quad (2)$$

Where m_0 is the initial dry weight and m_1 is the final dry weight after exposure to fungus.

3. RESULTS AND DISCUSSION

Before impregnation, the samples had mean moisture content 8.6 % with a standard deviation of 0.1 %.

3.1. Retention and oil uptake

Table 2 shows the retention of preservatives and oil. The average uptake for Wolmanit CX-8 was 25.2 ± 3.2 kg/m³, which is as twice high as the uptake achieved by a „ Lowry process"[15]. It has been reported that average uptake of chitosan is 30 kg/m³, which is comparable with gained results in this study [16].

Samples directly exposed to hot oil after impregnation process had higher oil retention compared to samples with 24 hour fixation. According to previous studies of Royal process, the oil uptake increases with increasing fixation time. Higher oil uptake of wood samples without fixation could be explained by cracks that developed due to faster drying on end-sealed surfaces [3].

Table 2: Mean retention of solutions and mod. linseed oil

Solution	Retention [kg/m³]	Treatment	Oil retention [kg/m³]
CX-8	25.2 (3.2)	directly	151 (43)
		24 h fixation	63 (25)
ScanImp	34.8 (1.2)	directly	207 (54)
		24 h fixation	75 (17)
Kitoflokk	33.2 (4.4)	directly	110 (40)
		24 h fixation	75 (29)
Tannin	32.1 (5.0)	directly	102 (37)
		24 h	62 (13)

		fixation	

3.2. Moisture content before and after Royal process

Moisture content after different oil treatments was significantly lower than it was expected (min 1.8 % ±0.5 % for CX-8 (24 h) treated with oil). Treated samples were all very dry and full of oil. Purpose for industry is to dry wood from wet stadium to a wood moisture content of 12 % – 20 % [3].

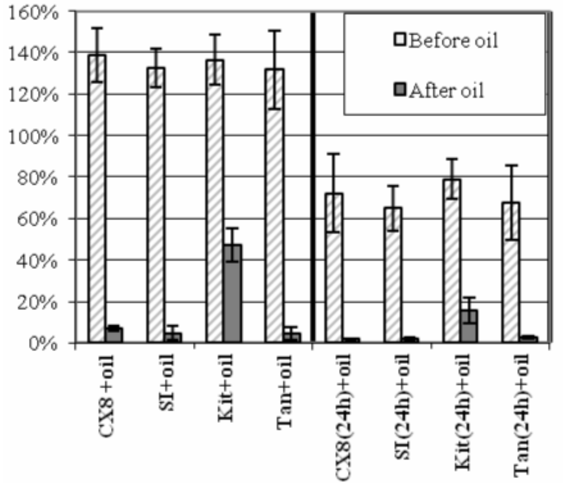

Fig.1. Wood moisture content of Scots pine sapwood before and after oil process, SI – samples treated with Scanimp, Kito – Kitoflokk, Tan- tannin

3.3. Decay test

The mass loss during fungal exposure is displayed inFig.4-7.Samples treated with CX8, Scanimp and their oil combinations showed less than 3% mass loss for both fungi species. According to other studies, chitosan and tannin have fixation problems [14]. This could not been proved by this study. However, chitosan treated sampleswithout oil show poor protective properties when exposed to brown rot. Furthermore, tannin- and chitosan- treated samples without oil show poor protective properties against white rot. Chitosan and tannin samples treated in oil directly after impregnation with a wood protection agent and after 24 hour fixation showed very high antifungal effect against brown rot.

However, chitosan and tannin treated samples without oil treatment showed low antifungal effect against white rot.

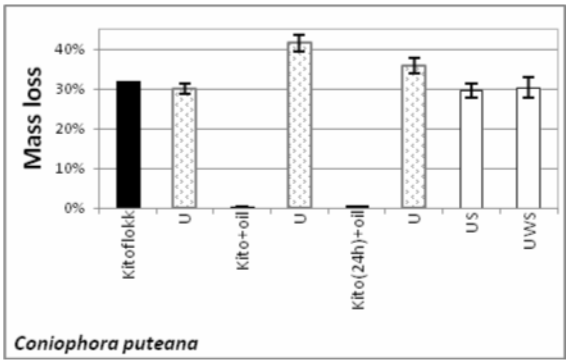

Fig.2.

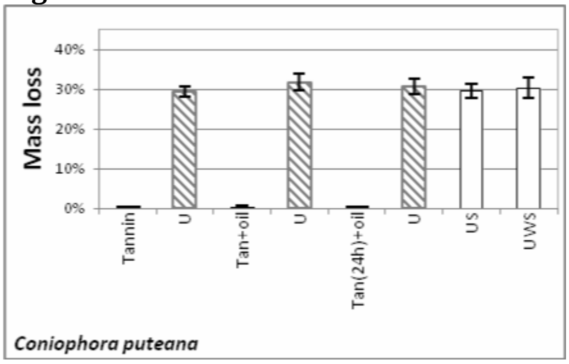

Fig.3.

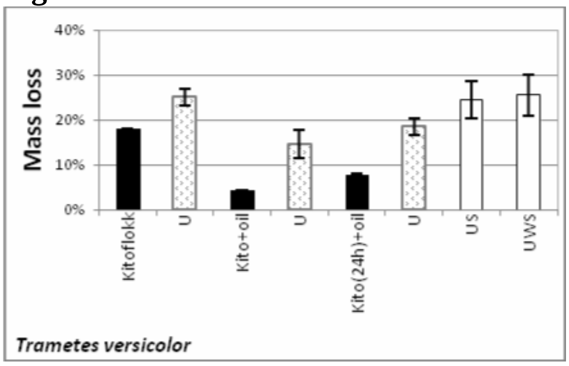

Fig. 4.

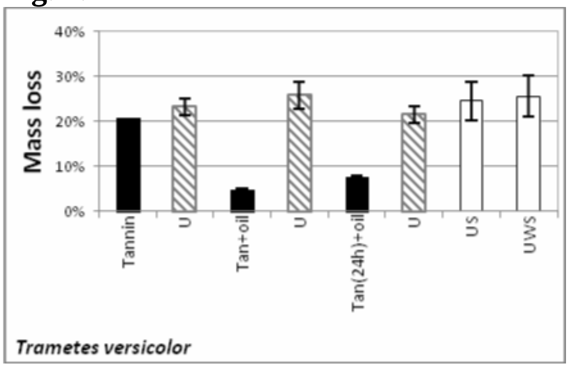

Fig.5.

Fig 2-5: Mass loss of different treated and untreated wood samples after 16 weeks of exposure to brown rot (*Coniophora puteana*) and white rot (*Trametes versicolor*). U-untreated sample, US-virulence with end grain sealing, USW-virulence without sealing.

4. CONCLUSIONS

The two tested commercial wood preservatives alone or in combination with an oil treatment showed high resistance against fungal attack.
The natural product chitosan showed low resistance against fungal attack. However, in combination with an oil treatment a high resistance against brown rot attack could be shown. In contrast, white rot attack could not be prevented with chitosan in combination with oil.
Wood samples treated with the natural product tannin and in combination with an oil treatment showed good antifungal properties when exposed to brown rot. However, white rot attack could not be prevented. Tannins and chitosan used as a wood protection agent in a Royal process, might be therefore not be suitable as an alternative to CX-8 in Royal process.
Scanimp provides high antifungal effectiveness and as an organic biocide could be an alternative product for copper-based products used in Royal process.

5. ACKNOWLEDGEMENTS

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COMPARISON OF VALUES OF RESIDUAL STRESSES DETERMINED BY VARIOUS METHODS IN HARD NICKEL COATINGS PREPARED BY BRUSH-PLATING IN SULFATE SOLUTION

Lille, H.; Ryabchikov, A.; Kõo, J.; Reitsnik, R.; Veinthal, R.; Mikli, V. & Sergejev, F.

Abstract: *Hard nickel coatings were deposited from a sulfate solution onto brass substrates (strips, unclosed rings).*
The equations used for calculating of residual stresses are based on the conventional curvature method. For comparison, residual stresses were determined by the semi-destructive hole-drilling method and by the X-ray technique. The values of residual stresses determined by mechanical methods and by the X-ray technique were comparable.
The surface morphology and microstructure of the coatings was studied by means of scanning electron microscopy (SEM).
The values of the modulus of elasticity and micro- and nanohardness of the coatings were obtained.

Keywords: brush-plating, nickel coating, residual stresses, curvature method, hole-drilling, X-ray technique, morphology, microstructure, hardness.

1. INTRODUCTION

Brush-plated hard nickel coatings investigated in the present study are generally used in repair and maintenance [1,2,3,4].
One of the difficulties related to brush-plating is the problem of layer delaminating due to the unfavourable residual stress state.
To determinate residual stresses, a conventional curvature method was used, where a coating is deposited on a strip or unclosed ring strip substrate with slipping ends or edges, which deforms without bending during deposition. The change of the axial deformation of the free surface of strip substrate during the manually coating depositing process was measured by a self-temperature compensated strain gauge. The slit increment of the unclosed ring substrate was measured at certain coating thicknesses. The dependence of the deformation parameter on coating thickness was used as experimental information.
The experimental results were previously approximated by an analytical expression assuming that the dependence of residual stress on coating thickness is linear-fractional [5].
Residual stresses of the coating on strip substrate were determined by the hole-drilling method. The hole-drilling technique, known as a semi-destructive method, is the most common method for measuring residual stresses and it can be used directly for coated machine parts. This method requires drilling a small hole, typically 1-4 mm in diameter, to a depth approximately equal to its diameter.
Residual stresses were also measured by the X-ray technique. Calculation was done according to well-known Bragg’s formula.
The values of the modulus of elasticity and micro- and nanohardness of the coatings were obtained by instrumented indentation.
The morphology and microstructure of the studied coatings were investigated.

2. EVALUATION OF RESIDUAL STRESSES

Residual stresses in one and the same layer are expressed, according to the general algorithm of layer growing/removing method, as the sum of the initial and the additional stresses [6]. Stresses in the superficial layer are named initial stresses. Additional stresses are understood as the stresses which arise in this layer when subsequent layers are applied. The coated substrate (part) is usually so rigid that residual stresses are practically equal to the initial stresses. The equation used in calculations is based on the Brenner and Senderoff's concept [5], where the substrate is examined as the beam with slipping ends (momentless condition), the equation for the ring substrate is modified to account for biaxial stresses and the shell shape of the substrate which is taken into consideration by an appropriate coefficient [5, 8].

$$\bar{\sigma}(h) = -E_1'(h_1 + \nu h)\frac{d\varepsilon(h)}{dh}, \qquad (1)$$

$$\bar{\sigma}(h) = \frac{E_1 F}{12\pi R_0^2}\frac{f_4}{f_2}\frac{d\delta(h)}{dh}, \qquad (2)$$

where ε is the measured axial deformation on the free surface of the substrate, δ is the measured slit increment, h_1 is substrate thickness; h is the variable thickness of the coating, $\nu = E_2'/E_1'$ is the ratio of the elastic parameters of the coating and substrate, $E_1' = E_1/(1-\mu_1)$, $E_2' = E_2/(1-\mu_2)$, E_1, E_2 are the moduli of elasticity, μ_1 , μ_2 are Poisson's ratios for the substrate and the coating, respectively (in this study μ_1 = μ_2 = μ), R_0 is the middle radius of the substrate, the coefficient

$$F = \frac{1-\mu^2 k}{(1\text{-}\mu^2)(1-\mu k)}, \quad k = \frac{2}{\beta b^*}\frac{\cosh\beta b^* - \cos\beta b^*}{\sinh\beta b^* + \sin\beta b^*},$$

the ratio k depends on

$$\beta = \sqrt[4]{\frac{3(1-\mu^2)\bar{f}_1^2}{R_0^2 \bar{f}_4}},$$

b is the width of the substrate,

$$f_1 = h_1 + \nu h_2, \; f_2 = h_1^2 + 2h_1 h_2 + \nu h_1^2,$$

$$f_4 = h_1^4 + 4\nu h_1^3 h_2 + 6\nu h_1^2 h_2^2 + 4\nu h_1 h_2^3 + \nu^2 h_2^4,$$

As the derivative of the deformation parameter (its values fluctuating to a great extent) in the calculation equations is presented in accordance with coating thickness, residual stresses were calculated assuming that the dependence of residual stress on coating thickness is linear-fractional [5]

$$\bar{\sigma}(h) = \bar{\sigma}_0 \frac{h_2 + h}{h_2 + ch}, \qquad (3)$$

where $\bar{\sigma}_0$ is the initial value of residual stress, h_2 is the final coating thickness, c is the dimensionless parameter.

Taking into account relation (3), the following equation is obtained from expressions (1) and (2) for approximation of the measured deformation and slit increment

$$\varepsilon(h) = \frac{\bar{\sigma}_0}{E_1'}\int_0^{h_2}\frac{h_2 + h}{(h_2 + ch)(h_1 + \nu h)}\mathrm{d}h, \qquad (4)$$

$$\delta(h) = \frac{24\pi R_0^2 \bar{\sigma}_0}{E_1{}' F}\frac{f_1}{f_4}\int_0^{h_2}\frac{h_1 + h}{(h_1 + ch)}[e(h) + h]\mathrm{d}h. \qquad (5)$$

where $e = (h_1^2 - \nu h^2)/2f_1$ is the distance of reduction surface from the interface between the coating and the substrate.

The purpose was to find the unknown constants, i.e. the initial value of the initial stress $\bar{\sigma}_0$ and the dimensionless parameter c, so that measured deformation $\varepsilon(h)$ and slit increment $\delta(h)$ can be approximated in the best way. This problem was solved by using the regression function *genfit* (v*x*, v*y*, v*g*, *F*) of the mathematical program *Mathcad 14.0* [9].

Assuming that residual (initial) stresses $\bar{\sigma}$ are distributed uniformly throughout the coating thickness, residual stresses in the coating are expressed by the following equations [8]

$$\bar{\sigma} = -E_1'(h_1 + \nu h)\Delta\varepsilon/h_2 \qquad (6)$$

$$\bar{\sigma} = \frac{E_1 F}{12\pi R_0^2}\frac{f_4 \Delta\delta}{h_1 h_2 (h_1 + h_2)}, \qquad (7)$$

where $\Delta\varepsilon, \Delta\delta$ are the mean values of the measured deformation and slit increment.

As the experimental data for the strip substrate were obtained at elevated deposition temperature, then for comparison of residual stresses to those obtained by the hole-drilling and the X-ray techniques, thermal correction should be introduced by the following equation [6]

$$\sigma_2^T(h) = E_2' h_1 \Delta T \frac{\alpha_1 - \alpha_2}{h_1 + \nu h_2}, \qquad (8)$$

where α_1 and α_2 are the coefficients of the linear expansion of the substrate and the coating, respectively, and ΔT is the difference between room temperature and deposition temperature.

Residual stresses were measured by X-ray technique at the Moscow Institute for Roentgen Optics [10,11]. The deformation of the crystal lattice $\varepsilon = (d - d_0)/d_0$ causes a displacement of the centre of gravity of the diffraction peak which can be expressed by the following equation

$$\varepsilon = -\Delta\theta \operatorname{ctg} \theta_c, \qquad (9)$$

where $\Delta\theta = \theta_c - \theta_{c0}$.

The sum of the principal stresses ($\sigma_1+\sigma_2$) is determined according to Hooke's law by the following formula

$$\sigma_1 + \sigma_2 = -E_2\varepsilon/\mu_2 = (E_2/\mu_2)(\theta_c - \theta_{c0})\operatorname{ctg}\theta_c . \qquad (10)$$

For the determination of the stresses σ_φ in the desired direction x, the $\sin^2\psi$ method was applied. According to this method, measurements are made at 3 – 6 tilts of ψ. Further, the coordinate of the centre of gravity of the diffraction peak θ_{ci} is determined for every ψ tilt. Using the least-square method the linear dependence of ε on $\sin^2\psi$ is obtained by the following formula

$$\varepsilon = b_0 + b_1 \sin^2\psi, \qquad (11)$$

where b_0 and b_1 are the regression parameters.

The stresses σ_ϕ were calculated from the slope of this line as

$$\sigma_\phi = b_1 E_2/(1+\mu). \qquad (12)$$

Residual stresses in the nickel coating deposited onto a strip substrate were determined by the hole-drilling method whereby residual stresses were calculated from the measured relieved strains using the specialized computer program *H-DRILL* [12]. As coating thickness was relatively small for integral approach, it was assumed that residual stresses were distributed uniformly throughout coating thickness.

Reduced modulus of elasticity was calculated by equation

$$E_{red} = E_1'(h_1 + \nu h_2)/(h_1 + h_2). \qquad (13)$$

3. EXPERIMENTAL PROCEDURE

Strips and rings were cut from a rolled brass ribbon (E_1=112 GPa, μ_1=0.34, $\alpha_1=2.05\times10^{-5}$, 62–65% Cu [13]). The dimensions of the strips were (22×70×0.95) mm, with a coated length of 51 mm and the dimensions of the rings were (11.4×96.0×0.94) mm, with a middle radius of R_0=15.12 mm. The substrate was prepared for the deposition process and the coated surface of the substrate was polished to roughness Ra=0.062 μm.

A pure nickel coating with the elastic coefficients E_2=163 GPa (determined in the coatings on the strip substrate by four-point bending) and μ_2=0.31, $\alpha_2=1.33\times10^{-5}$ [14] was deposited from the electrolyte with the following composition: $NiSO_4\times7H_2O$, 350 g/litre; HCOOH, 60 g/litre; $MgSO_4\times7H_2O$, 10 g/litre; gravity 1.19±0.01 g/cm^3, pH=1.57-1.63 (determined at 20ºC).

The experimental measuring system presented in [6,14] was used for deposition of the coating. It allows continuous measurement and recording of deformations and temperature during the coating process. The stylus was swabbed over the area where the coating was to be deposited.

For coating the outer surface, the ring substrate was fixed to a mandrel, which makes free slipping of the edges as well as instantaneous deformation of the coated substrate possible. The coated substrate with a certain coating thickness was released from the mandrel, and the slit increment of the substrate was measured. The plating technology is described in details by Lille et al [5].

Residual stresses in the nickel coating on the strip substrate were determined by the hole-drilling method. The procedure for determination of residual stresses is described in the standard ASTM 837-08 [15]. Surface preparation for strain gauge rosette bonding was carried out according to the instruction bulletin B-129 [16]. As the thin substrate was deformed before hole-drilling, it was then cast into a mortar cradle to avoid additional deformations caused by the drilling process (Fig.1).

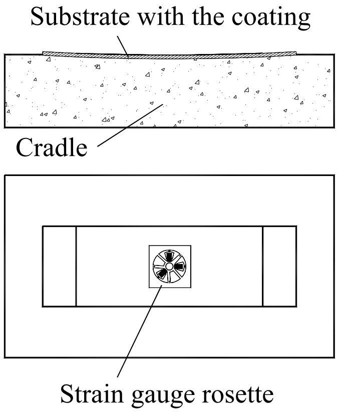


Fig. 1. Mortar cradle for fixing and positioning of the strip substrate, and bonded strain gauge rosette.

The precision high-speed milling guide *Vishay* model *RS-200* [17], powered by air compression of 3.0 bar, was accurately centred with an alignment set-up over the drilling target on the rosette and a hole with a diameter of 1.75 mm was drilled through the geometric centre of the rosette (Fig. 2).

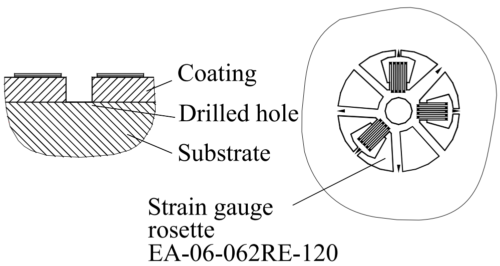


Fig. 2. Installed strain gauge rosette and the drilled hole.

The blind hole was only drilled through the studied coating. Strain gauge rosettes of type EA-06-062RE-120 were bonded onto the middle region of each specimen with the glue Z70, wired and connected to the *Vishay Strain Indicator and Recorder Model P3*.

As the coating thickness of the brush-plated Ni coating was too small for application of the integral method, a hole was drilled with one step equal to the coating thickness of 40 μm. Hard metal end mills coated with a highly wear resistant PVD coating (AlCrNi) were used for drilling a hole and the orbiting of the end mill was applied.

The residual stresses were measured by the X-ray technique on specimens with different final thicknesses of the coating. The specimen prepared for measurement of residual stresses by the X-ray technique is shown in Fig. 3.

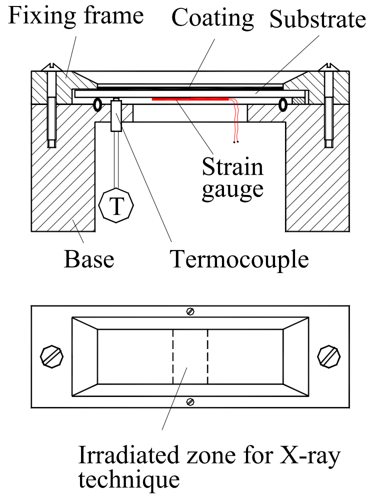


Fig. 3. Strip substrate fixture and the irradiating zone for applying the X-ray technique.

The experiments were carried out with the portative diffractometer *DRP-3* [11], based on the $\sin^2\psi$ method [10]. The residual stresses were determined in the axial and transversal directions using FeKα radiation in the {311} reflection of the coating in the middle region, when the coated substrate was placed onto the equipment for deposition.

Young's modulus and Poisson's ratio for electrolytic nickel were 179 GPa and $\mu = 0.3$, respectively (determined by the nanoindentitation method; the lower value was used in calculations, as there were cracks in the coating).

The morphology and microstructure of the studied coatings were investigated by means of scanning electron microscopy (SEM) in *Zeiss EVO MA-15*.

The values of the modulus of elasticity and micro- and nanohardness of the coatings were obtained by instrumented indentation using the *MTS Nano Indenter XR®* and the *Micromaterials Nano Test system* pendulum-type nanohardness tester.

4. RESULTS AND DISCUSSION

The stylus, equipped with a graphite anode wrapped in the absorbent, was swabbed over the area where the coating was to be deposited at a current density of 64 A/dm^2.

According to the deformation readings, coating thickness was divided into 91 equal parts. Thus we had 91 pairs of readings per single experiment. Since all experiments were carried out under similar conditions, the data of the three experiments, 273 readings each, were pooled. Using the computer program *MS Excel* and the calibration results, the experimental data were converted to the axial deformation of the substrate ε depending on coating thickness h (Fig. 4, a).

As is evident, the measured values fluctuate to a great extent. One reason for this phenomenon may be temperature fluctuation during the depositing process.

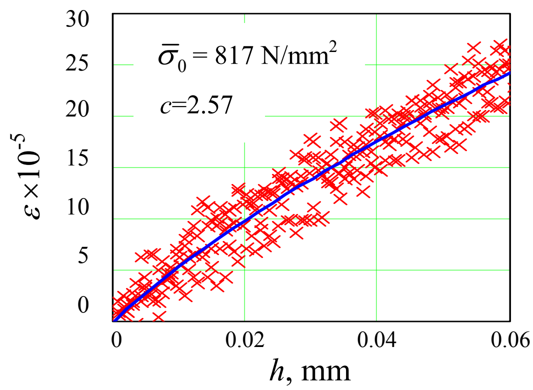
A series of ring substrates (20 specimens) were coated with coatings of different thicknesses, at a cathode velocity of 0.39 m/sec and a current density of 100 A/dm^2. The electrolytic nickel anodes were wrapped in the absorbent recommended by SIFCO Company. The experimental data obtained on the ring substrate fluctuated somewhat less (Fig. 4, b), as the coating is deposited by uniformly rotating speed and the brush is fed continuously by drops of electrolyte from a bottle, which guarantee a relatively homogeneous temperature of the cathode.

The results of approximation by the equations (4) and (5) for strip and for unclosed ring are shown in Fig. 4.

The coated machine parts are usually so rigid that residual stresses in the coatings are practically equal to the initial stresses and in our experiments they were 817 N/mm^2 and 623 N/mm^2 in the elaborated electrolyte nickel coatings.

It is essential to mention that the labor consuming indirect curvature method was applied to determine the initial stresses, which is also suitable to obtain the mean values of residual stresses. It is possible to determine the residual stresses in the coatings on machine parts directly by hole-drilling or by X-ray technique, but the equipment are much more expensive.

a



b

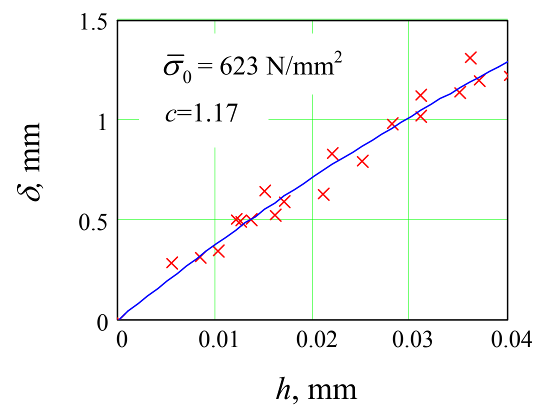


Fig. 4. Experimental values **(a)** of the axial deformation ε and **(b)** of slit increment δ on the coating thickness h and the curve of approximation.

Dependence of residual stresses on the coating thickness calculated by equation (3) is presented in Fig. 5.

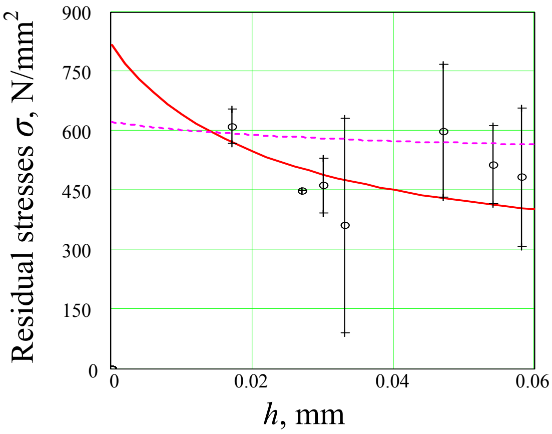


Fig. 5. Dependence of residual stresses $\bar{\sigma}$ in the coating of the strips at room temperature (solid line) and in the coating of the unclosed rings (dotted line) on thickness h; o - stresses were measured in the axial direction of the strip by the X-ray technique.

With the aim of studying the influence of the current density and the cathode velocity on residual stresses, three series (5 specimens in each series) were coated with the same coating thickness of 15 μm at the same cathode velocity of 0.31 m/sec and at different current densities. The mean value of residual stresses was calculated by equation (7).

Residual stresses through coating thickness in the coating on the ring substrate do not change much and remain in the limit of experimental uncertainty, hence using the equation (7) is proper in spite of the relatively thick coating. The results can then be compared to the mean values of residual stresses determined by the hole-drilling method.

The values of residual stresses determined by different techniques are summarized in Table 1.

Average current density, A/dm^2		65	70	100	100	130
Average working voltage, V		18.0	9.5	11.5	12.0	17.0
Velocity of the cathode, m/s		manually	0.31	0.39	0.31	0.31
Deposition temperature, °C		75	95	95	95	95
Coating thickness, mm·10^{-3}		40	15	14	15	15
Mean residual stresses, $\bar{\sigma}$, N/mm^2	curvature method	616	756	615	621	714
	hole-drilling technique	551±66				
	X-ray technique	543±295				

Table 1. Conditions of electrodeposition and mean values of residual stresses.

The mean values of residual stresses obtained for coatings deposited with two technologies on strip and ring substrates are in the same order within the limit of experimental uncertainty.

It is evident that the values of residual stresses are not directly affected by current density and do not practically depend on cathode velocity.

Residual stresses determined by the hole-drilling technique were somewhat higher than those obtained by the curvature method. The reason might be the generation of additional stresses during the drilling process.

Residual stresses determined by the X-ray technique were somewhat lower than those obtained by curvature method, however uncertainties of measurements of stresses constituted half of the mean value.

Coatings structure and morphology is presented in Fig. 6.

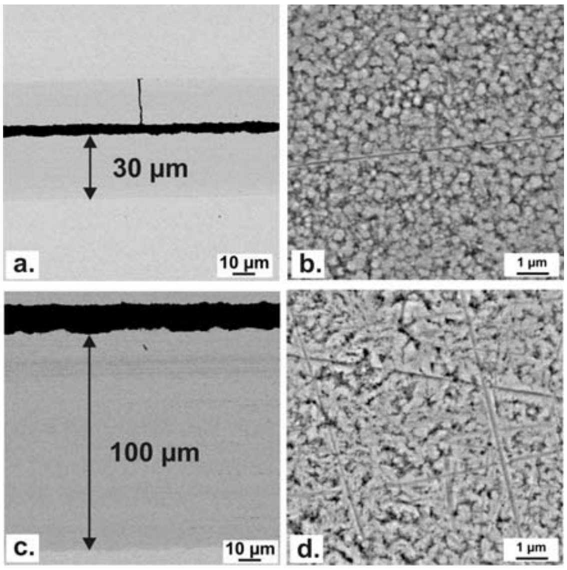


Fig. 6. SEM images at the surface and cross-section of samples: (a) and (b) ring substrate; (c) and (d) strip substrate.

Both coatings are thick and built up on 100-300 nm size Ni nanoparticles. Ni coating on the strip substrate was 100 µm and on the ring substrate 30 µm. Due to the high residual stresses Ni coating has vertical cracks in the ring form substrate coating (Fig. 6, a).
Residual stresses in brush plated nickel coatings are usually up to three times as high as the residual stresses in nickel coatings deposited from a similar bath solution [18]. It is well known that high values of tensile residual stresses and several cracks in nickel cause a significant reduction in the fatigue strength of the restored machine parts [19].
The microhardness obtained for the nickel coatings was 341±16.5 $HV_{0.025}$ and 395±15.1 $HV_{0.050}$, respectively in literature (520-580 HV [2]); nanohardness (load 50mN) was 5.400±0.342 GPa, and the modulus of elasticity was E =197±18 GPa. In calculations of residual stresses by the X-ray technique the lower value of the modulus of elasticity was used. The microhardness strongly depends on the grain size, while the value of the modulus of elasticity is affected by the grain size to a small degree [20].

5. CONCLUSIONS

The values of residual stresses in the coatings manually deposited on the strip substrate and automatically on the ring substrate determined by the curvature methods were comparable.
Residual stresses determined by the hole-drilling method and by the X-ray technique were in the same range and somewhat lower than those obtained by the curvature method, however comparable within the maximum limit of experimental uncertainty.
As the microstructure of the coatings was fine-grained (Ni nanoparticles), the values of residual stresses were high, which resulted in a number of cracks in places in the coatings, which reduce the lifetime of coated machine parts.

6. ACKNOWLEDGEMENT

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The electrolyte was elaborated by PhD M. Pille from the Estonian University of Life Sciences.
The residual stresses by the X-ray technique were determined by Dr D. Matveev from the Institute for Roentgen Optics (Moscow).

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MANUFACTURING OF CELLULAR STRUCTURES OF THE PERFORATED STEEL TAPE

Mironovs, V.; Lisicins, M.; Boiko, I.; Zemchenkovs, V.

Abstract: *The research regards to the development of the methods of manufacturing of the cellular structures with through channels of different form from the perforated steel tape. These methods allow recycling the metal wastes (bands), which are obtained during stamping of fine-sized details. There are given examples of steel bands with different physical-mechanical properties and geometry.*
The methods of profiling and welding of thin perforated materials are studied. The methodology for calculating of the parameters of through channels is proposed.
Key words: cellular structures, perforated steel tape, profiling

1. INTRODUCTION

Metallic cellular materials are effectively used in production of the cellular building construction, in aircraft building, in catalyser and filter production etc. [1-3].
The technologies of manufacturing of the cellular structures from the perforated metallic materials, for example from plate or band, are actual and developing methods. Metallic bands are already used in production of different cellular constructions [3]. For example, there are known aluminum cellular constructions, which are produced by USA Company *Ultrathin* [4]. Using of bent thin-walled elements as basis for sandwich panels allows receiving the high-strength fireproof cellular constructions.
The aim of this paper is to investigate the possibility to recycle the metal wastes (bands), which are obtained during stamping of fine-sized details, by manufacturing from them cellular structures by profiling and welding.

2. METHODS AND MATERIALS

2.1 Methods

There are different methods exists for manufacturing of cellular structures from sheet material:

- Stretching method (Fig.1): sheets are based layer-by-layer and then joined in the lines, for example, by gluing, then received package are stretched.

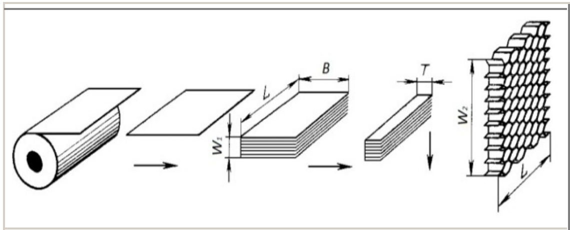


Fig. 1. Scheme of the cellular structure manufacturing by stretching method [3]

- Channeling method (Fig.2): during forge-rolling the sheets are obtained in defined form. After layer-by-layer placing and fastening the cellular construction is generated.

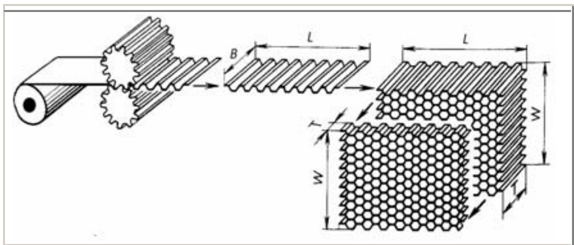
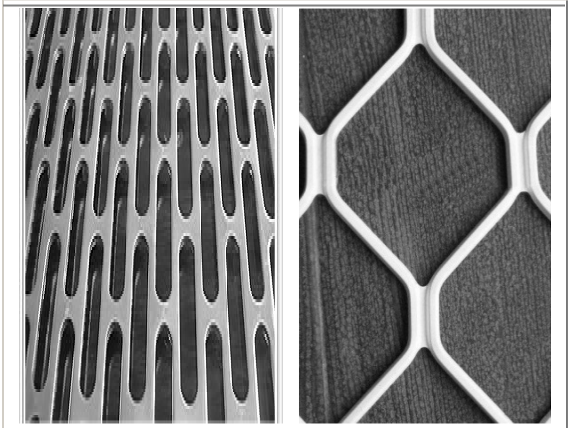


Fig. 2. Scheme of the cellular structure manufacturing by preliminary channeling of sheet material [3]

- Cutting and stretching method: on the tape on longitudinal direction the slots are done (Fig.3). Then the tape is stretched in crosswise direction. The form and dimensions of cells as well as parameters of tape can be easily changed by variation of length and width of slots and degree of stretching of the tape.
- Method of interlacement of the perforated tape: previously perforated tapes are interlaced for rigid construction creation (Fig.4). Simple but low-output method.



a) b)

Fig. 3. Changing of form and dimensions of cells by cutting and stretching method: initial tape (a) and tape after stretching (b)

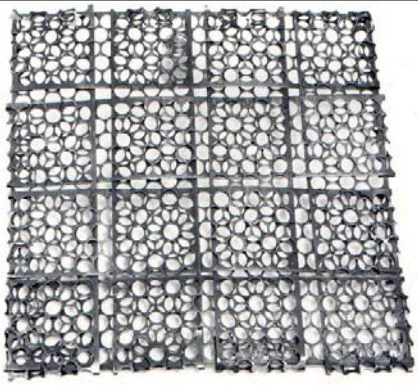


Fig. 4. Fragment of panel obtained by method of interlacement of the perforated tape

- Method of twisting of the perforated tape: relatively simple method for obtaining single-layer (Fig.5), multi-layer cylindrical or conical type cellular structures.

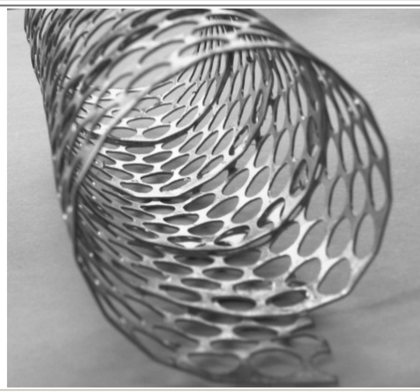


Fig. 5. Fragment of tubular cellular construction from perforated tape of cylindrical (a,b) and conical (c) type

- Welding: spot or seam resistance welding can be used for manufacturing of the profiled cellular structures (Fig.6).

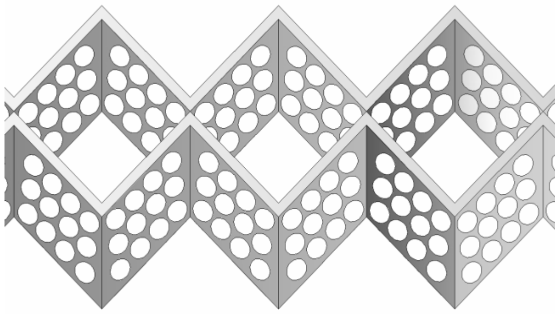


Fig. 6. Scheme of perforated tape forming before resistance welding

2.2 Materials

Perforated metallic materials are widely used in the ventilation and acoustic systems for sound insulation and attenuation; for manufacturing of filters and covering for safety devices in building (decorative ceiling, bars, U-troughing for electric wiring) and in technologies of material sorting. Using of perforated material open a new possibilities in manufacturing of cellular materials and constructions.

For perforated tape production following materials are often used: carbon steel, stainless steel, aluminum alloy, copper alloy and others. Most advisable from economic and technological point of view is to use qualitative carbon steels.

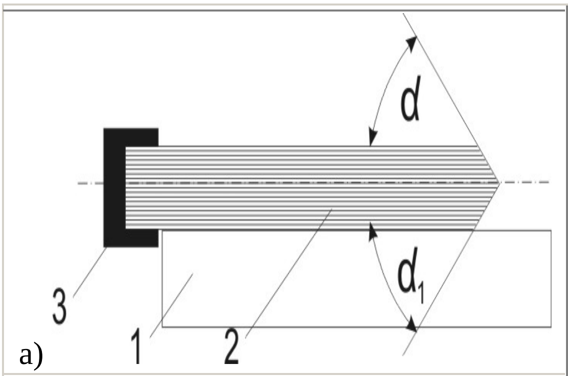
Perforated steel tape usual is made by notching with certain spacing and frequency on specialized forming or rolling equipment [5]. It should be mentioned, that productivity of rolling mill is much higher than forming press, but by rolling we can produce only thin tapes (0.5…2.0 mm), forming press – tapes with thickness up to 10 mm and thicker. For sheet perforating laser and another thermal cutting is used [5].

After perforating of tape the cleaning, corrosion protection and degreasing is needed. Additionally painting or galvanizing can be done.

More significant perforated tape parameters in manufacturing of cellular materials are the following: perforation type, arrangement of holes, relative area of perforation, thickness and width of tape. It is reasonable to use the perforated tape with oval and circular holes especially in the case when certain fixed placement of perforated tape is needed. Oval and rectangular holes allow easily joint several taps with displacement relative to one another.

3. NEW METHOD FOR MANUFACTURING OF CELLULAR STRUCTURES

In our opinion promising is the method of sheets shifting. This method has been proposed in Riga Technical University in 2011 [7].First of all from sheets *1* the multilayer package *2* is formed, which is clamped throughout one side by mechanical clamp *3* (Fig.7).



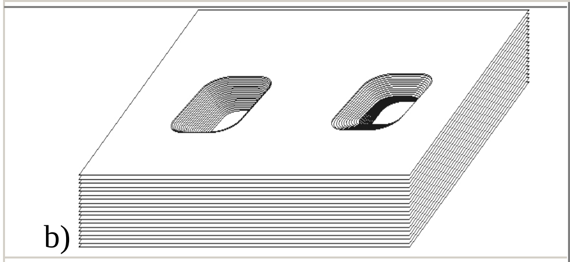


Fig. 7. Scheme of the shifting device (a) and fragment of tape with cells of variable sections (b)

3.1 Methodology for calculating of the parameters of through channels

Main problem in profile modelling is the definition of the form and amount of holes in tape – definition of the geometrical characteristics of cross-section.

Object of our investigation is the cellular structures with through channels (Fig.8).

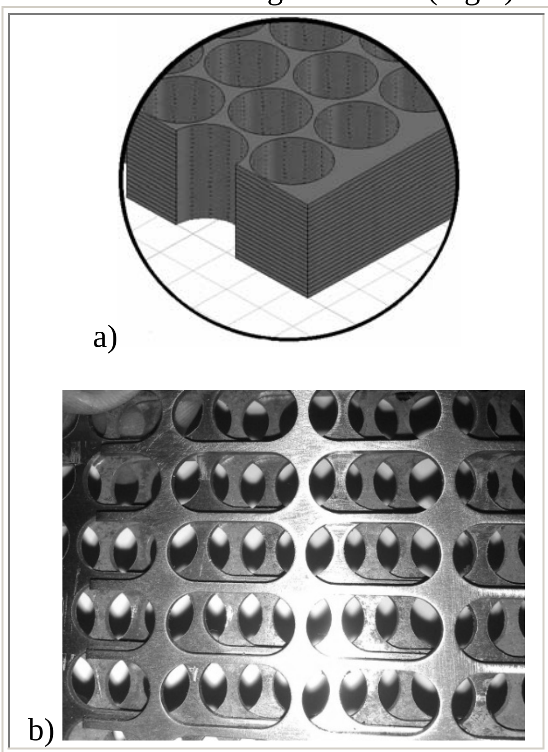


Fig. 8. Formation of through channels during coaxial placing (a) and displacement of perforated elements relative to one another (b)

Such through channels arises after layer-by-layer deposition of sheet or tape perforated material. At shifting of perforated elements in package on the

spacing value the dimensions of the through channel are changed (Fig.9).
We propose to use following formulas for calculating of the parameters of through channels:

$$\alpha = ctg\frac{t}{a} \qquad (1)$$

$$L_0 = a \cdot n \qquad (2)$$

$$L_1 = \frac{a \cdot n}{\cos\alpha} \qquad (3)$$

where a – thickness of sheet; b – spacing of displacement; n – sheets number in package; L_0 – thickness of package; L_1 – length of the channel; α – angle between axis of channel and vertical line.

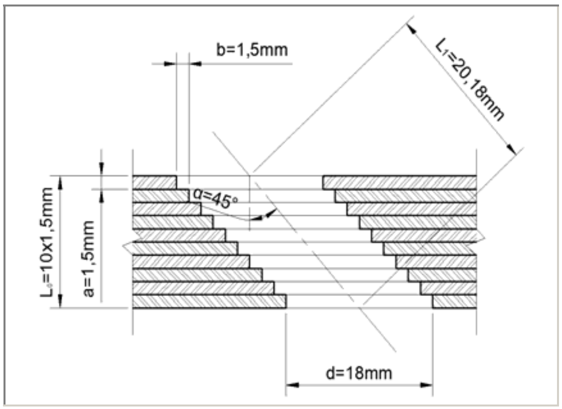


Fig. 9. Scheme illustrated calculation of the parameters of through channels

3.2. Experimental

In experimental investigation we use samples from metallic perforated tape, achieved as waste in forming of products [6]. Methods of producing of steel perforated tapes are examined in [5]. Samples of cellular structures were made from steel perforated tape using cutting, profiling and welding. Parameters of investigated perforated tapes are given in Table 1.
Producing of profiles shown on Figure 10 was made by bending in stamp. Profiling was made in longitudinal direction (Fig.10,a) and in crosswise direction (Fig.10,b). Previously profiled tapes were joined. As a result cavities were generated between tapes (Fig.12). Subsequently cavities may be filled by powder, granular and fibrous filler.

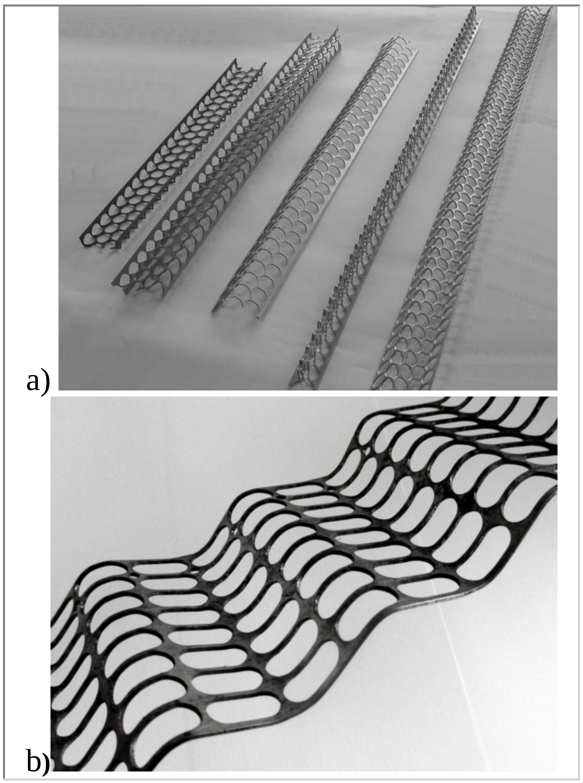
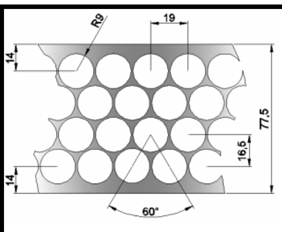
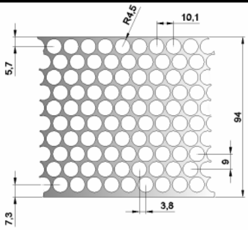
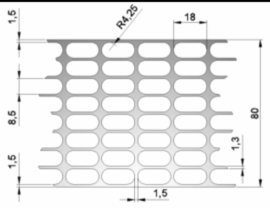
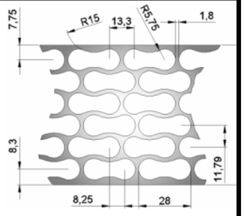


Fig. 10. Profiles from steel perforated tape (width 100 mm, thickness 1.2 mm) produced by longitudinal (a) and crosswise (b) profiling

Previously profiled tapes were joined by resistance spot welding (RSW) using experimental AC RSW equipment „Impulse KM” earlier elaborated in Riga Technical University (Fig.11).

Fig.11. RSW experimental equipment „Impulse KM”

Table 1. Properties and sizes of investigated perforated tape

Type of band				
Designation	LM - 1	LM - 2	LM - 3	LM - 4
Mark of steel	St08	St08	St50	St08
Standard	GOST 503-81	GOST 503-81	GOST 2284-79	GOST 503-81
Permeable area, %	69,10	66,97	70,50	69,97
Thickness, mm	1,50	1,00	1,20	1,80
Cross – sect. area (brutto), mm^2	116,25	94,00	96,00	135,00
Cross – sect. area (netto), mm^2	25,13	12,91	14,44	29,27
Max. load, N	5549,39	4139,75	13541,87	12500,11
Tensile strength, N/mm^2	220,83	320,66	937,80	427,06

Nowadays RSW is one of the main methods for joining of sheet metal in all industry, as well as low carbon steel is one of the most readily spot welded materials [8]. The main RSW welding parameters for steel S235JRG2 welding (material thickness is 1.2 mm) are given in Table 2.

Welding parameters	Welding current range, kA	Electrode force, kN	Weld time, sec (50 Hz cycles)
Conditions	8…9	3,5…4	0,18..0,20

Table 2. RSW welding parameters

Welding was performed by using copper electrodes with a diameter of 7 mm. The view of welded cellular structure is given in Figure 12, but view of the welding nugget is shown on the Figure 13.

a)

b)

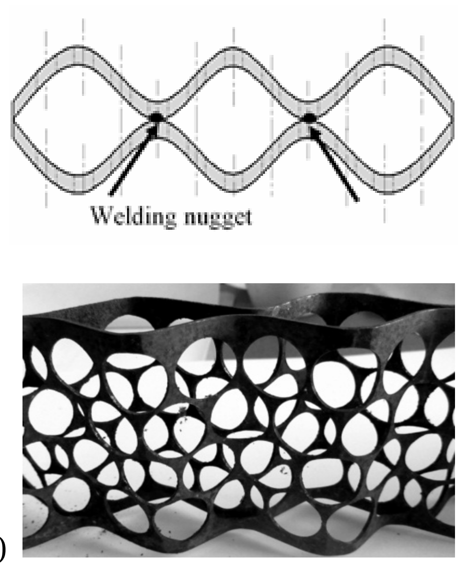


Fig. 12 Conceptual view of assembly of steel tapes (a) and cellular structures from steel S235JRG2 perforated tapes (width 100 mm, thickness 1.2 mm) produced by RSW (b)

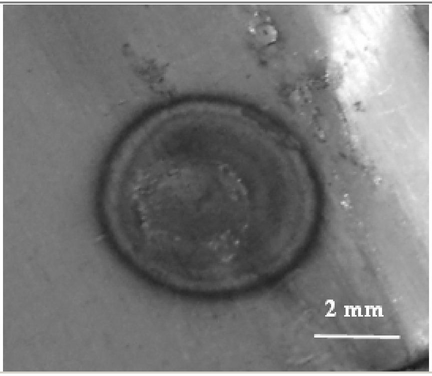


Fig. 13 View of steel S235JRG2 welding nugget

4. RESULTS AND CONCLUSION

As a result of investigation we can assume that the manufacturing of the cellular structures from the perforated metallic materials (from tape or band) is a perspective technology.
Choosing of tape parameters and material is important decision that influence on mechanical properties of the products from cellular material and on its future application. Most advisable from economic and technological point of view is to use qualitative carbon steels. Parameters of through channels can be easily changed by perforated elements displacement per spacing in package.
First experiments in joining of cellular elements by resistance welding were successful. Future investigations will be connected with elaboration of spot and seam resistance welding technology for joining of cellular elements.
It is shown that welding nugget is of good performance (without spattering, cracks, welding nugget diameter on external surface was varied from 5 to 7 mm). Future investigations will be related with research on the properties of welding joints achieved under different welding conditions and applying another joining scheme.
The possibility to recycle the metal wastes (bands) by manufacturing from them cellular structures by profiling is proved. New method for manufacturing of cellular structures i.e. shifting method is proposed. Technological abilities of new method are shown. The methodology for calculating of the parameters of through channels is proposed. Preliminary experiments were revealed that the resistance welding is an appropriate technology for generation of cellular structures.

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MEASUREMENT OF DEFORMATION HARDENING OF HEAT-RESISTANT STEEL OF THE WWER-TYPE REACTOR

Okipnyi, I.; Maruschak, P.; Sorochak, A. & Sergejev, F.

Abstract: *Presented investigations allowed revealing the correlation between microhardness and the characteristics of strength of heat-resistant steel 15Kh2MFA(II). The sensitivity of the indentation methods is shown to be dependent on the degree of involvement of structural levels in the process of deformation. At the initial stage, this is the intragranular sliding, at the next stage – shear of grains and grain conglomerates, and their self-coordinated propagation in the steel. On the one hand, this allows attaining greater macrodeformation, and, on the other hand, does not cause the ultimate exhaustion of the material plasticity at the macrolevel.*

Key words: fracture, microhardness, structure, damage

1. INTRODUCTION

Deformation processes in heat resistant steels can be described using the phenomenological approaches, which allow establishing the relationship between failure mechanisms, material structure, and its mechanical properties [1]. Additional information about the material hardening kinetics can be obtained by the indentation method. This method allows revealing the fundamental regularities in the coalescence, accumulation, and self-organization of the dislocation substructure of the material [2].

However, there are a number of works, in which the regularities in plastic deformation of the material during microindentation contradicted the main regularities of the theory of plasticity [3,4]. This confirms the need in considering the scale factor during investigations of materials, in particular, the geometrical correlation between the indentation size and structural elements of the heat resistant steel.

It is known that “large” indentations have a significant gradient of the implementation strain, which is preconditioned by dispersion of the dislocation accumulation kinetics in different structural elements of the material. In this case, boundary values are “averaged” within the limits of the area analyzed. Microindentation, on the contrary, provides for localization of the dislocation accumulation in structural components of the material [5]. In previous works, a number of regularities were found, in particular, a close correlation between microhardness and true strain of the material deformed under high temperature conditions [6,7]. In addition, a relationship was found between the density of dislocations within the low-angled boundaries and hardness (microhardness) of a number of heat resistant steels. These results allow for the engineering assessment of the structural condition of the material based on the indentation results. They are also an attempt to bring together the approaches of the theory of dislocations and mechanics of the deformable solid body, which requires further development and generalization.

The purpose of this work is to evaluate hardening of heat resistant steel 15Kh2MFA(II) after high-temperature deformation.

2. MATERIALS AND RESEARCH TECHNIQUE

In this work, 15Kh2MFA(II) (Cr-Mo-V) steel was investigated, which is used for producing of the pressure vessels of WWER-440 and WWER-1000 reactors. The mechanical characteristics and chemical composition of steel after thermal treatment, which simulates the material embrittlement in the middle of service life of the WWER-440 reactor: tempering at 1273 K for 6 hours in oil followed by annealing, are given in table 1.

Table 1

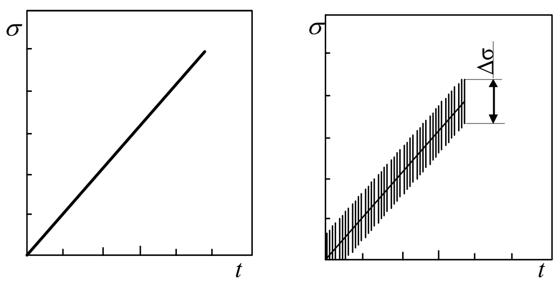
Mechanical characteristics of tested steel 15Kh2MFA(II)

Steel	*Yield strength*	*Trensile strength*	*Elon-gation*	*Neck-ing*
	$\sigma_{0,2}$, MPa	σ_m, MPa	δ, %	ψ, %
15Kh2MFA(II)	900	1000	15.8	39.2

Chemical composition

Elements	C	Mo	Si	V	Mn
Content, wt.%	0.18	0.62	0.27	0.29	0.48
Elements	Cr	S	P	Ni	Ti
Content, wt.%	2.58	0.019	0.013	0.16	0.011

The tests were performed on the STM-100 servo-hydraulic machine. In case of the combined loading, the static tensioning was superimposed by the cyclic sinusoidal loading with the frequency of 25 Hz and amplitude of $\sigma = \pm$ 90…110 MPa. Specimens were deformed under uniaxial and combined loading at temperatures of 150 °C and 350 °C. Schemes of loading are given in Fig. 1.



a b

Fig. 1. Scheme of deformation of heat resistant steel 15Kh2MFA(II) under static (a) and combined loading (b).

During the experiment, the longitudinal strain of the specimen and the loading force were measured. The true current strain of the specimen was determined from formula [7]:

$$e = \ln(1+\varepsilon), \qquad (1)$$

where $\varepsilon = (l_k - l_0)/l_0$, l_0 is the initial specimen length, l_k is the current specimen length.

In order to study the effect of strain on microhardness of steel 15Kh2MFA(II), the true transverse necking $\tilde{\psi}$ was calculated from formula [7]:

$$\tilde{\psi} = \ln(F_0 / F_k), \qquad (2)$$

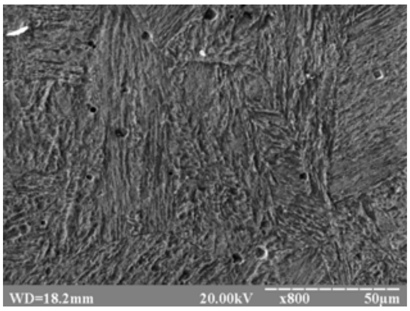
where F_0 and F_k are the initial and current areas of the specimen cross-section, respectively.

The quantitative evaluation of the material hardening after plastic deformation was made at different values of $\tilde{\psi}$ based on the microhardness measurement data. Microhardness was measured using the PTM-3 device with an load of 1 N and a hold time of 15 s.

3. RELATIONSHIP BETWEEN STRUCTURE AND STEEL HARDENING PROCESSES

Steel 15Kh2MFA belongs to heat resistant steels of the pearlitic class. During thermal treatment, which simulates radiation embrittlement of the material under the action of neutron irradiation in the middle of service life of the WWER-440 reactor pressure vessel, steel 15Kh2MFA has a bainitic-martensitic structure (Fig. 2).

Based on the results of earlier investigations, a banded dislocation microstructure in the form of a system of parallel dislocation subboundaries is found in the bainitic component of steel. Needle-shaped carbide protrusions are oriented in one direction at an angle of approximately 60° to the dislocation subboundaries (Fig. 2, a). The presence of carbide protrusions oriented at an angle of 60° to the crystal axis allows identifying the structure as bainite, in contrast to the tempered martensite, in which lamellar protrusions are observed in three orientations simultaneously [8]. Apart from the needle-shaped carbide protrusions, the bainitic-ferritic structure contains finely dispersed protrusions and carbide protrusions on boundaries of structural elements (Fig. 2, b).



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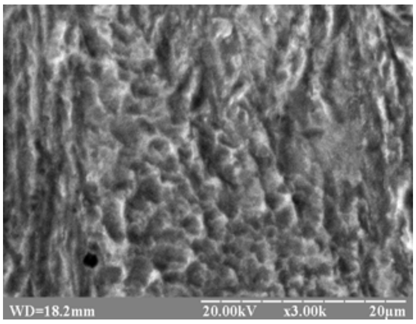
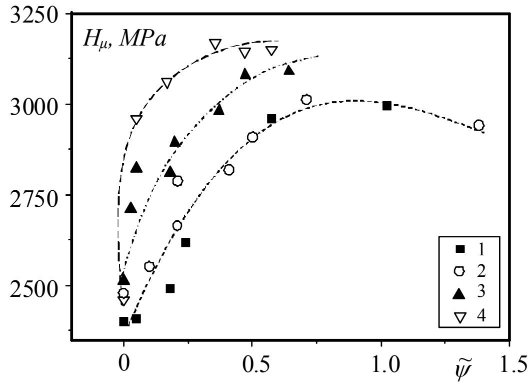


b

Fig. 2. Microstructure of steel 15Kh2MFA(II): a, b – bainitic-martensitic structure

Martensitic sections of the structure represent a dislocated lath martensite. Parallel laths of martensite form martensite pockets (Fig. 2b). Plastic deformation causes an increase in the number of dislocations in the material, the resistance to their displacement increases accordingly, which is depicted by the increased microhardness that also characterizes deformation properties of the material. Microhardness measurements of steel 15Kh2MFA(II) after plastic deformation in case of different values of the true transverse necking of specimens are presented in (Fig. 3a). An increase in the values of plastic strain leads to an intensive material hardening. Later on, microhardness becomes stable (it attains saturation), Fig. 3a. The stabilization of microhardness is accompanied by an increase in the non-uniformity of deformation of surface layers, which manifests itself in the formation of corrugations. Thus, it is possible to identify several stages of development of deformation processes in the material:

- stage of deformation hardening (I) – this stage is accompanied by an intensive dislocation reorganization and accumulation of dislocations on boundaries of grains and subgrains of the material;



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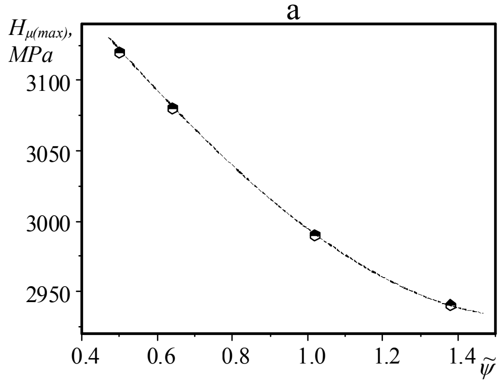


b

Fig. 3. Dependence of microhardness (a) and hardness (b) of steel 15Kh2MFA(II) on the true transverse necking of the specimen at temperatures of 150 °C (1,4) and 350 °C (2,3) after static (1,2) and combined (2,3) deformation

- stage of saturation (II) – this stage is characterized by the stabilization of the deformation process with the formation of plastic shears in the material structure, the dislocation density increases along with the value of microdistortions of the material lattice, a surface corrugation is formed on the specimen surface;

- stage of prefailure (III) – the nucleation and coalescence of pores and structural defects take place, which are then accompanied by the appearance of a macrocrack.

Deformation of specimens from steel 15Kh2MFA(II) by static and combined tensioning increases the real plastic strain $\widetilde{\psi}$ and microhardness of the material due to the accumulation of dislocations [2]. Irrespective of the temperature conditions during testing, microhardness of the deformed steel increases in accordance with similar laws.

Imposition of the cyclic component causes intensification of the material deformation, Fig. 3a. It is found that microhardness of steel 15Kh2MFA is by 150…350 MPa greater than that under static deformation at the same values of the real necking. Moreover, the material hardening at 150 ^oC is more intensive at the macrolevel as compared to deformation at 350 ^oC. Obviously, plastic deformation at a higher temperature (350 ^oC) is accompanied by the processes of thermal turn, which consist in a certain liquidation of the off-balanced residue of point defects and reorganization of the dislocation structure. In earlier works it was found that in case of the voluntary structural reorganization of steel 15Kh2MFA the free crystal energy decreases. Therefore, the dislocation density decreases as a result of the thermal turn, and the remaining dislocations form stable configurations in the form of low-angled boundaries [8].

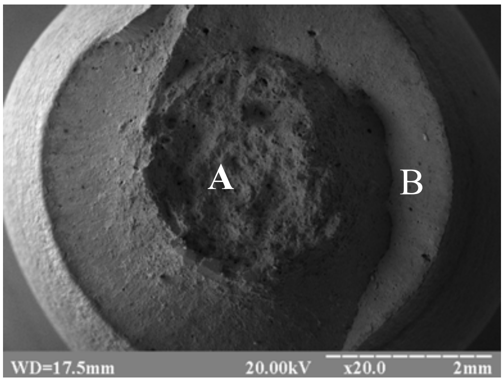
Thus, at the microstructural level the effect of deformation is depicted by an increase in microhardness, and, accordingly, dislocation density in low-angled boundaries, an increase in the disorientation of subgrains of the bainitic structure, fragmentation of martensitic laths, a decrease in the distance between low-angled boundaries (decrease in the size of structural elements), whereas at 350 ^oC it consists in the formation of stable configurations in the form of low-angled boundaries resulting from the thermal turn. The said factors cause an increase in the stress necessary for the propagation of microcracks through the boundaries of structural elements, which increases the separation stress of steel 15Kh2MFA(II). A dependence of the maximum microhardness values on the real necking value revealed during failure of specimens by different deformation schemes is shown in Fig. 3b. The results obtained can be described by a single dependence, because in all the cases investigated an increase in the ultimate strain was accompanied by an increase in microhardness.

Based on the results of earlier investigations it was found that strength of the heat resistant steel increases after plastic deformation [8,9]. For steel 15Kh2MFA(II) investigated, an increase in the test temperature leads to a change in the regularities of the material failure. Localisation of the deformation processes moves from the specimen surface to its centre, Fig. 4a, d, which preconditions a transition from the mixed micromechanism of failure to the intragranular one by the scheme "shear+separation", Fig. 4 b, c, f.

A change in the orientation of the fracture macrosurface is caused by a transition from the localised failure to the multicentric one. Moreover, these changes can be connected with the test temperature effect on the material anisotropy at the macro- and microlevel. The fracture surface of the materials investigated at 150 ^oC and 350 ^oC is perpendicular to the specimen axis, Fig. 4 a, d. The source of failure (stress concentrator) is located on the specimen surface and has a shape of a dead spot whose size increases with an increase in the test temperature. The deformation relief in the form of longitudinal bands is formed on the specimen surface. Figure 4 e shows a fragment of the deformation relief on the specimen lateral surface. As is seen, the non-uniformity of strain distribution reveals itself most clearly near the specimen surface. Macrolocalization of the plastic yielding develops around these zones, which then leads to the material failure [10].

Two characteristic zones are found on the fracture surface of the specimens investigated, Fig. 4 a, d:

- *near surface zone*, in which failure took place by the scheme “shear + separation”. This zone is formed by concentric scaly layers perpendicular to the outer surface. At the macrolevel, the relief contains flat sections with a smooth structureless surface typical of the intergranular failure. Elongated dimple-like formations with traces of shear are found within individual sections.



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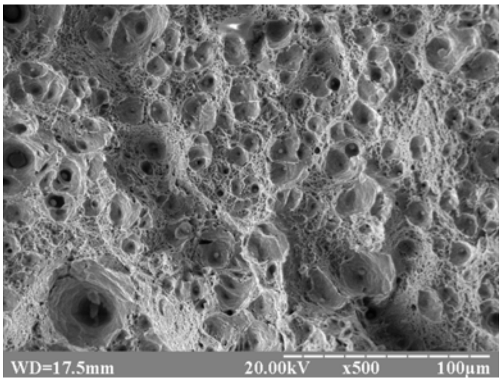

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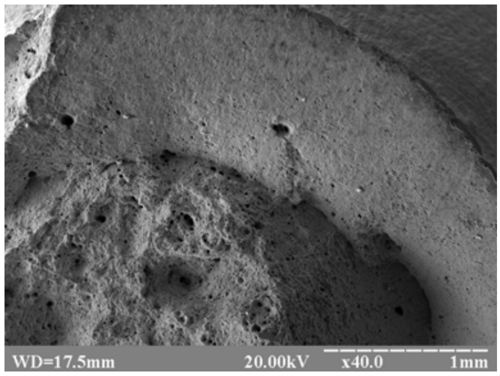

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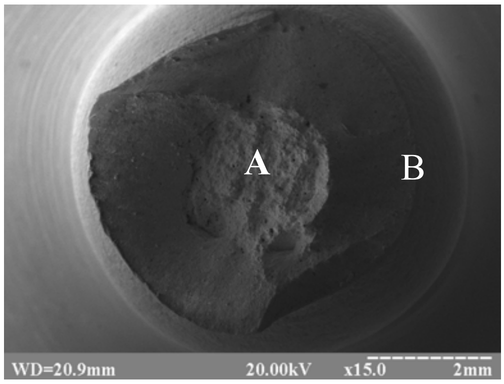

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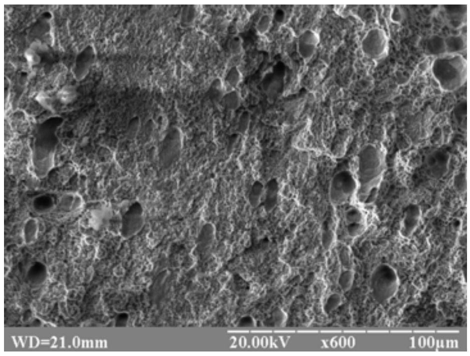
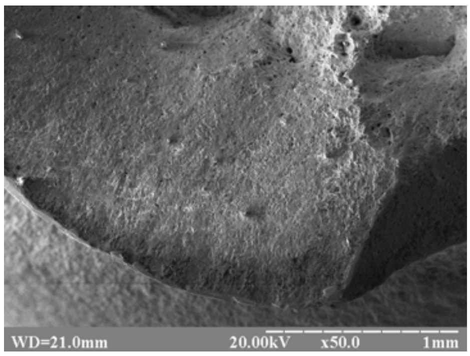


e



f

Fig. 4. Failure fractograms of the specimen from steel 15Kh2MFA(II) at 150 ^{o}C (a-c) and 350 ^{o}C (d-f), respectively: *A* is the near surface zone of failure, *B* is the internal zone of failure

- *internal layer*, in which the material failed according to the intragranular mechanism by the normal separation scheme. The fracture surface is located at an angle of 85 ... 90^{o} to the specimen axis.

Development of shear strains in the vicinity of the stress concentrator leads to the quasi-brittle failure of the specimen by the shear mechanism. The main crack is formed in one of the macrobands of the localized deformation.

CONCLUSIONS

We investigated the effect of deformation by static tensioning and tensioning with the imposition of the cyclic low amplitude component (combined tensioning) on the microstructural changes in steel 15Kh2MFA after thermal treatment, which simulates radiation embrittlement of the material under the action of neutron irradiation in the middle of service life of the reactor pressure vessel. It is found that with an increase in the real material necking the microhardness of steel 15Kh2MFA increases irrespective of the loading type and temperature conditions during testing.

An increase in the real strain after deformation by tensioning and combined tensioning leads to an increase in microhardness, which is more pronounced after deformation at 150 ^{o}C than at 350 ^{o}C. This confirms the previously obtained results, which link the high temperature deformation to the formation of such dislocation structures that provide for the material hardening and preserve its plasticity.

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ACCURATE MEASUREMENTS OF ELECTRICAL CONDUCTIVITY OF METALS IN THE RANGE FROM 2 MS/m TO 14 MS/m

Parker, M.; Pokatilov, A; Raba, K. & Kübarsepp, T.

Abstract: *The accurate method for electrical conductivity measurements has been established. In the realization of the method Van der Pauw' DC-measurement technique is applied. The measurements were conducted for five metal plates whose electrical conductivity nominal values are in the range from 2 MS/m to 14 MS/m. The limiting factors of the accuracy in DC-measurements of electrical conductivity have been studied. The electrical conductivity measurements are directly traceable to the Estonian national standards for electrical units, for length and for temperature. The relative uncertainty estimates of the measured electrical conductivity values can be less than 0.3% (k=2).*

1. INTRODUCTION

Electrical conductivity measurements are widely used in industry for production and inspection of metals. For example in aviation an electrical conductivity measurement is used to identify defects in metal products, eg aircraft wings. The electrical conductivity measurements are also used in coin industry where this kind of measurement is applied for quality assurance of metals and also for detecting counterfeited coins.
The electrical conductivity could be measured with different measurement methods. The widely used commercial devices are based on electromagnetic (eddy-current) method. By using this type of devices accurate measurements in relative terms can be obtained. However, in order to provide traceability to measurement units, eddy-current devices need to be calibrated with appropriate reference standards.
In this paper we describe accurate electrical conductivity measurements by using a well-known Van der Pauw method. We present measurement results and thoroughly studied uncertainty budget. The limiting factors in achieving high-accuracy results by using our measurement technique are briefly discussed.

2. THEORETICAL BACKGROUND

The Van der Pauw' method could be used to determine electrical conductivity of a sample with any geometrical shape [1]. The electrical conductivity of a squared shaped test piece could be determined according to [2]: where *d* is the thickness of the sample

$$\frac{1}{\sigma} = \frac{\pi d}{\ln 2}\frac{R_a + R_b}{2} f(r), \qquad (1)$$

and σ is the electrical conductivity of material, R_a and R_b are resistances measured at two different sides of the test piece, (Fig. 1). In Eq (1) the coefficient $f(r)$ is equal to one with accuracy 0.001% when the resistance R_a and the resistance R_b differ from each other less than one percent [2]. In case the measured resistances R_a and R_b differ more than one percent, the coefficient $f(r)$ should be, however, calculated [1].
In order to take into account several influencing effects in our measurements we have used following equation [3]:

$$\frac{1}{\sigma} = \rho = \frac{\pi d}{\ln 2}\frac{R_a + R_b}{2} f(r) K \qquad (2)$$

where the coefficient *K* is [3].

$$K = (1 + \delta_{rth})(1 + \delta_{cont})(1 + \delta_T) \qquad (3)$$

The coefficients δ_{th}, δ_{cont} and δ_T represent effects of thermal voltage, contact size and

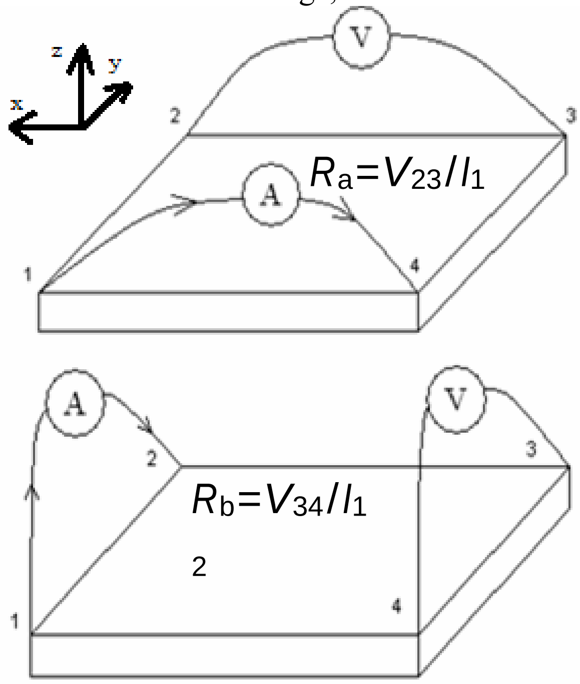

Fig. 1. Determination of resistances R_a and R_b.

temperature on electrical conductivity measurements, respectively.
Some samples can exhibit differences in the measured resistances R_a and R_b even if the sample is of the square shape. To validate our developed method we measured the resistances R_c and R_d also. The resistances R_c and R_d are measured just at opposite sides of the resistances R_a and R_b respectively (Fig. 1).

3. MEASURMENTS

The realization of electrical conductivity scale by the Van der Pauw' (VdP) method requires accurate electrical, temperature and dimensional measurements.
For conductivity measurements by the VdP technique we used a dedicated measurement tool, which ensures firm contacts of measurement leads to the corners of samples, see Figure 2.
The electrical conductivity values of five square metal plates in the range from 2 MS/m to 14 MS/m have been measured by the Van der Pauw method. The presented measurements results have been obtained on the measurement equipment of

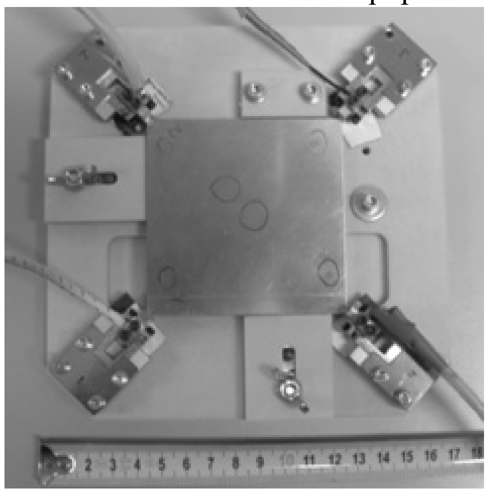

Fig. 2. Measurement tool for the Van der Pauw method.

AS Metrosert at the National Standards Laboratory for Electrical Quantities [4]. The performed measurements are traceable to the Estonian national measurement standards.

Dimensional measurements
For a symmetrical square plate only the accurate measurement of the thickness is necessary [2].
In order to test the squarness of our plates, we measured their sides along the X and Y axis (Fig. 1) by the electronic height gage TESA Micro Hite Plus M600 with the measurement uncertainty less than 40µm.

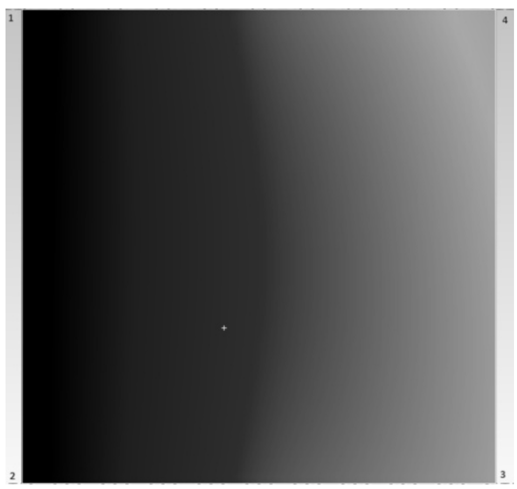

Fig. 3. The measured thickness change of the CuNi sample. The thickness of sides

denoted as 1-2 is 3.005 mm thick and 3-4 is 2.974 mm.
The relative difference between the lengths L_a and L_b of the sides of the studied plates are presented in (Table 1).
The thickness of the sample d is the major dimensional parameter affecting accuracy of the conductivity value. The thickness has been measured at nine points for each plate by the universal length measurement machine ULM Opal 600 with the measurement uncertainty of less than 3 µm. For all plates the measured thickness changes across the plate are less than 10 µm. Except the CuNi plate, which has the highest change in thickness around 30 µm as illustrated in Figure 3.

Resistance measurement
The resistances R_a and R_b are determined from comparison to a 1 Ω standard resistor by use of the current range extender MI 6011B as a precision current transformer. The direct current of 10 A is supplied from the current source MI 6100A to the VdP fixture through the current transformer where it is divided to the 100 mA level, see Figure 4. The applied high current value

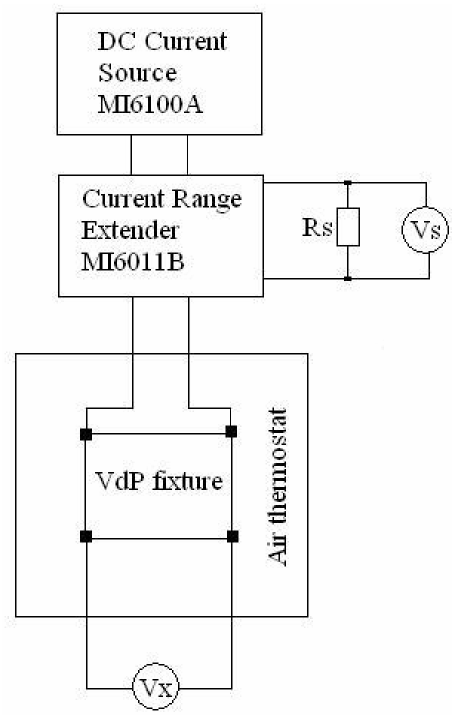

Fig. 4. Set-up for resistance measurements of samples under test.

Rs- shunt, Vs-voltmeter Fluke 8508A, Vx-nanovoltmeter Agilent 34420A.

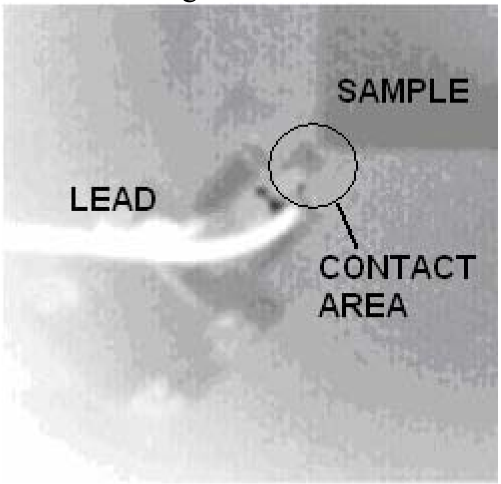

Fig. 5. Infrared image of a contact of the VdP tool. The brightest part of the image illustrates the current lead with increased temperature.

ensures required sensitivity in the voltage drop measurement. However, it can cause a temperature gradient across the plate by increasing the temperature of the measurement leads and contacts.
Temperature distribution around a contact of the VdP tool can be checked by the Infrared imaging and measurement system FLIR ThermaCAM SC 3000. In Figure 5 an infrared image of a contact of the VdP tool is shown. The temperature of the contact exhibit no significant change in temperature at the measurement current of 10 A. The increase in temperature is mainly observed in the measurement leads.
The resistance value is obtained from the ratio of two voltage drops U_x and U_s measured at the plate and standard resistor by the nanovoltmeter Agilent 34420A and multimeter Fluke 8508A respectively:

$$R = \frac{U_x}{U_s} \cdot R_s \cdot k \qquad (4)$$

where R_s is the value of the standard resistor and k is the ratio of the current transformer. The thermal voltages arising in the measurement system in the junctions of dissimilar metals are cancelled out by reversing the current direction for each resistance measurement. The total measurement uncertainty of the resistance value is estimated to be less than 0.1 % of the measured value.

Temperature measurement

In the measurements the VdP measurement tool was placed in the air thermostat at the temperature of 20 ˚C. This was done to minimize the effect of temperature fluctuation on the electrical conductivity measurements. The temperature values have been measured at five points on the plate by the calibrated resistance thermometers with the measurement uncertainty less than 0.1 ˚C.

The voltage and temperature measurements performed in the study were automated by the specially developed software.

By using the equation (2) the conductivity values of five metal plates have been determined. The conductivity values and relative measurement uncertainties are summarized in Table 1.

5. DISCUSSION

The largest components in the uncertainty budget of electrical conductivity are due to thickness and temperature measurements (Table 2). The latter depends very strongly on the temperature coefficient of a material. As expected, the uncertainty of electrical conductivity of samples with well-defined shape (eg square) could be comparably small. For example, the relative measurement uncertainty of the sample T178 is 0.1%. (Table 2)

In the measurements of two samples CuNi and T178 the significant difference of the measured resistances R_a and R_b was observed, which was about 3.6%-3.8%. Partly, this difference can be explained by small deviation from squarness of the CuNi sample. We have measured four resistances R_i and four lengths L_i for each plate, where index i= a, b, c and d. From these measurements of the CuNi-sample we have determined that the $R_a - R_b$ difference 1.6% is caused by the non-perfect square shape of CuNi sample. In case of a square sample with $L_a - L_b$ difference less than 0.4% the

ID	Material	Dimensions [mm]	La-Lb, %	Ra-Rb, %	Electrical conductivity	Uncertainty
T178	Titanium	80.0x80.0x10.1	0.0	3.4	2.172 MS/m	0.1%
CuNi	CuNi	79.5x80.0x3.0	0.6	2.2	3.103 MS/m	0.7%
U178	NordicGold	80.1x80.0x10.1	0.0	0.5	9.571 MS/m	0.1%
NG2	NordicGold	80.0x80.0x3.0	0.0	0.5	9.973 MS/m	0.2%
C178	Brass	80.0x80.0x9.9	0.2	0.2	14.294 MS/m	0.2%

Table 1. Parameters of the metal plates measured in the present study.

Parameter	Value	Uncertainty	Sensitivity coefficient	Uncertainty [Ωm]
Thickness d	$10.0581\cdot10^{-3}$ m	$2.81\cdot10^{-6}$ m	$4.58\cdot10^{-6}$ Ω	$1.29\cdot10^{-10}$
Constant	2.2662	$2.89\cdot10^{-10}$	$4.60\cdot10^{-7}$ Ωm	$1.33\cdot10^{-16}$
Resistance R_a	$9.9256\cdot10^{-6}$ Ω	$1.02\cdot10^{-9}$ Ω	$2.28\cdot10^{-2}$ m	$2.33\cdot10^{-11}$
Resistance R_b	$10.2783\cdot10^{-6}$ Ω	$1.03\cdot10^{-9}$ Ω	$2.28\cdot10^{-2}$ m	$2.35\cdot10^{-11}$
$f(r)$	0.99989	$8.85\cdot10^{-7}$	$4.60\cdot10^{-7}$ Ωm	$4.07\cdot10^{-13}$
δ_{rth}	0	$1.14\cdot10^{-4}$	$4.60\cdot10^{-7}$ Ωm	$5.26\cdot10^{-11}$
δ_{rT}	0	$2.80\cdot10^{-4}$	$4.60\cdot10^{-7}$ Ωm	$1.29\cdot10^{-10}$
δ_{cont}	0	$2.89\cdot10^{-8}$	$4.60\cdot10^{-7}$ Ωm	$1,33\cdot10^{-14}$
Resistivity	$4.6047\cdot10^{-7}$ Ωm	Uncertainty, k=1		$1.93\cdot10^{-10}$
Conductivity	2.172 MS/m	Uncertainty, k=2	0.002 MS/m	
IACS	3.744 %			

Table 2. The electrical conductivity value and uncertainty of the sample denoted T178.

correction for the measured difference of resistances is insignificant. However, the remaining differences are of the order of few percents (Ti and CuNi). The reason for that is not exactly known but it could be due to material properties (eg crystal lattice structure) and/or manufacturing technology (eg rolling, pressing).

In addition, the wedge-shaped geometry of a sample can have an effect on the measurement uncertainty. For example, the change in thickness of the sample CuNi was about 30 µm. This causes increase in the uncertainty of average thickness estimate which, in turn, increases the uncertainty in the determination of electrical conductivity. For the sample CuNi the relative uncertainty estimate was 0.7%.

6. CONCLUSION

The electrical conductivity scale at the direct current in the range from 2 MS/m to 14 MS/m has been realized by means of the Van der Pauw technique.

The performed conductivity measurements are traceable to the Estonian national standards for electrical units, for length and for temperature.

The limiting factors of accuracy in the Van der Pauw' method have been thoroughly investigated. In case of a square sample the highest uncertainty component is due to thickness measurement of the plate. For the investigated samples the relative uncertainties are estimated to be in the range from 0.1% to 0.3% of the measured value.

7. ACKNOWLEDGEMENTS

The research within this project, leading to these results, has received funding from the Tallinn University of Technology under Grant No BF04. Also, the authors would like to thank Dr Olev Märtens from the TUT for providing the Van der Pauw' tool in our measurements.

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TWO-BODY ABRASIVE WEAR OF WC-CO HARDMETALS IN WET AND DRY ENVIRONMENTS

Pirso,J., Juhani, K., Viljus, M., Letunovitš,S.

Abstract: *A comparison of two-body abrasive wear behaviour of WC-Co hardmetals in both wet and dry environments is presented. Five different composites were studied. Two-body abrasive wear tests were conducted on a block-on-ring tester, described in the ASTM B611-85. The steel wheel was replaced with an alumina grinding wheel. The wet environment promoted lower wear rate compared to the dry conditions. The wear volume decreases with the increase in bulk hardness. SEM examination of the wear tracks in the worn blocks suggests that abrasive wear mechanisms are similar in dry and wet environment and occur through surface elastic-plastic and plastic deformation.*

Key words: WC-Co, Hardmetal, Dry abrasion, Wet abrasion, Wear mechanism.

1. INTRODUCTION

Abrasive wear behaviour of a material is dependent on a number of factors, such as chemical content and structure of the material, contact geometry, surface roughness, speed, load, temperature, environment and lubrication [1]. Two-body wear occurs when the grits, or hard particles, are rigidly mounted or adhere to a surface, where they remove the material from the opposite surface. The common analogy is that of material being removed with sand paper or abrasive wheel. In the conditions of abrasion usually multiphase materials – cemented carbides or hardmetals – are used in which extremely hard carbide grains are dispersed throughout a softer matrix. WC-Co hardmetals are well-known high wear resistant materials [2,3].

There is a long history of examination of the abrasive wear behaviour of WC based hardmetals [4-14]. It has been demonstrated that the abrasive wear rate of WC-Co hardmetals mainly depends on the carbide/cobalt ratio and the size of the carbide grains. The wear rate increases in proportion with increase in the cobalt content [4-12] and size of the carbide grains [10-19].

It is found that the abrasive wear resistance of the hardmetals increases with increasing of the carbide content, which also causes a gain in the hardness of the composite [8-12]. These studies have proved the existence of a direct connection between abrasive wear resistance and the hardness of material.

The effect of carbide grain size on the wear rate of hardmetals can be different. Usually fine-grained hardmetals are more wear resistant than coarse-grained ones. Jia and Fisher [12] also found that WC–Co nanocomposites possess an abrasion resistance approximately double that of the most resistant conventional material. At the same time Engqvist et al. [13] have found that coarse-grained hardmetals show a lower abrasive wear rate than the fine-grained ones.

O'Quigley et al. [14] also found that the coarser grades have higher abrasion resistance in the 1000–1600HV hardness range while the finer grades are expected to have a higher abrasion resistance at hardness values higher than 1600 HV.

The main objective of this work was to compare abrasion behavior of WC-Co composites in dry and wet conditions.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The WC-Co samples were fabricated at Tallinn University of Technology using a conventional cemented carbide production route [2]. The structure of cermets consists of tungsten carbide grains with mean grain size 1-2 µm in a metal binder.

Two-body abrasive wear tests were conducted on a modified block-on-ring tester, described in our former work [9]. Steel wheel was replaced by abrasive grinding wheel. Specimens of different WC-Co composites with dimensions of 23x14x5 mm were clamped in a holder and held rigidly against a rotating 225 mm diameter abrasive wheel under normal load of 20 N. Alumina used in these tests as abrasive has Knoop hardness of 1900[15]. The structure of a vitrified grinding wheel is composed of sharp abrasive grits, a bonding system, and a large number of pores. The abrasive grits average size was 0,3 mm. The rotation speed of the abrasive wheel was 235 RPM, which gave a linear speed of 2.8 m s^{-1}. Sliding distance was 50 m. Prior to each wear testing, the abrasive wheel was sharpened, and each specimen ran on fresh surface of the abrasive wheel.

The blocks were ground to a surface roughness (R_a) of about 1 µm prior to testing. Each specimen was weighed before and after testing to an accuracy of 0.1 mg. Weight loss was converted into the volume loss. The abrasion results were averaged over three samples for each material.

The surface of the specimens after wear tests was observed with scanning electron microscope (JEOL JSM 840A). The hardness of the samples was measured using a Vickers pyramid indenter. Measurements were made under a load of 10 kgf using a load time of 30 s. An average hardness value was determined, based on 5 indentations.

3. RESULTS AND DISCUSSION

3.1. Volume loss

The wear behaviour of hardmetals in dry and wet environment is different. As seen in Fig.1, the volume wear of WC-Co hardmetals in dry conditions increased approximately linearly with increasing of the binder content.

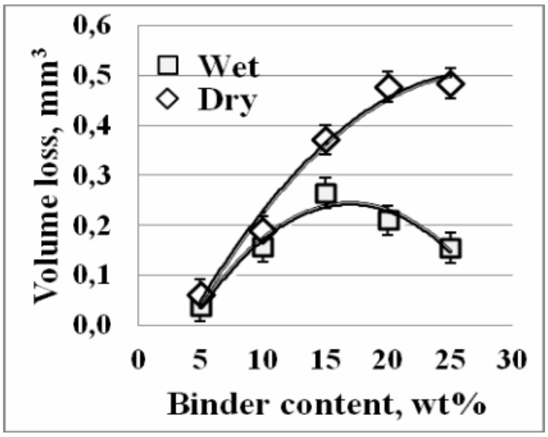
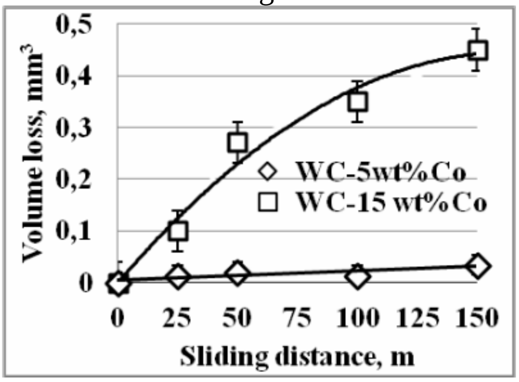


Fig. 1. Two-body abrasive volume wear of cermets depends on binder content

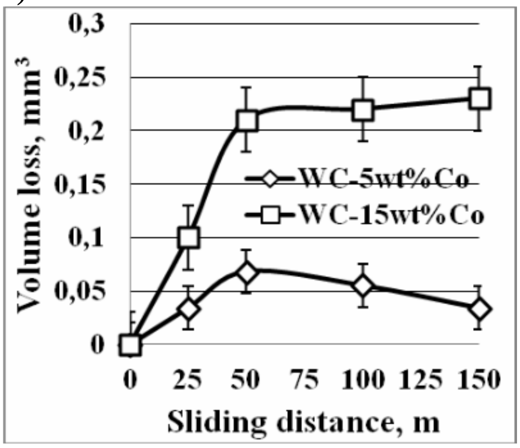
In wet condition the volume wear increases also linearly up to 15 wt% binder content and above that boundary decreases. The reason for this is not completely clear.

Factors which may contribute are cooling of the abrasive contacts by the water and consequent reduction in temperature at the surface. Such reason of different wear rate was noticed by Grant et al [20]. The second reason may be that extruded cobalt filled the pores in the abrasive wheel and by such way the water wedge formed and behaved as a lubricant. It leads to decrease specific loads in the contact area and stress redistribution into the bulk, causing a drop in the material removal rate. The both reasons are significant for high binder compositions.

Fig.2 shows that the volume loss of hardmetals appears to increase with the increase in the sliding distance.



a)



b)

Fig.2.Volume loss of WC-Co hardmetals in dry and wet environment vs. sliding distance. a – dry; b- wet

In dry condition the volume of wear varies in an approximately linear manner during all 150 m sliding distance. In wet conditions after 50 m run the water layer was formed between the surfaces and the volume wear rate stabilized or decreased. The abrasive surface deteriorates during its contact with the specimen and becomes less effective in removing material from the sample.

As seen in Fig.3 the wear rate of the coarse-grained WC–20 wt.% Co hardmetals is approximately twice lower than that of the alloys with medium-size grains. These results are similar with Engqvist et al. [13] and Okamoto et al. [16] showing that the abrasion resistance of the alloys with wide carbide grain size distribution is higher than that of the conventional ones. They suggest that materials with smaller WC grains are brittle, whereas those with larger grains are ductile.

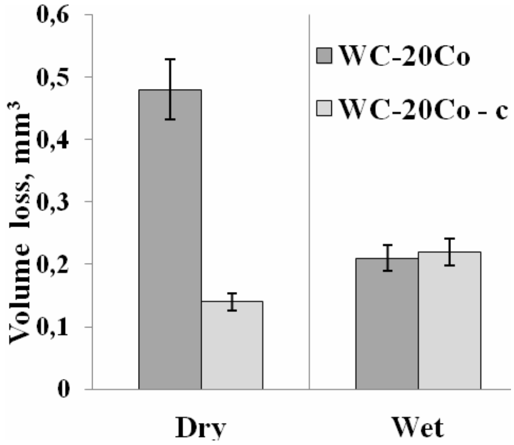


Fig.3.Volume wear of WC-20wt.% hardmetals with medium and coarse carbide grain size in dry and wet environment

As seen from Fig.4, the volume wear in dry conditions depends on the bulk hardness of the composites and decreases with increase in the bulk hardness.

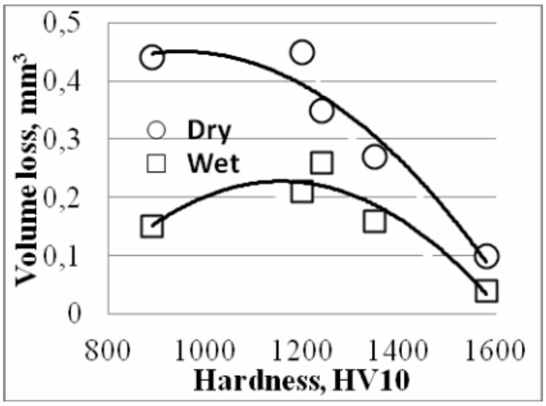
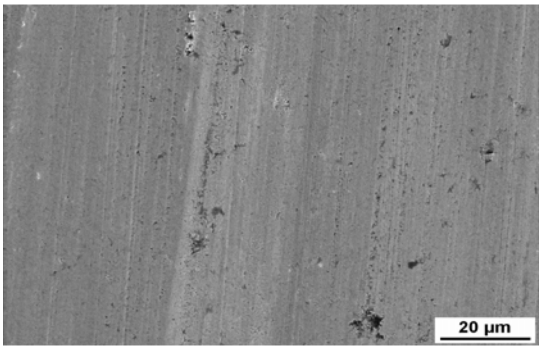


Fig. 4. Wear volume loss after 50 m run vs. bulk hardness of hardmetals.

The penetration depth of the abrasive particles is determined by the hardness of the wearing material. In general, the abrasion damage is inversely proportional to the material hardness, which affects the penetration of the abrasive particles into the target surface. A small penetration depth results in less subsurface deformation, and thus, less abrasive wear. As seen in Fig.4 such behavior of hardmetals is not applied for wet environment. It may be explained by wedge effect of high binder content alloys as shown before.

3.2. Wear mechanism

The two-body abrasive wear is most undesirable, due to its dramatic surface damage. Figs. 5 and 6 illustrates the typical behavior of WC-5wt% Co and WC-20 wt% Co hardmetals sliding against an alumina wheel in dry and wet environment.
Fig. 5 shows a typical behaviour of the hardmetals after dry sliding of 1 m against an abrasive wheel. In Figs. 5a and 5b, the worn surface of WC–5 wt.% Co hardmetal is shown. The abraded surface is relatively smooth and featureless. A small plastic deformation of the surface by the alumina particles can be observed. As seen in Fig. 5b, some extrusion of the binder phase has taken place, followed by pullout of small carbide grains from the surface.
Figs. 5c and 5d illustrates the behaviour of WC–20wt.%Co hardmetal in dry condition. Significant plastic deformation has occurred and deep grooves were formed parallel to the sliding direction. The surface is filled with deep grooves and lateral ridges, parallel to the sliding direction. The passage of the abrasive particles causes plastic deformation of the surface which results in the formation of grooves with material pile up at the groove edges.



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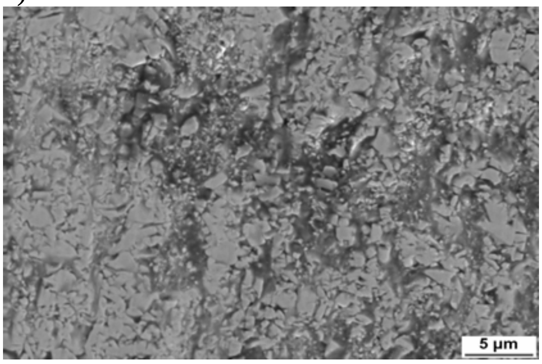

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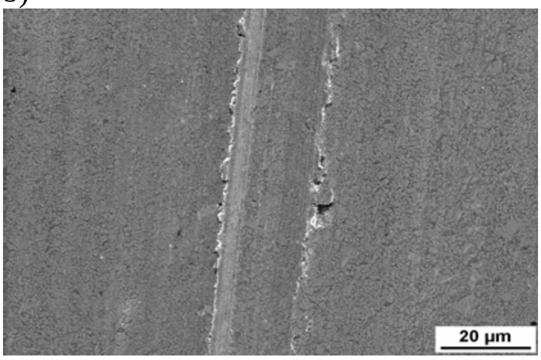

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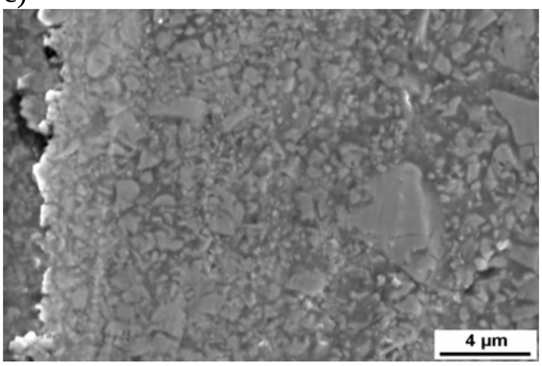
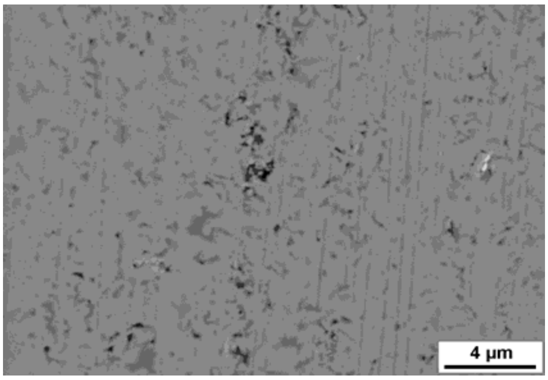


d)

Fig. 5. Wear damages on the WC-Co hardmetal surface after 1 m run on the abrasive wheel in dry environment .
a, b) WC-5wt%Co; c,d) WC-20wt%Co.

Examination at high magnification showed significant damage on the wear surface (Fig. 5d). Considerable fracture of the WC grains can be seen. Many small fragments of carbide grains had been entered into the binder phase regions of the worn surface. The carbide grains thus lose their binder phase support and fall out of the surface.

The deformation in the surface changes from elastic to elastic-plastic or plastic. The abraded surface of the low binder cermets (WC-5wt%Co) in wet environment is also relatively smooth and featureless, indicating that the binder phase and carbide framework were worn down simultaneously (Fig.6a). Several pits can be observed on the worn surfaces.



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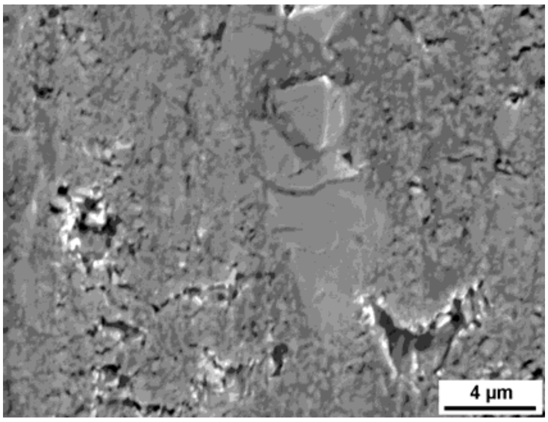

b

Fig. 6. Wear damages on the WC-Co hardmetal surface after 1 m run on the abrasive wheel in wet environment.
a) WC-5wt%Co; b) WC-20wt%Co.

In high binder content alloys (15wt% and more Co) significant plastic deformation occurs (Fig.6b) with corresponding fracture and fragmentation of WC grains and delamination of the material from the surface. Although some of these small fragments of WC grains are removed from the wear surface, many still remain in the materials structure.

Surface shearing and grooving displaces the carbide grains, leading to an extrusion of the Co binder phase towards the surface. The binder phase is partly removed from between the tungsten carbide grains by a combination of plastic deformation and micro-abrasion.

4. CONCLUSION

Two-body abrasive wear behaviour of WC–Co in dry and wet environment was studied.

1. The wear resistance of the hardmetals in both cases depends on the carbide/binder ratio. The wear rate was low and increased with an increase in the binder content, corresponding to a decrease in the bulk hardness.
2. The volume wear of hardmetal samples in wet condition was approximately twice lower than that in dry conditions. The reason for this is not completely clear.
3. The volume wear of hardmetals increases approximately linearly with the sliding distance up to the first 50 m in dry and in wet environment. After that distance the wear volume in wet environment stabilized.
4. The material removal mechanism during wear is similar. Wear of the low binder cermets (up to 15 wt. % binder phase) is elastic-plastic deformation of the surface, followed by fracture and fragmentation of carbide grains and carbide framework after multiple deformations. In the hardmetals with high binder content (more than 15 wt. % Co), significant plastic deformation

occurs with displacing of the material to groove edges without direct material removal, binder phase extrusion and brittle cracking of the carbide grains.

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THE EFFECT OF SUBSTRATE MICROSTRUCTURE ON MORPHOLOGY OF ZINC COATINGS

Sepper, S.; Peetsalu, P.; Mikli, V.; Saarna, M.

Abstract: *in this paper the influence of substrate microstructure on iron-zinc alloy layer formation was studied. To achieve different microstructures laboratory heat treatment was used. Heat treatment parameters were chosen to imitate the heat affected zone in welding and thermal cutting processes. Steel grades S355JR, S700MC, C45E and C60E with different microstructures were immersed in a zinc bath at the temperature 450 °C. Results show that the ferrite grain size does not affect the coating formation. The coating structure and thickness are influenced by carbide grain size.*

Key words: hot dip galvanizing, iron-zinc phases, substrate microstructure, heat affected zone

1. INTRODUCTION

Hot dip galvanization has gained importance in recent years, especially in the construction manufacturing, as a very effective corrosion protection method. Increase in the sizes and capacities of galvanizing kettles makes galvanizing large constructions possible [1]. Hot-dip galvanized constructions might consist of different steel grades: carbon steels and high-strength microalloyed steels, which are welded together in fabrication. Construction production might also include thermal cutting processes, which change the steel microstructure in the heat affected zone (Figure 1). The metal in the heat affected zone (HAZ) undergoes a thermal cycle, which leads to significant micro-structural modifications during welding or thermal cutting process [2].

Although the hot-dip galvanizing has existed for more than 250 years, the precise mechanism of coating formation has still not found a completely satisfactory explanation [3, 4, 5, 6]. There are many investigations describing the influence of steel chemical composition on the hot dip galvanizing, but little research has been done on the effect of substrate microstructure on morphology of zinc coatings.

Hisamatsu [7] postulated that finer grain size of interstitial-free steel is more reactive. More grain boundary area is available for reaction and more rapid Fe-Zn phase growth results. Recent investigations have shown that the substrate grain size has no significant effect on the kinetics of phase growth in a galvanizing bath containing less than 0.001 wt% Al [8]. Galvanizing bath containing 0.20 wt% Al led to outburst formation with finer substrate grain size [8]. Thiele [9]

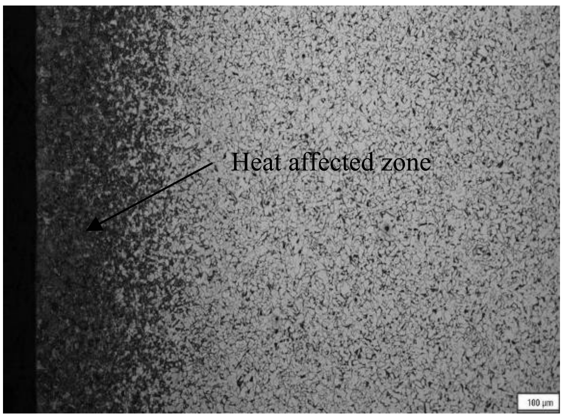

Fig. 1. Heat affected zone of plasma cutting

postulated that annealing Si-containing steels before galvanizing reduces the coating thickness because potential hydrogen traps are to be expected.

The objective of the present study is to investigate the effects of substrate microstructure on Fe-Zn reaction kinetics and phase formation during hot dip galvanizing process.

2. EXPERIMENTAL

2.1 Substrate preparation

Four steel grades (hot rolled S355JR and S700MC with thermo-mechanical treatment, cold rolled softly annealed C45E and C60E) with different silicon equivalents were used in the experiment. The chemical compositions of the steels are presented in Table 1. The substrate materials were 3 mm thick.

To achieve different microstructures with same chemical composition laboratory heat treatment was used:
1) Changing the ferrite grain size – substrate specimens were austenitized at the temperature 900 °C, 1000 °C and 1200 °C for 2 hours followed by water quench and tempering at the temperature of 600 °C for 1 hour.
2) Changing the size of carbide grains – C45E and C60E were austenitized at the temperature 900 °C for 30 minutes, quenched in water and tempered at the temperature 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C for 1 hour.

To guarantee the same chemical composition and surface roughness of the specimens the decarburized layer was removed by mechanical grinding before hot dip galvanizing process.

2.2 Hot dip galvanizing process

Steel sheets were degreased for 15 minutes in acid degreasing agent (Keboclean VZS) and then pickled for 45 minutes with a 10% HCl containing inhibitor for the protection of metal surfaces. Next the sheets were rinsed in water and then dipped in a flux bath consisting of 233 g/l $ZnCl_2$ and 189 g/l NH_4Cl which was kept at 40 °C. The fluxed sheets were dried for 15 minutes at 120 °C in drying oven. Then the sheets were dipped in the zinc bath for 4 minutes at the temperature 450 °C. The zinc bath consists of zinc (99.3 wt. % Zn) containing also Al (0.0025 wt. %), rest Bi, Fe, Ni, Sn, Pb.

2.3 Microstructure studies

For the examination of the microstructure, hot dip galvanized specimens were cross sectioned, hot mounted, grinded and polished. Final polishing was done using a 0.05 µm Masterpolish suspension (Buehler). A nital etchant (nitric acid: 3 wt.%) was used to reveal the microstructures of the specimens and observations were made with optical microscopy Axiovert 25 and scanning electron microscopy EVO MA-15 (Carl Zeiss).

2.4 Coating thickness, Vickers hardness and ferrite grain size measurements

The thickness of coatings was determined by electromagnetic thickness gauge (Dualscope MP0). The Vickers hardness was measured with Micromet 2001 microhardness tester. Vickers hardness at the load of 1 kg was measured at the polished cross-section of a specimen after galvanizing process. Ferrite grain size (G) was determined with reference images of the standard DIN 50601.

Steel	C	Si	P	Mn	Cr	Si_{eq}
S355JR	0.10	0.01	0.015	0.42	0.02	0.05
S700MC	0.05	0.45	0.016	1.85	0.35	0.49
C45E	0.44	0.21	0.007	0.66	0.21	0.23
C60E	0.58	0.05	0.001	0.69	0.24	0.05

Table 1. Chemical composition of the substrate steels, wt %

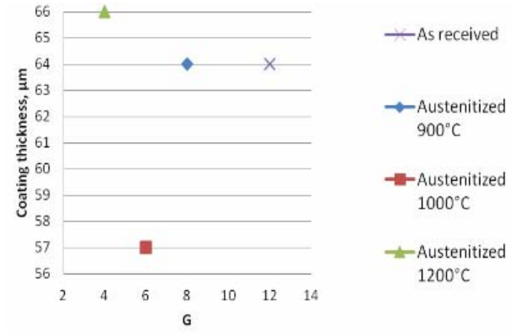

Fig. 2. Effect of S355JR ferrite grain size on coating thickness

Heat treat.	S355JR		S700MC		C45E	
	G	Coating thickness, µm	G	Coating thickness, µm	G	Coating thickness, µm
1	12	64	14	135	12	124
2	8	64	10	147	8	105
3	6	57	8	149	6	100
4	4	66	4	140	3	106

Table 2. Effect of ferrite grain size. Heat treatments: (1) – as received; austenitized (2) – 900 □C, (3) – 1000 □C, (4) –1200 □ C followed quenching in water and tempering 600 □C

3. RESULTS AND DISCUSSION

3.1 Effect of ferrite grain size

Ferrite grain growth in the HAZ is the dominant microstructural feature of the material´s welding and cutting processes. Also different strengthening mechanisms are used in steel production process, which change the ferrite grain size and during hot dip galvanizing might affect the formation and the appearance of the coating.

To achieve different ferrite grain size above mentioned laboratory heat treatments were used. To determine the overall rate of reaction, the total Fe-Zn alloy layer thickness was measured. The effect of ferrite grain size on formation of hot dip galvanized coating is presented in Figure 2 and Table 2. The total Fe-Zn layer growth for each steel grade showed the

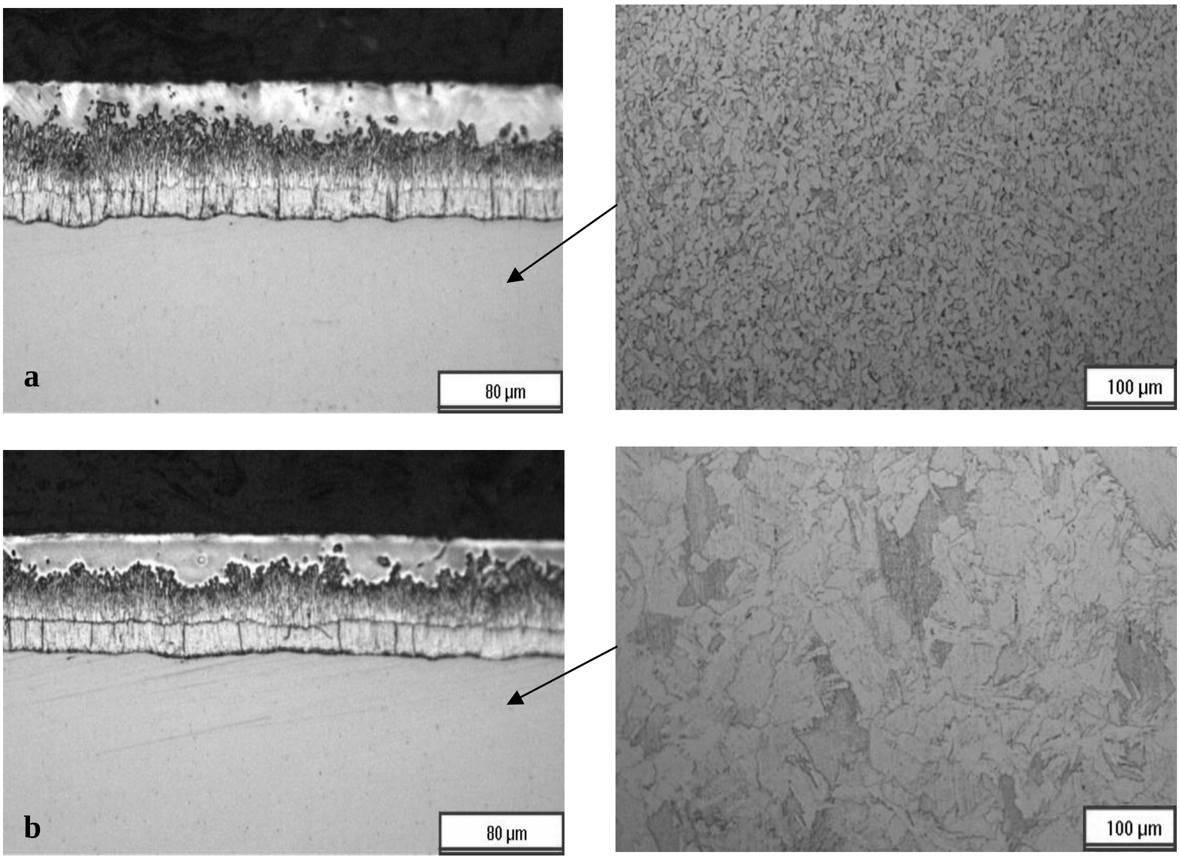

Fig. 3. The micrographs of the cross-sections of the coatings – (a) S355JR with ferrite grain size G12, (b) S355JR with ferrite grain size G4

same behaviour despite the ferrite grain size. In Figure 3 is shown the coating microstructure of steel S355JR with ferrite grain size G12 and G4. The results show that coating structure and thickness is not connected with substrate ferrite grain size.

3.2 Effect of the size of carbide grain

As a result of heat treatment in HAZ, the carbide grain size might also change. To achieve different carbide grain sizes above mentioned laboratory heat treatments were used. In the present study the consideration that the substrate hardness increases with decreasing of carbide size was taken into account.

Differences in the size of carbides influence the coating formation. The higher the hardness of substrate, the smaller the carbide grain size and during hot dip galvanizing thinner coating is formed (Figure 4, Figure 5). The effect of carbide

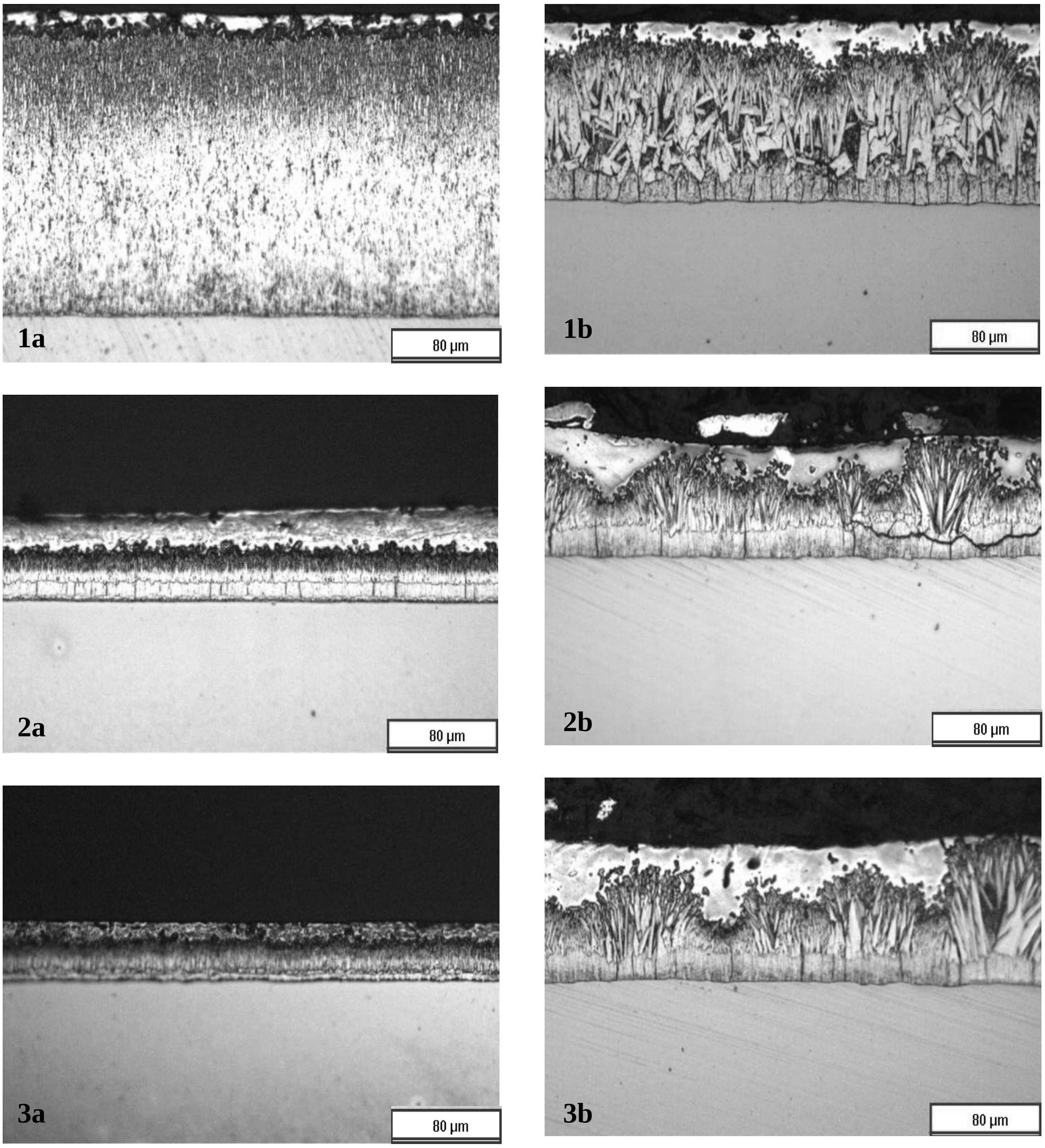

Fig. 4. Effect of „a“ C60E and „b“ C45E carbide grain on formation of hot dip galvanized coatings. Heat treatments: (1) as received (softly annealed); (2) austenitized 900°C, tempered 300°C; (3) quenched in water

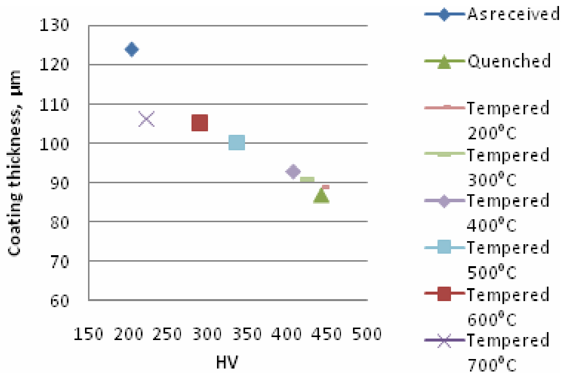

Fig. 5. The relationship between the coating thickness and substrate (C45E) hardness

grain on formation of hot dip galvanized coatings is presented in Figure 4. The reduction in coating thickness was remarkable with steel C60E (Figure 4-a). The silicon content of substrate belongs to the Sandelin range and during galvanizing process a rapid growth of the alloy layers occurred, producing a coating with excessive thickness. As a result of hardening, carbide size decreased and continuous, compact zinc coating formed. Heat treatment reduced the layer thickness from 207µm (as received condition- softly annealed) to 40 µm (quenched in water). Heat treatment of C45 (silicon equivalent 0.23) changed the carbide size and reduced the layer thickness from 124 µm (as received condition- softly annealed) to 87 µm (quenched in water).
The different microstructures of heat treated C60E is shown in Figure 6. In softly annealed microstructure are spheroidal carbides (the size of carbides 0.5 – 4µm). Austenitized and tempered 300 °C microstructure has small carbides in nanometric scale.
Results obtained that the austenization and tempering of the substrate influence the coating thickness and the coating microstructure. Hardening reduces iron-zinc reactivity and thinner coating is formed (reduction is remarkable with steel from Sandelin range). Larger carbides accelerate the zinc coating formation. The thinnest coatings were formed on quenched substrates, were originally after heat treatment no carbides are in the steel microstructure. Carbides are formed in quenched specimens during hot dip galvanizing process where steel is heated to 450 °C (zinc bath temperature). The effect of carbide grain size on coating thickness is influenced by silicon equivalent.

Drawing parallels with enamelling process where fish-scale formation is characterized by the hydrogen permeability (T_H) and the microstructure of the substrate might assume that hydrogen permeability plays also an important role in galvanizing process [9]. The hydrogen does not distribute homogeneously in steel, but various trapping sites exist for hydrogen atoms [10]. Fabian et al. [11] have proposed that the carbide shape and the

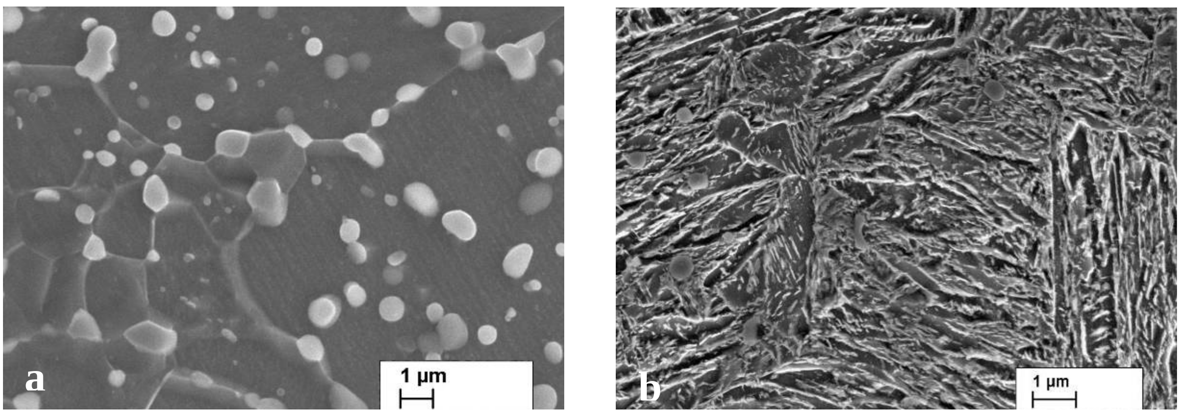

Fig. 6. The microstructure of C60 with different carbide grain sizes. Heat treatments: (a) as received (softly annealed); (b) austenitized 900 °C, tempered 300 °C

carbide size play an important role in the T_H time, but ferrite grain size has no significant effect on T_H value. However, more experiments are needed to draw parallels between the hot dip galvanizing process and enamelling process.

4. CONCLUSIONS

In the present paper the laboratory heat treatment was used to imitate the formation of heat affected zone in welding and cutting process to understand how the substrate microstructure affect the hot dip galvanized coatings. The following conclusions can be drawn from the present study:

1. The thickness of the coating and iron-zinc reactivity is related with the microstructure of the substrate.
2. Ferrite grain size does not affect the morphology of zinc coatings.
3. Differences in the size of carbides influence the coating formation. The higher the hardness of substrate, the smaller the carbide grain size and during hot dip galvanizing thinner coating is formed.
4. Silicon equivalent affects coating reduction with different sizes of carbides.

Further research is needed to support the hypotheses of hydrogen role in hot dip galvanized coating formation.

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DETERMINATION OF THE MECHANICAL PROPERTIES OF CARBIDE COMPOSITES BY SPHERICAL INDENTATION

Sergejev, F.; Petrov, M. & Kübarsepp, J.

Abstract: *Carbide composites are materials based on the carbide phases of the refractory or high melting temperature metals. The hard carbide phase (WC, TiC) is usually embedded into soft matrix – pure metals (Fe, Co, Mo, Ni and others) or their combinations. The hard phase supports high hardness and strength of the carbide composites, while matrix is needed for toughness and plastic properties.*
The ordinary tensile testing is not applicable for yield stress determination in case of carbide composites. The ball indentation depth sensing technique was used to determine yield stress of hard materials.
In present work the first results of the determination of the yield stress of the WC-Co and TiC-Fe/Ni carbide composites using spherical indentation are presented.

Key words: carbide composites; yield stress; spherical indentation.

1. INTRODUCTION

The use of indentation techniques for mechanical properties (hardness, fracture toughness) evaluation of brittle materials (metal matrix composites, ceramics, hardmetal, cermets etc.) is very popular because of ease of tests conduction, no need for precise and expensive specimen preparation, standard tools (indenters) and equipment are used of specified geometry, a lot of measurements can be conducted on relatively small testpieces and so on.
Those techniques are improved and supplemented by new analytical procedures to gain better understanding of abilities, restrictions and accuracy of indentation methods [1,2]. The method for measuring hardness and elastic modulus by instrumented indentation techniques has been adopted and widely used for the characterization of mechanical behavior of materials at small scales. Its attractiveness stems largely from the fact that mechanical properties can be determined directly from indentation load and displacement dependences (curves) without the need to image the hardness impression [3]. The indentation size effect is investigated for application at nano-scale [4] also.
Instrumented indentation tests results have shown steep dependence on the load. The materials indentation hardness and indenter penetration depth are in linear dependences from indentation load [1-4].
The stress measured by instrumented indentation technique is the actual response of the material to the indentation, hard and stiff indenter penetration into the materials surface. The stress field generated by the indentation process is heterogeneous and leads to plastic deformation and damage in the vicinity of the tip. Using Hertz's theory, the spatial dependence of the stress components during indentation can be estimated, by considering the elastic contact of a spherical indenter with a semi-infinite half space.
Numerous studies are conducted to investigate the elastic-plastic indentation stress field employing the spherical indenters (Hertz's theory) as most reliable one, supported by finite-element (FE) methods [5,6]. Only few of them are describing indentation behavior of hard materials [7].

2. EXPERIMENTAL PART

2.1 Materials tested

One TiC-based cermet with nickel-molybden binder (TiC-Ni/Mo), and conventional hardmetal (WC-Co) are tested. The main mechanical properties along with composition and microstructural parameters can be found from Table 1. All materials were produced in Powder Metallurgy Laboratory at Tallinn University of Technology (TUT). The testpieces were produced through conventional press and vacuum sinter powder metallurgy according to ASTM B406. Then specimens were prepared to following dimensions (width × height × length) - (15.0±0.3) × (5.0±0.3) ×35 mm^3. Finally specimens were ground and polished on cloth with 1 μm diamond paste to a surface roughness of about R_a=0.2 μm on two sides (measured along 8 mm of the specimen by the Surtronic 3+ apparatus, using CR filter), see Figs. 1 and 2. Opposite ground faces were parallel within 0.03 mm. In order to remove surface contaminants, the samples were cleaned in alcohol and dried by compressed air.

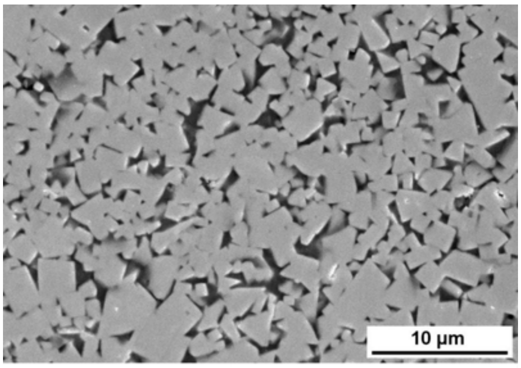

Fig. 1. SEM micrograph of tested H15 carbide composite.

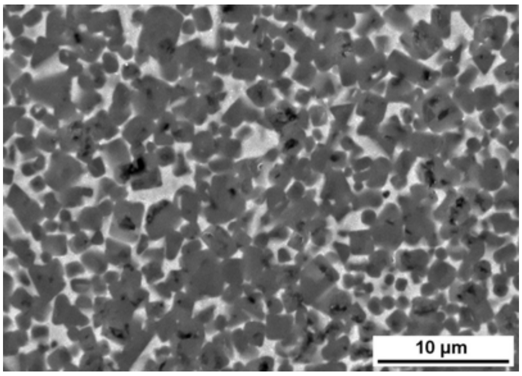

Fig. 2. SEM micrographs of tested T30A carbide composite.

2.2 Spherical indentation procedure

The indentation tests were performed using Zwick ZHU/Z2.5 apparatus.
The difference in the materials response related to indenter shape is obvious if compared with indentation curves made with Berkovich indenter at nanoindentation [8] and micro-macro indentations with Vickers pyramid, see Fig. 3.

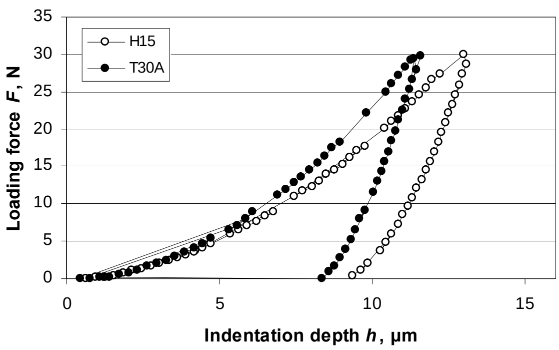

Fig. 3 Spherical indentation curves for studied H15 and T30A carbide composites.

The yield stress determination is related with elastic stresses and materials response to elastic strains and is best characterized

Table 1. Composition, mechanical properties and microstructural parameters of carbide composites tested

Grade	Composition and microstructure			Mechanical properties				
	Carbide, wt%	Binder, wt%	Average carbide grain size d_g, μm	Transverse rupture strength R_{TZ}, MPa	Vickers hardness HV, MPa	Elastic modulus E, GPa	Fracture toughness K_{IC}, MPa·m1/2	Poisson ratio v
H15	WC, 85	Co, 15	1.98	2900	1170	560	15.2	0.23
T30A	TiC, 70	Ni/Mo, 30	2.00	1600	1280	395	16.9	0.31

by spherical indentation. The comparative load-displacement spherical indentation curves for studied materials are shown in Fig. 4.

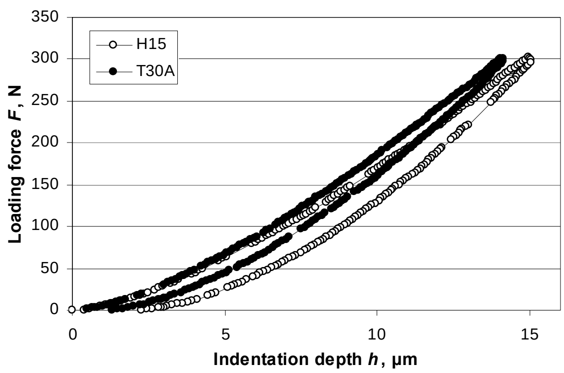

Fig. 4. Vickers indentation curves for studied H15 and T30A carbide composites.

To determine mechanical properties more precisely the spherical indenter of relatively high elastic modulus *E*=640 GPa and Vickers hardness of about 1750 MPa was used. Used spherical indenter is made of hardmetal (WC-6 wt/%Co), and is commercially available from RedHill precision balls and roller producer.

2.3 Additional measurements

The indentations cavities (indents) parameters were inspected by Mahr profilometer. The cross-section profiles of the residual indents for studied carbide composites are shown in Figs. 5 and 6.

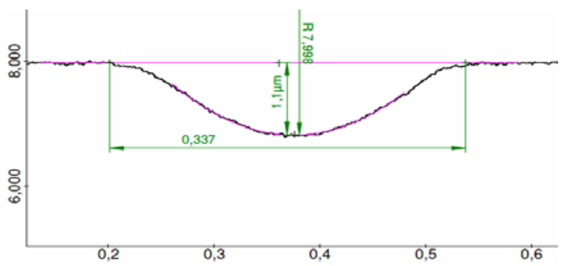

Fig. 5. Indent cross-section dimensions of T30A cermet for 300 N indentation load.

The vertical (indent depth) axis is in micrometers, and the horizontal (indent width) axis is in millimeters.

The residual radius R_r designated in the Figs. 5 and 6 as R can also be found using equation:

$$\frac{1}{R^*} = \frac{1}{R} - \frac{1}{R_r}, \qquad (1)$$

where R^* - is the modified radius, can be found from simple relation (2); R – is the indenter radius.

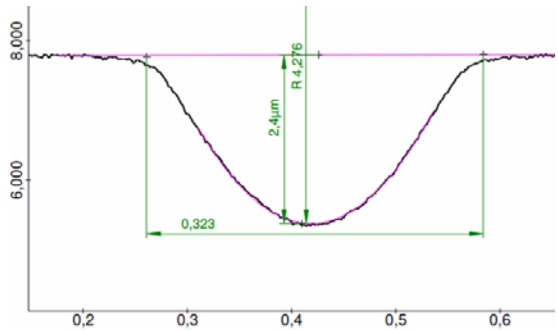

Fig. 6. Indent cross-section dimensions of H15 hardmetal for 300 N indentation load.

The modified radius can be found from Hertz equation for contact displacement:

$$h_c = \frac{a^2}{R}, \qquad (2)$$

where a - is the projected contact radius.

3. RESULTS AND DISCUSSION

The results of indentation hardness measurements performed on a range of brittle solids demonstrate that the indentation pressure is indenter shape insensitive over a wide range of geometries. Observations (and numerical calculations) indicate that the plastic zone exhibits spherical symmetry, regardless of indenter geometry and that identical plastic zone boundaries develop for spherical and Vickers pyramidal indentations of equal volume [[9]]. In current study we have used the spherical indenter as the Hertz analytical model for stress assessment analysis is simple and in case of carbide composites the plastic deformations are very small, or can be neglected. The elastic straining response is desired and the appropriate stress conditions at relatively shallow indentations can be achieved only by spherical indentation, see Fig. 7.

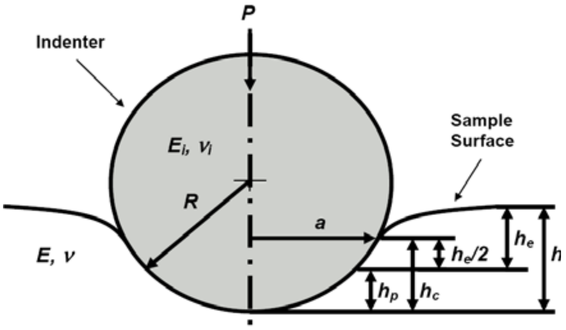

Fig. 7. Schematic of indenter contact with a sample surface [10].

The main mechanical properties can be measured by indentation are yield strength or yield point (in case of elastic materials with low plastic deformations the proof stress determined as the yield at 0,2 % strain), Young's modulus or modulus of elasticity and Poisson's ratio.
The reduced Young's modulus can be determined by equation derived by Hertz:

$$E^* = \frac{3P}{4\sqrt{R^* \cdot h_e^3}}, \tag{3}$$

where P - is the load applied on the indenter; $R*$ - is the modified radius; h_e – is the indenter elastic displacement.

The materials modulus of elasticity (E) can be then calculated from:

$$\frac{1}{E^*} = \frac{1}{E_i} + \frac{1}{E}, \tag{4}$$

where E_i - is the Young's modulus of indenter.

The materials Poisson ratio is then

$$E = \frac{E^*}{1 - v_i^2}, \tag{5}$$

where v_i - is the Poisson's ratio of indenter.

The most efficient way to extract effective stress-strain dependences form indentation data is to use the simple relations proposed by T. F. Juliano et al [10] for true indentation stress

$$\sigma = \frac{P}{\pi \cdot a^2}\left(\frac{h}{h_c} - 1\right), \tag{6}$$

where h_c - is the contact depth and h – is the total indenter penetration depth.

and modulus of elasticity

$$E = \frac{1 - \nu^2}{\frac{4}{3P}\left[\frac{2(h - h_c)}{\left(\frac{2h_c}{a^2 + h_c^2}\right)^{1/3}}\right]^{3/2} - \frac{1 - \nu_i^2}{E_i}}, \tag{7}$$

where ν - is the Poisson's ratio of material.

The effective stress-strain curves based on calculations according to equations (6) and (7) from indentation data are shown in Figs. 8 and 9.
The offset yield point (proof stress, $\sigma_{0,2}$) for WC-15 wt.%Co (Grade H15) hardmetal is equal to approx. 2920 MPa.

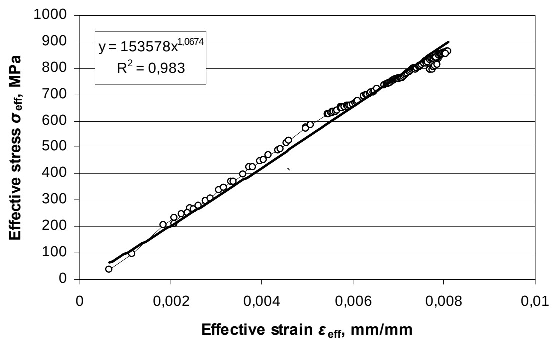

Fig. 8. Indentation effective stress-strain curve for H15 hardmetal.

The offset yield point (proof stress, $\sigma_{0,2}$) for TiC-30 wt.%Ni/Mo (Grade T30A) cermet is equal to approx. 1800 MPa.

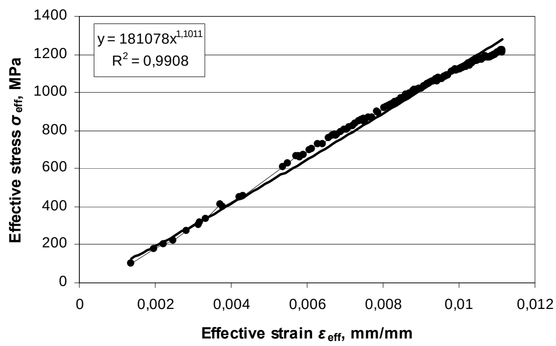

Fig. 9. Indentation effective stress-strain curve for T30A cermet.

The offset yield points (proof stresses) for studied carbide composites were obtained by analysis of the spherical indentation curves and extrapolation of the effective stress and effective strain dependences, as the effective stress-strain graphs (see Figs. 8 and 9) are limited by the indentation stress. The yielding of the materials starts at the stress levels equal to 700 MPa and 850 MPa for H15 and T30A, respectively, and is apparent due to the measurable residual indentation depth seen in the Fig. 4. However, the 0,2 % offset stress is located far beyond the limits of the indentation test results, the indentation force is limited by the testing apparatus, and can not be visualized on the effective stress-strain curves.

The higher proof stress for WC-Co hardmetal can be addressed to the higher strain absorption ability of the tungsten carbide grains compared with titanium carbide phase. As shown by previous studies the elastic strain energy storing in the composite may relax either by origin and propagation of microcracks, or by a local plastic strain. The resistance of a composite to brittle fracture depends, therefore, on the ability of its carbide phase to undergo local plastic strain (to absorb fracture energy by local plastic strain), was proved by XRD studies [11].

Although the offset yield point results obtained in current study are in good agreement with proof stresses ($R_{C0,1}$) for similar carbide composites published previously [11,12].

4. CONCLUSIONS

The spherical instrumented indentation technique can be used as express and reliable technique to measure main mechanical properties of carbide composites (WC-based hardmetals and TiC-based cermets). Obtained load-displacement (*P*-*h*) curves can be transformed into effective stress-strain (σ_{eff}-ε_{eff}) curves similar to true stress-strain curves from compression testing.

The properties measured from stress-strain curves, such as, modulus of elasticity, Poisson’s ratio and yield strength σ_y (or offset yield point $\sigma_{0,2}$) can be obtained even for very hard materials, if spherical indenter of higher than tested materials modulus of elasticity is used.

The current study neglects the effect of microstructure evolution, surface roughness, residual stress, and many other factors that may affect the indentation response, that should be studied in future works.

5. ACKNOWLEDGEMENTS

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SENSITIVITY OF TUNGSTEN AND TUNGSTEN DOPED WITH La_2O_3 TO DEUTERIUM PLASMA PROCESSING

Shirokova, V.; Laas, T.; Väli, B.; Priimets, J.; Ainsaar, A.; Demina, E. V.; Pimenov, V. N.; Maslyaev, S. A.; Gribkov, V. A.; Dubrovsky, A. V.; Scholz, M.

Abstract: *Experiments on the plasma focus devices PF12 and PF1000 have been carried out by using deuterium for investigating changes in the surface and structure of tungsten and tungsten doped with 1% lanthanum-oxide. The surfaces were analyzed and the damage factor of the irradiated samples was investigated by using electron microscopy. Also, microroughness and microhardness of the cross-sections of the specimens were investigated. As a mesh of microcracks, holes, bubbles, and a wavelike structure, due to the plasma effect, appeared on the surface, microroughness and micro-hardness of the surface change essentially. As tungsten is a very brittle material, the positive effect of lanthanum-oxide on the bulk and surface properties of the irradiated samples is considered.*

Key words: tungsten, lanthanum-oxide, bulk and surface damages.

1. INTRODUCTION

Today construction and planning of a number of large fusion facilities based on different plasma confinement principles are underway. Many of the basic problems investigated and solved are common for the two main types of fusion energy (magnetic and inertial confinement) devices as well as for various alternative ones [1-4]. The general problem associated with these devices is choice of a suitable plasma facing material. The influence of heat plasma loads on the construction materials (low-activation metal allow, ceramics) is of interest. Tungsten and CFC (carbon fiber composite), which are planned to be used as the ITER divertor's material, have many good properties, the most important of these is high melting temperature. However, there are some shortcomings, for example tungsten's brittleness and low recrystallization temperature [5-9], which can cause deterioration of bulk and surface properties of samples. Therefore, it is of importance to analyze different tungsten grades and alloys under various irradiation conditions.

Interest to these materials can lead to new ways of improvement of mechanical properties of the materials. Tungsten alloys and different grades can be better processed, and also, the nature of the bulk and surface damages can change under plasma influence differently.

In this work plasma focus devices are used as high temperature plasma generators, which allows one to apply different regimes of irradiation [6, 7]. The power flux density of the plasma streams $q \approx 10^5 - 10^{12} W/cm^2$ depends on the distance between the sample and the anode. Tungsten (W) and tungsten doped with 1% lanthanum-oxide La_2O_3 (WL10) have been investigated. Complex analysis of the irradiated samples has been carried out using different methods.

2. MATERIALS AND IRRADIATION CONDITIONS

The samples of tungsten (W) and tungsten doped with 1% lanthanum-oxide (WL10) was made from tungsten powder by isostatic pressing, sintering and rolling (manufactured in PLANSEE). The W plates were 2 mm and WL10 plates 4 mm thick. The experiments were carried out by PF-12 and PF-1000 with deuterium plasma. (See Fig. 1). The samples were irradiated by 2 and 8 pulses. The distance from the anode was 3.5, 6.5, 10.5 cm (in PF-12) and about 7-7.5 cm (in PF-1000). The initial pressure of deuterium was accordingly 1.25 Torr and 2.1 Torr. The capacitors were loaded up to 20 kV (in PF-12) and 24 kV (in PF-1000).

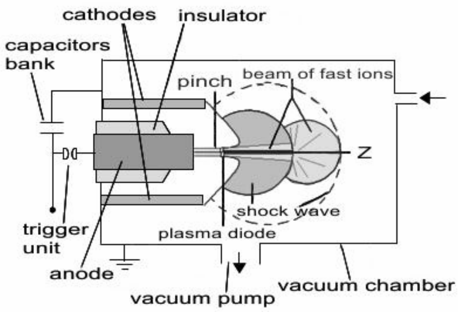


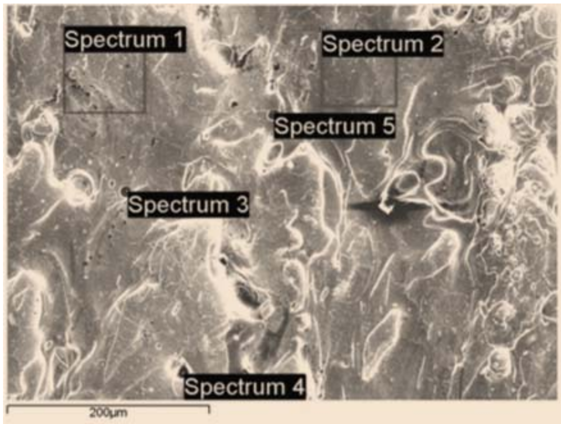
Fig. 1. Experiment's setup. Power flux density of the plasma streams depends on the distance between the sample and the anode.

If the distance is 3.5 cm (I regime), an attack of a slow plasma (ab. 0.1-10 keV) is followed by a stream of fast ions (ab. 100 keV) blowing off the layer of the slow plasma, therefore, as the power density of plasma is about $5 \cdot 10^8$ W/cm^2, the interaction time is about 200 ns. If the distance is 10.5 cm (II regime), fast ions reach the sample first, while the slow plasma reaches the sample in about 60-100 ns. The overall power density is about $5 \cdot 10^6$ W/cm^2, but the interaction time of the secondary plasma (with energy of a few eV) may be up to 0.1 ms. In the distance 6.5 cm between the sample and anode the fast ions and slow plasma should reach the sample simultaneously. At PF-1000 only I regime with overall power density 10^{12} W/cm^2 is used.

3. RESULTS

3.1 Chemical and surface analysis by SEM

A chemical analysis of samples by electron microscopy was investigated. Figures 2,3 show SEM images with the spectral analysis after irradiation.



a

Zone\element	O	Cr	Fe	Ni	Cu	W	Total
Spectrum 1	19.95		6.56			73.48	100.00
Spectrum 2	21.01		6.35			72.64	100.00
Spectrum 3	4.78	9.75	73.27	10.24		1.95	100.00
Spectrum 4			18.13			81.87	100.00
Spectrum 5	3.40	0.92	4.15	1.33	89.12	1.08	100.00
Max.	21.01	9.75	73.27	10.24	89.12	81.87	
Min.	3.40	0.92	4.15	1.33	89.12	1.08	

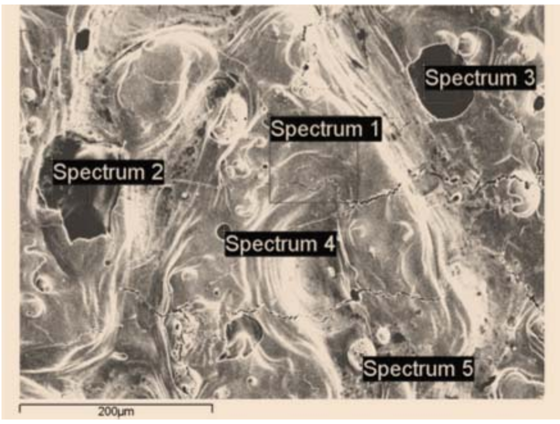
b

Fig. 2. Sample's chemical analysis: a – sample surface layer with marked zones; b – sample chemical composition (at.-%) after irradiation at PF-1000.

The same analysis was made with not irradiated samples. The chemical analysis of tungsten dispersed with 1% lanthanum-oxide shows the lanthanum presence on the break off, but on the surface layer there is more iron. The figures 2, 3 confirm the presence of all elements, vaporized from anode: Fe, Ni, Cr belong to composition of the cathode and Cu – to the anode of the chamber.

The surfaces of the irradiated specimens were investigated by using scanning electron microscopy. Figure 4 presents SEM photos of irradiated samples and photos by optical microscopy (see Fig 4 d, e).

The analysis by SEM images reveals that high-temperature plasma with fast ion stream produced melting of the surface layer of materials. There are met some wavelike structures (roughness without high-frequency terms) which are of the same wavelength and amplitude for both materials - W and WL10 irradiated under the same conditions. Microroughness does not vary very much at that.



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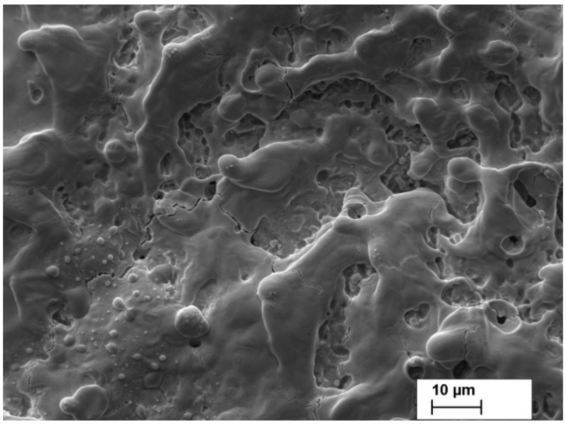
Zone/element	O	Cr	Fe	Ni	Cu	La	W	Total
Spectrum 1	25.74		5.34			1.07	67.84	100.00
Spectrum 2	7.82	3.88	15.78		68.35	0.00	4.17	100.00
Spectrum 3	7.26	3.36	12.94	1.68	71.37	0.39	3.00	100.00
Spectrum 4	14.43	4.15	16.26		43.66	0.00	21.51	100.00
Spectrum 5							100.00	100.00
Max.	25.74	4.15	16.26	1.68	71.37	1.07	100.00	
Min.	7.26	3.36	5.34	1.68	43.66	0.00	3.00	

b

Fig. 3. WL10 chemical analysis: a – sample surface layer with marked zones; b – sample's chemical composition (at.-%) after irradiation at PF-1000



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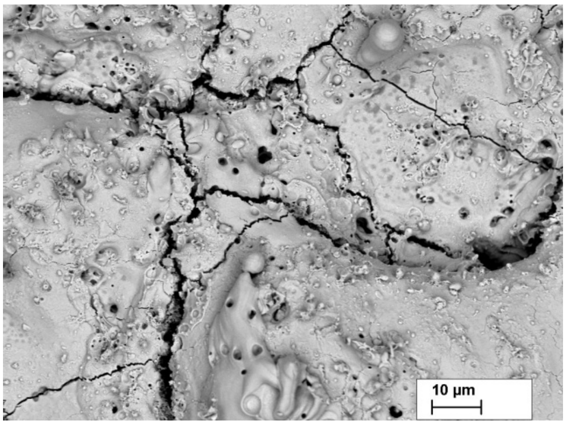

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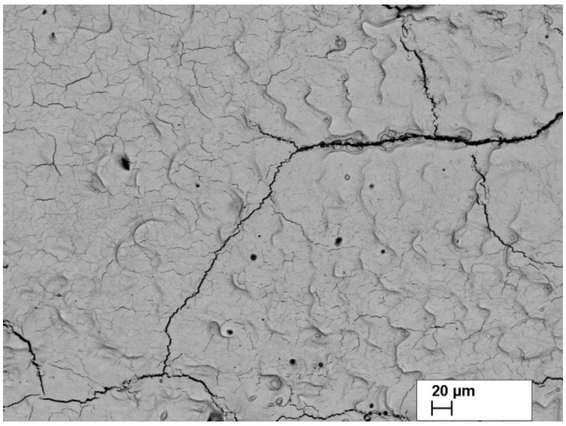
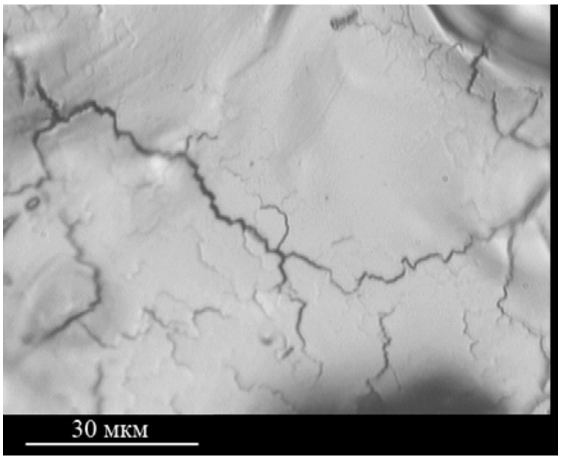
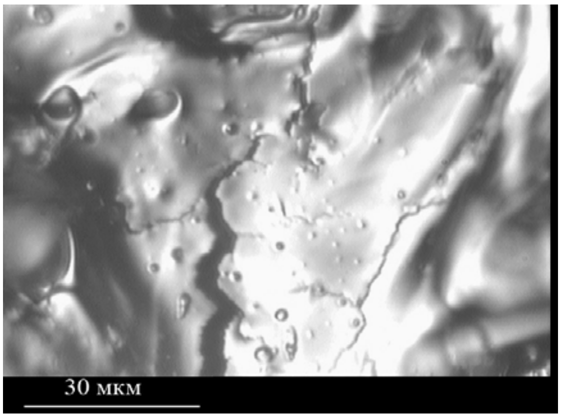


c



d



e

Fig. 4. a – WL10, 8 shots, distance from the anode 6.5 cm (with secondary electrons); b – WL10, 8 shots, distance from the anode 6.5 cm; c – W, 8 shots, distance from the anode 3.5 cm; d - W, 2 shots, distance from the anode 7 cm (at PF-1000); e – WL10, 2 shots, distance from the anode 7 cm (at PF-1000).

A mesh of cracks has appeared on the material surface caused by crystallization of the melted layer in the condition of fast cooling.

Also, the plasma influence on the thin melted layer of tungsten produces wave-like structures.

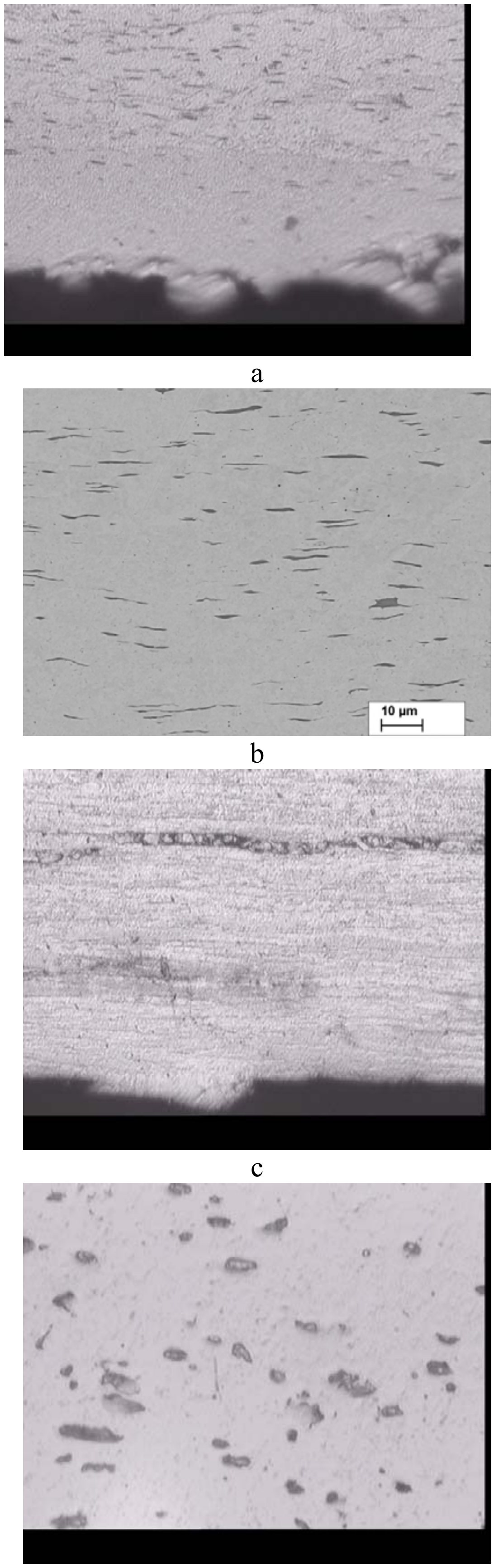
Table 1 shows the irradiation conditions and surface changes (characterization of damages) of materials under the plasma influence. As is seen from Fig. 4 (d,e) and from Table 1, the surface damages of irradiated materials depends on the power flux density. The same defects of WL10 appear at all power flux densities. In tungsten surface a power plasma gives a mesh of microcracks. The density of microcracks in the WL10 surface increases with the number of shots slower than in the W surface.

Table 1. Irradiation conditions and estimated damages. The first ten samples were irradiated at PF-12 the last two at PF-1000. d – distance between the anode and the sample, R_a – average mircroroughness.

No of sample	Material	d (cm)	Number of pulses	Ra (μm)
1	W	3.5	2	3.28
2	W	3.5	8	2.90
3	WL10	3.5	2	3.51
4	WL10	3.5	8	2.85
5	W	10.5	2	2.98
6	W	10.5	8	2.93
7	WL10	10.5	2	1.77
8	WL10	10.5	8	2.93
9	W	6.5	8	2.62
10	WL10	6.5	8	2.77
11	W	7	2	
12	WL10	7	2	

3.2 Cross-section and microhardness

For the hardness measurements the cross-section of samples was investigated. The measurements results are given in Figure 6. The cross-section of a longitudinal section (see Fig 5) of the samples were revealed, the last one analysed by optical microscopy.



a

b

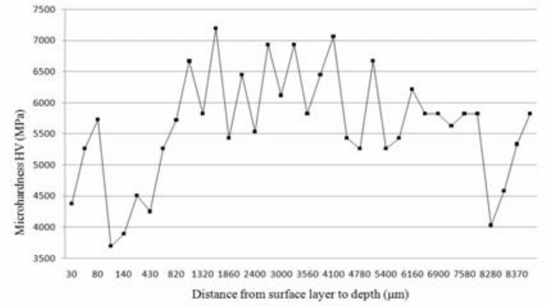
c

d

Fig. 5. Cross-sections. a - WL10, 2 shots, distance from the anode 7,5 cm (at PF-1000); b - WL10, 8 shots, distance from the anode 3,5 cm; c – W, 2

shots, distance from the anode 7,5 cm (at PF-1000); d – not irradiated WL10 (longitudinal section).

Analysis of the results shows that lanthanum oxide appears in the form of small dark strokes about 5-10 μm in length. The longitudinal section shows La_2O_3 inclusions in the form of the different grains. A chemical analysis by electron microscopy shows lanthanum and oxygen presence, showing lanthanum-oxide. These cracks appear in the depth of 60 μm from the surface layer.



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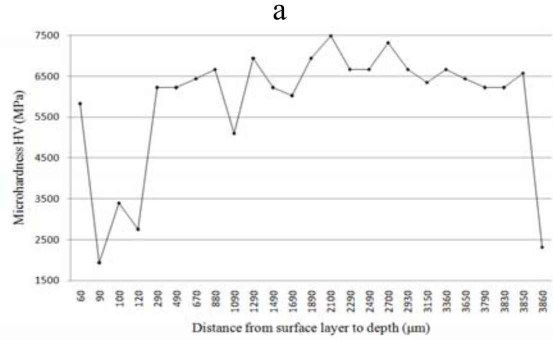

b

Fig. 6. The hardness of cross-section diagonally: a - WL10, 2 shots, distance from the anode 7 cm; b - W, 2 shots, distance from the anode 7 cm. The samples were irradiated at PF-1000.

Hardness changes quite abruptly in the border layer, but at the depth there are seen hardness oscillations about a mean value. With the depth increasing in some samples a hardness gradient is appeared. The hardness increases in bigger depths, out of the thermal influence zone. The main cause of the hardness gradient is the impact wave of plasma influence or the mechanical processing of the samples.

To explain the hardness gradient the mathematical model can be applied (See table 2).

Table 2. Mathematical model for the samples, distance from the anode is 3.5 cm.

No	Lanthanum	Number of shots	Hardness value
1	-	-	1233,42
2	-	+	1750,28
3	+	-	2653,84
4	+	+	3358,46

In the second column the sign "+" means the availability of lanthanum in alloy and "-" means a clean tungsten. In the third column sign "-" means 2 shots and "+" means 5 shots. The role of the number of pulses or the availability of lanthanum can be estimated by

$$b = \frac{\Delta y}{\Delta z}, \qquad (1)$$

where Δy is the sum of the hardness values with their sign from the second or third column and Δz is the number of the value.

This estimation reveals that lanthanum takes more influence on the hardness gradient than the number of shots. This model can be used for the roughness parameter and damage factor values. It can be concluded that for this distance (3.5 cm) the bulk and surface damages depend on the lanthanum availability. For the another distance the surface defects depend on lanthanum and the bulk damages on the number of shots. This model can be used for small power flux density as in the case of big power flux densities (samples no 11 and 12 in Table 1) the character of surface damaged changes essentially.

7. ACKNOWLEDGMENTS

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10. CONCLUSION

Researches have carried out experiments on tungsten and alloy W-1%La_2O_3 on PF-1000 and PF-12 with different radiation conditions. The results indicate that:

- Dense plasma shots and fast ions can create a wave-like relief on a surface after solidification of the melted layer.
- A mesh of cracks is a result of crystallization of a melted layer in conditions of fast cooling, the mesh density is bigger in cases of pure tungsten.
- Microhardness of the specimens does not vary very much.
- Microrougness of sample's surfaces is almost the same in the cases of W and WL10.

Taking into consideration that alloys W-%1La_2O_3 can be machine processed more easyly and the brittleness of WL10 is lower than W, WL10 may be considered as an alternative of W for the fusion devices.

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STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF BIRCH PLYWOOD DEPENDING ON MOISTURE CONTENT

Siim, K.; Kask, R.; Lille, H. & Täkker, E.

Abstract: *The objective of this study was to explore the physical and mechanical properties of three types of birch (Betula sp) with phenol glue of 9 veneers: ordinary plywood (OP), moisture-resistant plywood (MRP) and water-resistant plywood (WRP), as well as their dependence on moisture content. The studied properties were modulus of elasticity in bending (MOE), bending strength (BS) of plywood, shear strength of bonded joint (SSBJ) and Janka hardness (JH), which were tested according to the European Standards (EN).*

Comparison of different types of plywood showed that with increasing moisture content the strength properties of OR decreased significantly faster than the strength properties of MRP and WRP.

Keywords: plywood, bending strength, modulus of elasticity, shear strength, Janka hardness.

1. INTRODUCTION

Plywood is a laminated composite structure, where three or more veneers are across each other, connected by a bonded joint [1,2]. The classifications of plywood are based on the using in manufacturing tree species, surface appearance, application field, conditions, etc. This study proceeded from the classification of bonded joints by grade depending on moisture resistance. According to the standards EN 636-1, EN 636-2 and EN 636-3, there are three grades of glue joint: grade I – for use in dry conditions; grade II – for use in humid conditions and grade III – for use in exterior conditions.

This study investigated the physical and mechanical properties of birch plywood, which are classified as follows: OP – grade I, MRP – grade II and WRP – grade III. The requirements for the grades of bonded joints are enacted by the European Standard (EN) [3,4].

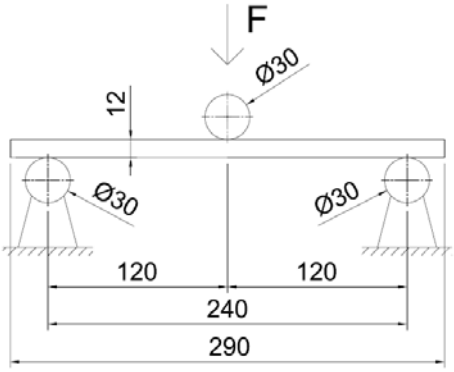
The studied properties were BS and MOE, determined according to the grain orientation of the first veneer. The SSBJ and JH as well as their dependence on moisture content were observed.

Three 9-layer plywoods of 12 mm thickness made by different manufacturers (Ust-Izhora, Sõktõvkar, UPM-Kymmene Otepää) were tested using the computer-controlled mechanically actuated universal testing machine Instron 3369. Various test methods determined by the European Standards (EN) were applied to study the above properties. The sensitivity of the measured data was studied and the expanded uncertainties of the computed mean values are presented.

Analytical expression was used to approximate the experimental data for the investigated SSBJ and JH depending on their moisture content.

2. EXPERIMENTAL PROCEDURE AND METHOD

The BS and the MOE in bending are found by three-point bending according to the standard EN (Fig. 1) [5]. Deflection for calculating the modulus of elasticity was measured by an optical gauge (Advanced Video Extensometer 2663-821). The experiments were made with three series (the minimum number of specimens in series is twelve). The specimens were cut according to the grain orientation to the first veneer: along the grain (parallel) and across the grain (perpendicular).



a)

b)

Fig. 1. Three-point bending and the points of deflection measurement: a) scheme b) photo

The MOE was determined by the following formula (see the standard EN [5])

$$E_m = \frac{l_1^3 (F_2 - F_1)}{4bt^3 (a_2 - a_1)}, \tag{1}$$

where l_1 is the length between the supports, (240mm); b is the width of a specimen, (50±1mm); t is the thickness of a specimen, (12mm); F_1 and F_2 are 10% and 40% from the maximum bending force, respectively; a_1, a_2 are deflections according to the loads F_1, F_2 (see Fig. 2).

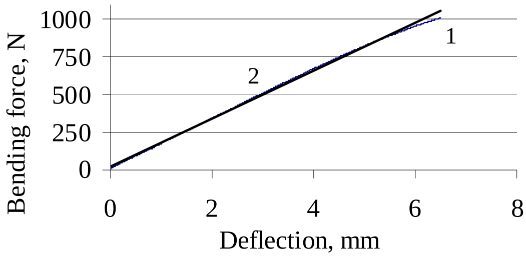


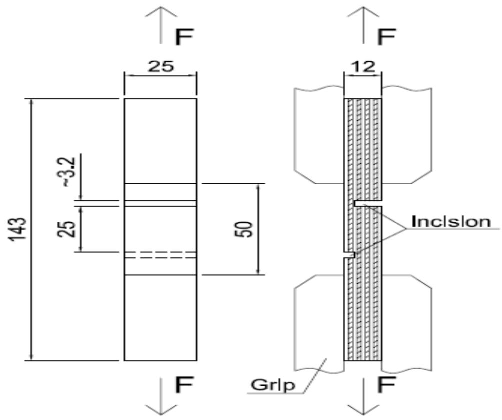
Fig. 2. Dependence of deflection on bending force: 1 – real curve; 2 – approximation line.

The BS was calculated by the following formula (see the standard EN [5])

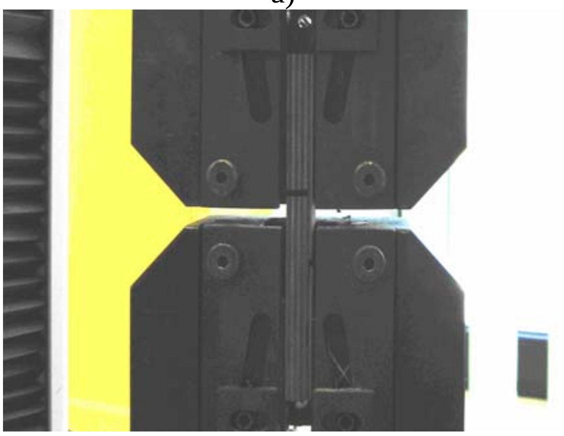
$$f_m = \frac{3F_{max} l_1}{2bt^2}, \tag{2}$$

where F_{max}, is the maximum load, N.

Experiments for determination of the SSBJ were carried out using specimens (see Fig. 3 a).



a)



b)

Fig. 3. The principle of determination of the shear strength of a bonded joint a) scheme b) photo

The SSBJ was determined according to the EN [3]

$$f_v = \frac{F}{bl}, \quad (3)$$

where F is the force, N; b is the width of the bonded test surface, mm; l is the length of the bonded test surface, mm.

Static hardness was determined by the Janka hardness test on the test machine INSTRON 3369 using 50×50 mm specimens [6].

The moisture content of the specimens was determined using the following equation [7]

$$W_{abs} = \left(\frac{m_1 - m_0}{m_0}\right) \cdot 100, \quad (4)$$

where m_1 is the mass before drying, m_0 is the dry mass.

The following analytical expression (based on the power function) was used to approximate the experimental data for the investigated bonding strength and Janka hardness depending on their moisture content

$$Y(x) = Y_{01} \times x^c \quad (5)$$

where Y_{01} is the value of the investigated parameter (x = 0.1), c is a dimensionless parameter.

The purpose was to find unknown constants so that the measured properties can be approximated in the best way. This problem was solved using the mathematical program *Mathcad 14.0.* regression function *genfit* (vx, vy, F).

3. MEASUREMENT UNCERTAINTIES

It is usually described by a parameter that defines the range within which the true value of the quantity to be measured is estimated to fall within a given confidence range – usually 95%.

Experimental standard deviation can be calculated by the following formula [8]

$$s_{w,j} = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(x_{i,j} - \overline{x}_i)^2}, \quad (6)$$

where n is the amount of specimens, $\overline{x}_i$ is the arithmetic mean of the input estimates $x_{i,j}$.

$$\overline{x}_i = \frac{1}{n}\sum_{j=1}^{n} x_{i,j}. \quad (7)$$

Calculation of expanded uncertainty of measurements is carried out according to the standard EVS-EN 326-1:2002.

The lower level of confidence at significance level 5%

$$L^q_{5\%} = \overline{x} - t_n s_{w,j}, \quad (8)$$

where t_n is the coverage factor.

The high level of confidence at 5% significance (level of confidence of the interval)

$$U^q_{5\%} = \overline{x} + t_n s_{w,j} \quad (9)$$

4. RESULTS AND DISCUSSION

The investigated plywood boards are tested according to the EN [5]; obtained BS and MOE are presented in the Fig. 4 and Fig. 5. The coverage factor in formulae (8, 9) was taken from the standard.

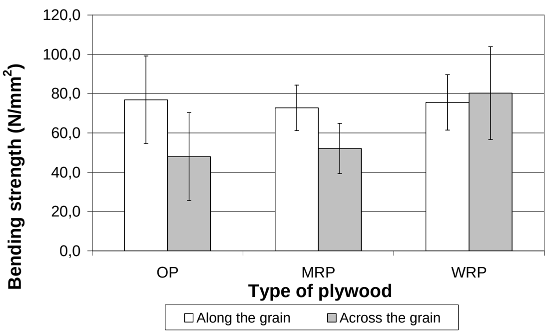


Fig. 4. Bending strength of plywood depending on the grade of the bonded joint.

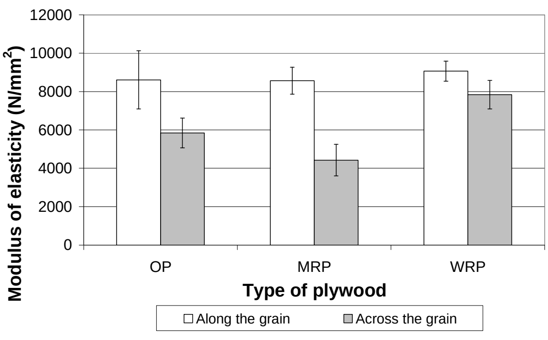
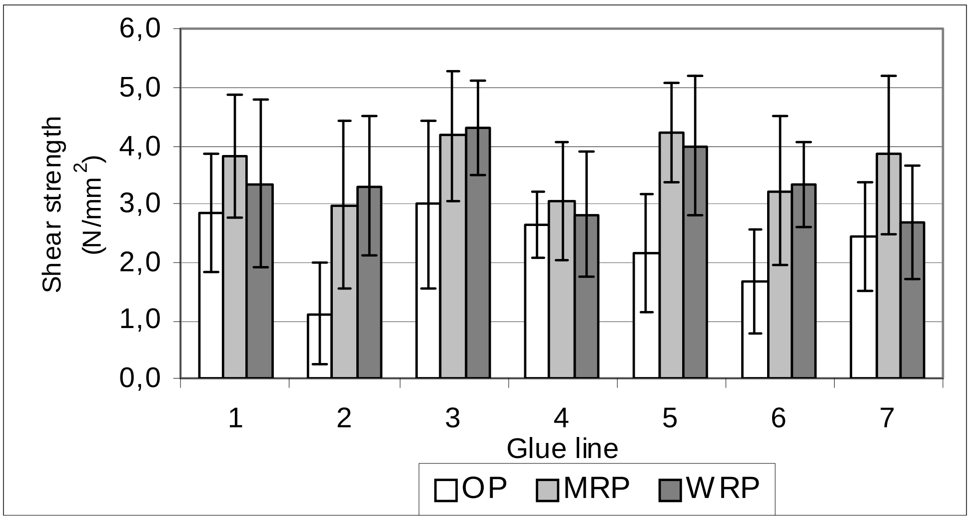


Fig. 5. Modulus of elasticity of plywood depending on the grade of the bonded joint

We can see that the BS and the MOE are considerably higher for WRP than for PO and MRP, which are cut across the grain. The values of these parameters are more similar for specimens cut along the grain. Long-term exposure to high levels of moisture causes reduction in strength and stiffness.



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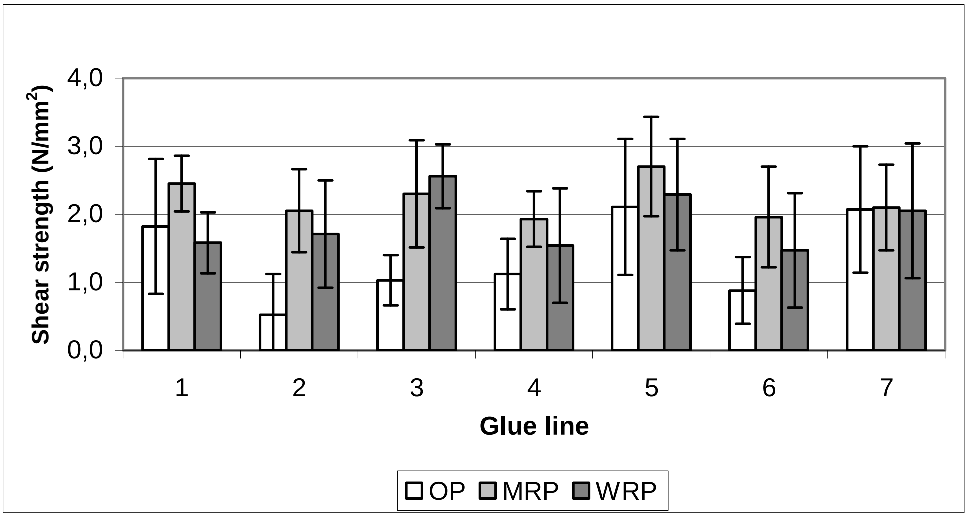

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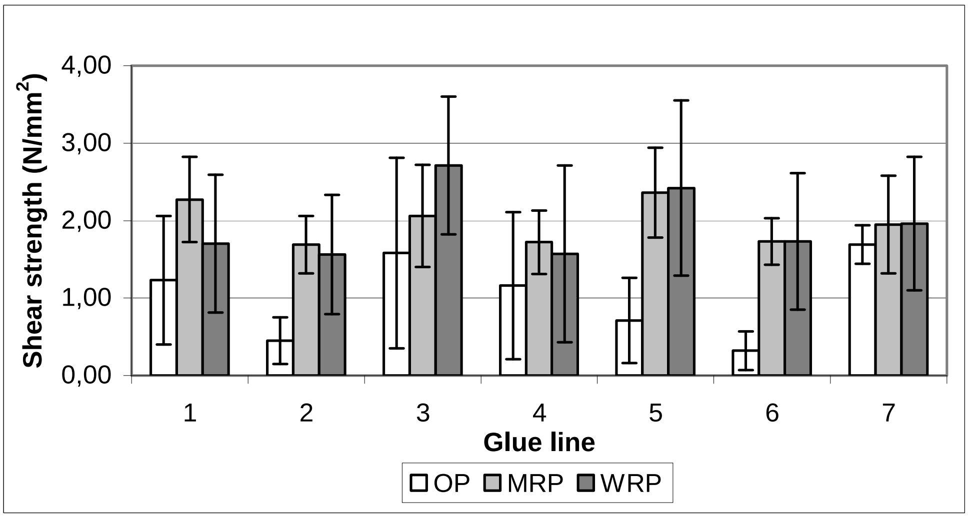

c)

Fig. 6. The SSBJ of glue lines of investigated plywood specimens determined on air-dry a), after 24 h of soaking in water b) and 6 h in boiling water c).

The SSBJ and their expanded uncertainty of a single glue joint fluctuated in great extent but for third and fifth they are a certain extend higher. The mean values are presented in Fig. 7.

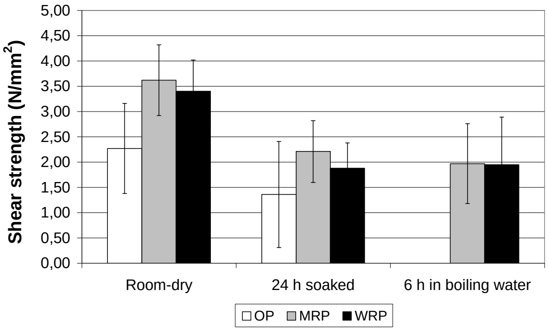

Fig. 7. Mean values of the SSBJ of all bonded joints depending on water immersion time (moisture content).

Independent of the grade of plywood, about 60% of the SSBJ remains after 24 h of soaking compared to room-dry. The SSBJ of MRP and WRP decrease similarly after 24 h of soaking or 6 h in boiling water.

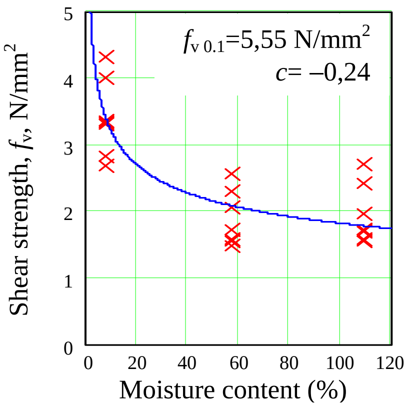

Fig. 8. The SSBJ of MRP depending on moisture content and the line of approximation.

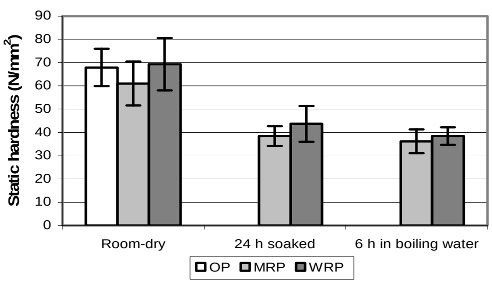

Fig. 9. Dependence of Janka hardness on moisture content (water immersion time).

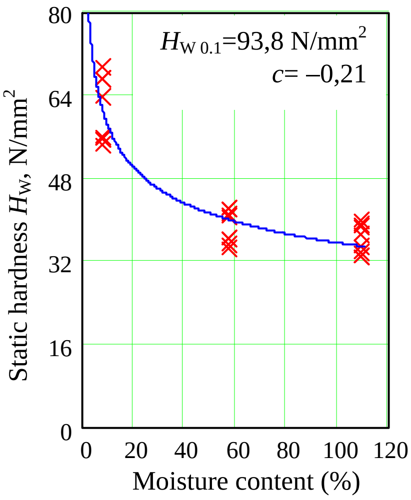

Fig. 10. Dependence of Janka hardness on moisture content and the line of approximation.

Janka hardness is similar for all air-dry boards, but this property is affected by moisture content equally so to MRP than to WRP is about two times lower after soaking for 24 h and 6 h in boiling water. The uncertainties of the determined properties are to some extent lower for MRP and WRP than for OP boards. The results of the study showed that the physical and mechanical properties are higher which are set by the standard.

5. CONCLUSIONS

The obtained BS and MOE for all three grades – OP, MRP and WRP – are relatively equal determined on specimens cut along the grain. The BS and MOE of specimens cut across the grain of the WRP board are noticeably higher.

In the standard, the enacted requirement for the SSBJ $f_v > 1$ N/mm² is carried out with suffice reserve.

A power function is proposed for approximation of experimental data of the SSBJ and static JH depending on the moisture content.

The presented analysis is limited to the data obtained from the above described experiments.

6. ACKNOWLEDGEMENT

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8th International DAAAM Baltic Conference
"INDUSTRIAL ENGINEERING "
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RESEARCH REGARDING ACOUSTICAL PROPERTIES OF RECYCLED COMPOSITES

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Abstract: *The paper presents the variation curves for acoustic properties (sound absorption coefficient, reflexive coefficient and impedance ratio) of new materials made from mixture of wood particles and textile waste with different types of binders. The experimental determinations are based on Kundt's tube method in accordance with ISO 10534 standard. The results show that one of the most important factors in sound insulation of composite materials is the type of binder. The proposed materials are intended to be light structures, recyclable or degradable and with high noise reduction efficiency, being proper in buildings structures, noise barrier structures and automotive components.*
Key words: acoustic, composite, noise control, absorption, Kundt's tube, noise barriers

1. INTRODUCTION

The noise control plays an important role in assuring acoustically pleasant environments [1]. One of the most important factors in noise reduction is represented by the materials used in different structures with soundproofing role. The use of composite materials based on textiles residues and wood chips or flacks for noise reduction have two major advantages, namely low production costs and small specific gravity [2, 3]. Knowing acoustical properties of these porous materials is useful for proper application in products such as sound barriers, walls, road surfaces [4, 5, 6]. In order to protect the environment on one hand by recycling the residues from primary and secondary technological process and on the other hand by attenuate the noise from industry or urban traffic, different systems were developed based on recycling solid waste (sterile municipal waste, wood chips, waste polystyrene, slag or fly ash with polymer matrix) [7]. Literature review relieved numerous studies regarding the sound transmission loss of different types of materials such polyester fibre, glass fibre and urethane foam [9]. Also, the variation of sound absorption coefficient carried out by Kundt's tube was determined for the following materials: porous textile materials, latex plate, rigid plate consisting on textile waste, synthetic leather glued on textile support [8, 9].

In this paper the assessment of the acoustical properties of new composite structures based on wood chips and textile waste bonded together with ecological binders is presented. In a previous work, the density and thermal conductivity coefficient were determined for each structure and compared with the expanded and extruded polystyrene values [10].

2. EXPERIMENTAL SET-UP

2.1 Method and materials

One of the widely used methods to determine the acoustic properties (absorption coefficient, impedance ratio, reflection coefficient) is the international standardized impedance tube method [11, 12]. The principle of this method is based on the measurement of transfer function between two signals of microphones mounted inside the tube. In accordance with measurement chain, a loudspeaker is placed at the end of the tube as can be seen in Fig. 1 [13].

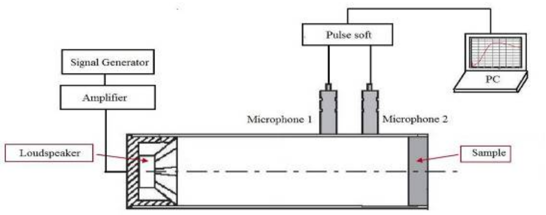

Fig. 1. Schematic view of the experimental set-up

When the tube is fed by 1/3 octave frequency bands, a stationary plane wave is created and pressure measured with microphones can be decomposed into its incident and reflected components. First, the equipment without samples was prepared, in order to configure the microphones and to calibrate them using the calibration function from Pulse soft. [14, 15] This operation is necessary because of phase and amplitude of the two microphones is not perfectly identical. In this sense the frequency response function is measured with the two microphones interchanged position. After calibration, each sample is properly inserted into the tube and the measurements started (Fig. 2).

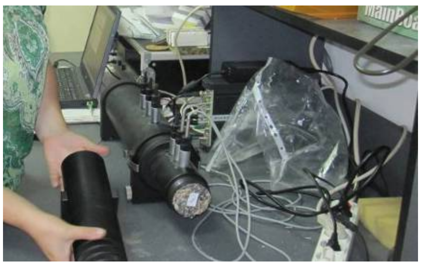

Fig. 2. The experimental set-up

The generated noise is connected to the amplifier and the tube filter emits the set signals. The emitted signal and reflected signal is captured by microphones and transmitted to Pulse hardware and displayed with the Pulse soft. The input data from the project set-up are presented in Table 1 and they are established automatically by soft in the calibration stage.

Table 1. The input data

Tube	**Input**
Type	Medium
Microphone Spacing:	0.0318 m
Distance to Sample from Mic. 2	0.0635 m
Distance to Source from Mic. 1	0.37 m
Diameter:	0.064 m
Lower Frequency Limit:	100 Hz
Centre Frequency (Hz):	1600
Generator	
Waveform:	Random
Signal Level:	1.414 Vrms

Due to the influence of the environment upon the measurements accuracy in situ, the tests were performed in the same environment conditions (atmosphere pressure - 1035.00 *hPa*, temperature - 28.00 *°C*, relative humidity - 46,00%, velocity of sound - 347.89 *m/s*, density of air - 1.195 kg/m^3, characteristic impedance of air: 415.8 *Pa/(m/s)).*

In this study were used green and biodegradable materials, found as inserts of wood (flakes or fibres) and textiles (wool or jute). For the experimental tests, the samples were cut into specimens with a diameter of 63.5 mm and the thickness in the range between 20 – 30 mm) (Fig. 3).

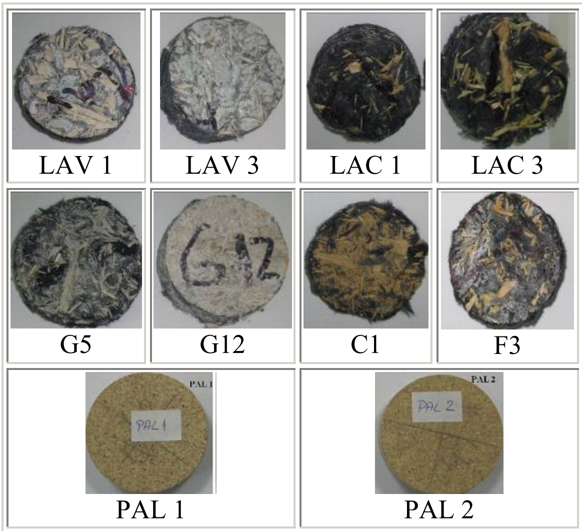

Fig. 3 The composite samples studied with impedance tube

The differences between samples consist on the quantities of raw materials or the type of binders, which conduct more or less to the compaction of the particles. The characteristics of composite materials are presented in Table 2.

Table 2. Characteristics of agglomerated structures

Code/ Weight m [g]	Content and amount	Density, ρ [g/cm^3]
White Acrylic Copolymer (WAC)		
LAV 1 20,958	Wood flakes 150 g, Wool 150 g 40% WAC, 60% water	0,197
LAV 3 20,327	Wood flakes 150 g, Wool 150 g 50% WAC, 50% water	0,244
Ecologic Acrylic Copolymer (EAC)		
LAC 1 13,866	Wood flakes 150 g, Wool 150 g 400ml EAC	0,157
LAC 313,958	Wood flakes 150 g, Wool 150 g 500ml EAC	0,193
Gyps solved in Water (GSW)		
G5 32,174	Wood flakes 150 g, Wool 150 g 600 g Gyps solved in water	0,415
G12 47,322	Wood flakes 100 g, Wool 100 g, Wood fibers 100 g 1000 g Gyps solved in 900 ml water	0,656
Clay solved in Water (CSW)		
C1 55,216	Wood flakes 150 g, Wool 150 g 800 g CSW in 500 ml water	0,626
Flour Solved Water (FSW)		
F3 22,854	Wood flakes 150 g, Wool 150 g 500 g FSW in 1000 ml water	0,130
Particle board (PAL)		
PAL 1 34,023	Wood chips Particleboard - commercial) Formaldehyde	0,700
PAL 2 37,63	Wood chips Particleboard - commercial) Formaldehyde	0,720

The binder and the amount of binder in the composition are different noted as: White Acrylic Copolymer (WAC), Ecologic Acrylic Copolymer (EAC), Gyps solved in Water (GSW), Clay solved in Water (CSW) Flour Solved Water (FSW), Particle board (PAL). All samples were obtained in the same laboratory conditions, including the pressure parameter.

2.2. Results and discussion

The sound absorption coefficient indicates what amount of sound is absorbed in the actual material and depends of the frequency type. In Fig. 4 the variation of sound absorption coefficient against the frequency is presented, for different materials.

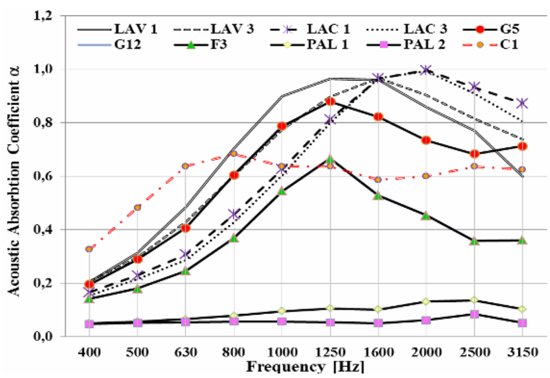

Fig. 4. The effect of type of binders on sound absorption coefficient

It can be noticed that the composition of tested materials have influence on the sound absorption.

According to the absorption classes described in the international standard ISO 11654 (Tabel 3) the samples can be grouped in following cathegories[14]:

- The samples LAV1, LAV2, LAC1, LAC3 and G5 are described by high absorption of sound for the frequency range between 1000 – 3200 Hz – class A
- The samples C1, G12 and F3 present a medium value of the absorption coefficient, arround 0,7 being part of class C. An interesting behaviour is recorded by sample which

contains clay solved in water, namely the constant capacity of materials to absorb a relative wide range of frequency (650 – 3000 Hz).

- The lowest absorption was recorded by samples PAL 1 and PAL 2, for all frequencies, being in E or below class.

Table 3. Absorption Classes[9]

Absorption coefficient α	**Sound Absorption Class**
1,00 – 0,90	A
0,85 - 0,80	B
0,75 – 0,60	C
0,55 – 0,30	D
0,25 – 0,15	E
0,10 – 0,00	Not classified

Figure 5 shows the variation of sound absorption coefficients against the density of the tested materials. First, the maximum values of absorption coefficients were selected from previous charts and then were compared to the variation of density. So, the increasing of the value of the density of materials leads to the decreasing of the absorption coeficient.

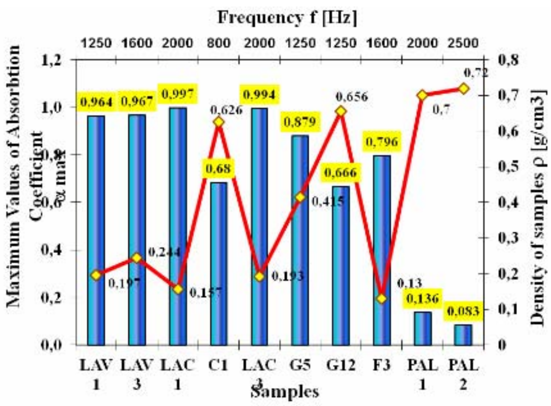

Fig. 5. The variation of sound absorption coefficient versus density of materials

For example, the samples L1, L2 and A1 have low density (range between 0,150 to 0,200 g/cm^3) and high absorption (over 0.9). For high densities as PAL 1 and PAL 2 have (ρ=0,700...0,750 g/cm^3), the absorption capacity of materials is lower. The most reflective materials are the composites PAL 1 and PAL 2, characterized by flat and smoth surfaces and a high degree of compaction of wood particles and chips.The tendency of all materials is to have a negative value of the reflection coefficient for the frequencies in the range of 1200 – 3000, which correspond to the maximum acoustical absorption.

3. CONCLUSIONS

The experimental investigation aimed to determine the acoustical properties of new materials obtained by waste textile and wood residues. These materials were designed for assuring a good acoustic and thermal insulation. Six types of materials were tested. The composition of binders (matrix) had a great influence upon the acoustical properties of the samples (absorption coefficient, impedance ratio, reflection coefficient). Concerning the sound absorption coefficient, the samples based on WAC, EAC and GSW present a very good sound absorption at high frequencies, fact that recommends the materials for sound insulation application. The other ones, as PAL 1 and PAL 2 are, have recorded a lower value of absorption coefficient against the frequency. An interesting acoustic behavior was performed by sample C1 (clay solved in water), due to its relative constant sound absorption at different frequencies, even the sample recorded only a medium value of absorption (around 0.683 at 600 Hz). For this reason, the research results of composites WAC (white acrylic copolymer), EAC (ecological acrylic copolymer) and GSW (Gyps solved in water) concluded to the fact that they can be used for sound absorbent panels for highways, railways and airports.

The study of sample C1 made of wood flakes, wool and clay binder can be continued in order to improve the sound absorption for a large frequency domain. Comparing the experimental results with others from literature (Fig. 6), it can be noticed that the biodegradable composite materials with textile inserts as new structures, present a very good absorption capacity that will be used for future researches regarding their applications. The others materials studied by Bratu, 2007 and Bratu 2011 are composites based on residues as textile waste, synthetic leather, wood chips, pet pellets, furnace slag and sterile municipal waste [7,8, 15].

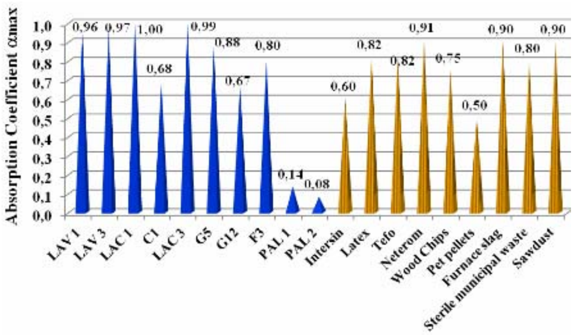

Fig. 6. Comparison between experimental and literature results

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EFFECT OF WOOD PARTICLE SIZE ON TENSILE STRENGTH IN CASE OF POLYMERIC COMPOSITES

Terciu, O. M.; Curtu, I. & Teodorescu-Draghicescu, H.

Abstract: *The paper presents experimental research results and aspects of mechanical characteristics of composite materials reinforced with wood sawdust, subjected to tensile stress. Sawdust, as wood waste resulting from sawing, is an important material resource, natural and renewable. The research sought to determine the influence of particle size on mechanical properties of composite. Like any other natural product, lignocelluloses materials are characterized by high diversity and variability of their properties, which are reflected on structures which incorporate them.*
Key words: composites, wood sawdust, tensile tests, polymeric resin, particle size.

1. INTRODUCTION

In recent years there are concerns for the production of wood structures and other materials. To achieve these, one of the requirements is to have compatibility between wood properties (mechanical, chemical) and the other materials that will allow obtaining a new product, with uniform structure and default properties.
Wood combined with other materials has multiple benefits and utilities, becoming a subject of active research area, with new ideas that are to be examined and then developed [1, 2].
The changes that occur during execution of the composite, both for natural fibres and for other components, allow obtaining superior properties of its own, which must be properly identified and used [3].
Experimental studies in the literature have pursued aspects of the structural composition of lignocelluloses materials, namely: the proportion of components, compatibility between components and types and characteristics of the matrix used [4].
Lignocelluloses fibres have a number of advantages and disadvantages compared with traditional glass fibres used to reinforce composite materials. Their ecological character, biodegradability, low cost, non-abrasive nature, safe handling, use with various possibilities as fillers, processing with low power consumption, important specific properties, low density and a large number of types of fibre are very important factors for their acceptance in markets where a large volume of materials is needed such as automotive industry.
However certain disadvantages, such as the tendency of agglomeration during manufacture, low resistance to moisture and quality changes due to the seasons of growth, reduce the potential for these fibres [5, 6].
An optimal cost composite can be obtained by embedding in its component the waste from other manufacturing processes or recycled materials. The waste sawdust is an important resource of raw material. A report by FAOSTAT (Food and Agriculture Organization of the United Nations) shows that the amount of wood of different species cut by sawmills in Europe in the year 2010 is about 125.36 million m^3 [7]. The sawdust losses resulting from sawing processes are between 5-11% of the total log volume. At a minimal loss value of 5% results in a volume of 6.27 million m^3 sawdust. So sawdust is an important

renewable raw material and can be used in other areas moreover than heating.

2. MATERIALS AND METHODS

Composite materials are made of polyester resin and oak wood particles. The mechanical characteristics of the polyester resin without reinforcing are shown in table 1.

Characteristics	Value	Unit of measure
Tensile strength	MPa	50
Tensile modulus	MPa	4600
Tensile elongation	%	1.6
Flexural strength	MPa	90
Flexural modulus	MPa	4000
Impact strength P4J	mJ/mm²	5.0-6.0
Volume shrinkage	%	5.5-6.5

Table 1. Mechanical characteristics of the polyester resin used

For these determinations have been used three types of materials using different grains of wood particles: 1 ÷ 2 mm, 0.4 ÷ 1 mm and 0.2 ÷ 0.4 mm.
In figure 1 can be seen that most part of the particles resulting from the sawing process are of the sizes mentioned above.

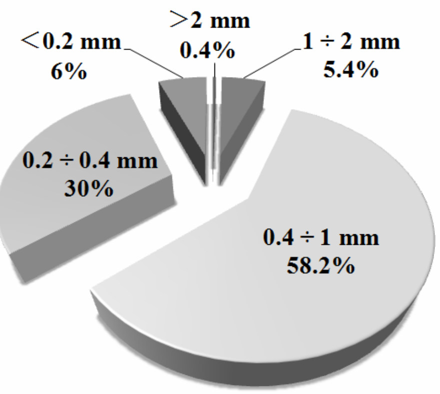

Fig. 1. Data results from a granulometric analysis of oak sawdust

Particle separation was achieved by sieving, resulting three types of particles shown in figure 2.

Fig. 2. Particle separation device and types of particles results

An important parameter of composites is the ratio of components. In this study we used fibre volume fraction which is defined as:

$$V_f = \frac{\rho_m W_f}{\rho_f W_m + \rho_m W_f} \qquad (1)$$

Where: V_f is the volume fraction of fibres; W_f is the weight of fibres; W_m is the weight of matrix; ρ_f is the density of fibres and ρ_m is the density of matrix.
To determine the volume of a certain quantity of particles is very important to know their density. It is known that wood is a porous structure consisting of wood cell membrane and cell lumena as can be seen in figure 3.

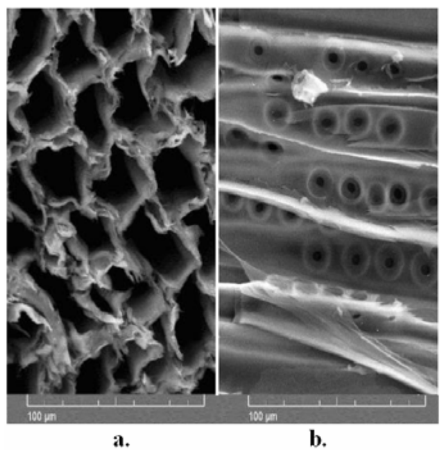

Fig. 3. Micrographs of spruce wood structure (1000x): a – cross section; b – radial section [8]

Oak density is between 0.71 - 0.75 g/cm^3, but wood substance density (without cellular gaps) of the same wood species varies in the range 1.53 - 1.56 g/cm^3.
Pycnometer method by measuring the mass of liquid displaced by a certain amount of wood particles was used to determine the particle density. The liquid used for these determinations was Petrosin. For each size range of wood particles were analyzed three amounts of wood particles. The average values determined for different types of grains can be seen in figure 4.

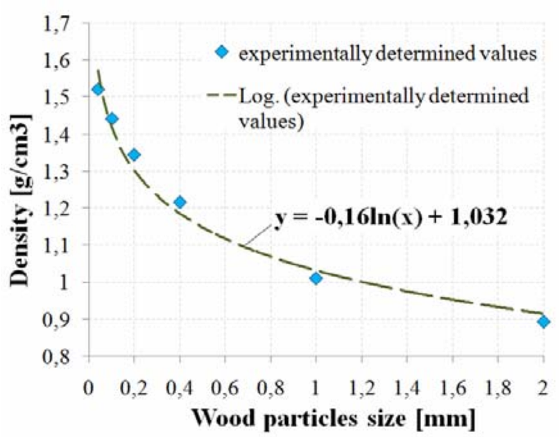

Fig. 4. Oak wood particle density for different sizes determined by pycnometer method

Knowing the density of wood particles can calculate their volume, respectively the volume fraction of fibre reinforcement.
To determine the effect of wood particle size on mechanical properties of the composite, tensile tests were performed. Tensile test is known to be the most important and commonly used static test due to the procedure's simplicity on obtaining the strength and stiffness characteristics.
The specimens have the specific shape and dimensions of tensile test composite materials reinforced with fibre, according to ASRO SR EN ISO 527 and were made by directly-moulded. Fibre volume fraction of wood particles was 20% for all three types of specimens. The three types of samples can be seen in figure 5.

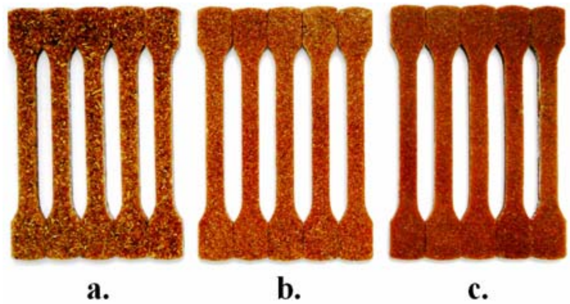

Fig. 5. Types of specimens tested: a. specimens with 1 ÷ 2 mm wood particles; b. specimens with 0.4 ÷ 1 mm wood particles; c. specimens with 0.2 ÷ 0.4 mm wood particles

The equipment used is a tensile test machine with constant speed of 1 mm per minute, provided with specimen fixing devices. In order to measure the specific elongation of the specimen was used an extension measuring instrument. Specimens fixing in tensile test machine and method of breaking them can be seen in figure 6.

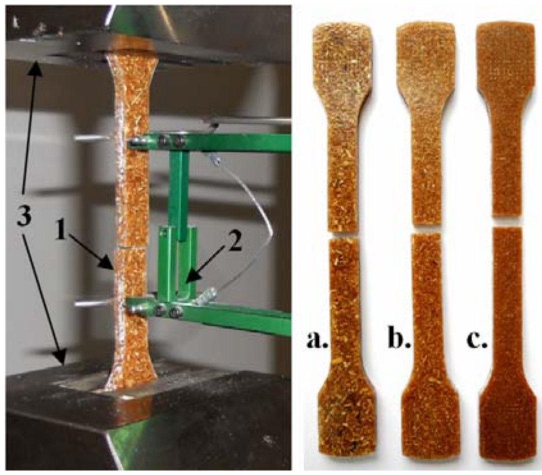

Fig. 6. Tensile testing devices and specimens: 1 – composite material specimen with different wood particle sizes (a.1÷2 mm; b. 0.4÷1 mm; c. 0.2÷0.4 mm); 2 – extension measuring instrument; 3 – tensile test machine jaws

3. RESULTS AND DISCUSSION

After processing the machine data, tensile tests diagrams load-extension were made, as presented in figure 7, 8 and 9.

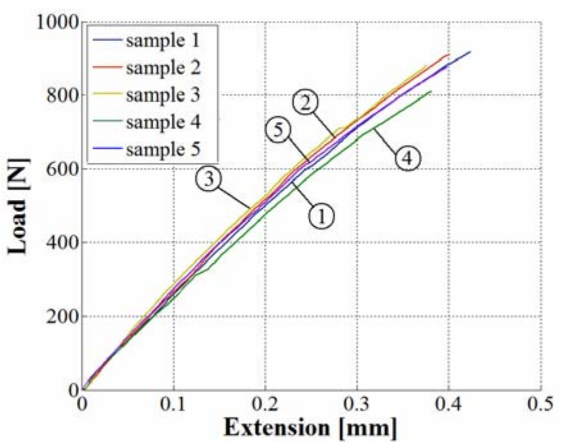

Fig. 7. Tensile tests diagrams for specimens with 1 ÷ 2 mm wood particles

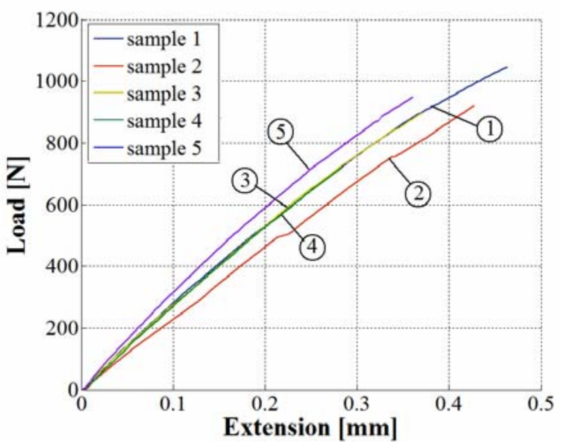

Fig. 8. Tensile tests diagrams for specimens with 0.4 ÷ 1 mm wood particles

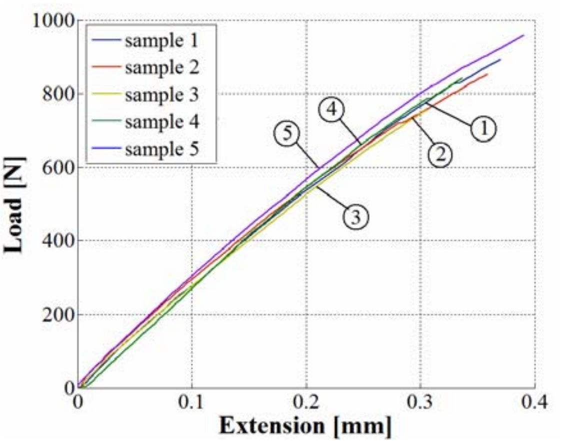

Fig. 9. Tensile tests diagrams for specimens with 0.2 ÷ 0.4 mm wood particles

In figures 10, 11 and 12 strain-stress correlations for the three types of specimens can be seen.

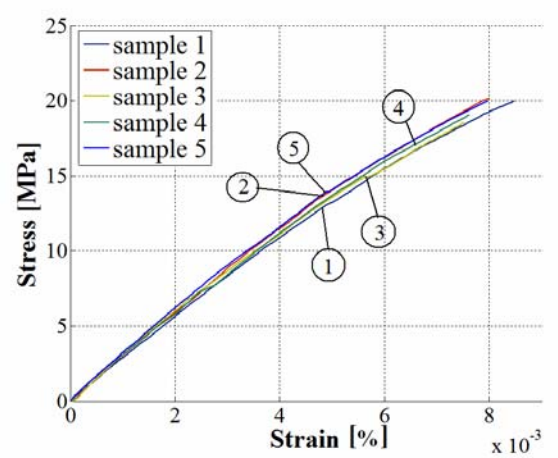

Fig. 10. Stress-strain σ-ε curves recorded in tensile test for specimens with 1 ÷ 2 mm wood particles

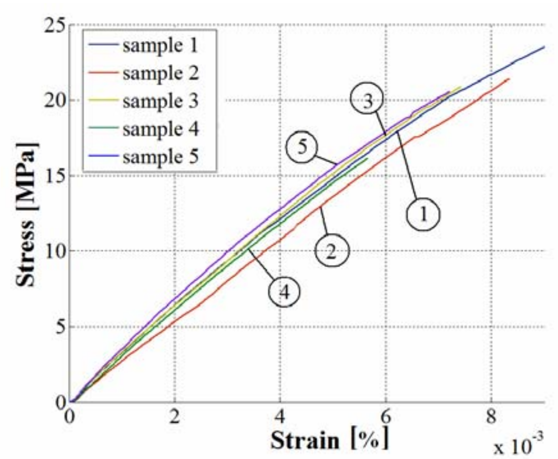

Fig. 11. Stress-strain σ-ε curves recorded in tensile test for specimens with 0.4 ÷ 1 mm wood particles

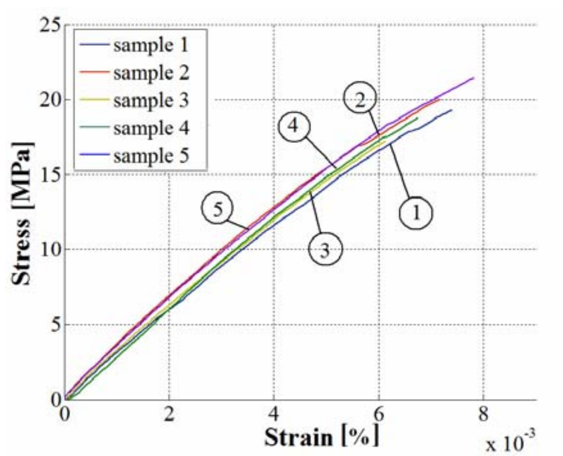

Fig. 12. Stress-strain σ-ε curves recorded in tensile test for specimens with 0.2 ÷ 0.4 mm wood particles

It may be noted that for the same category of specimens there is not a large dispersion of values.

The absorbed energy required to produce a fracture, per area unit or mechanical work done during the break, per area unit is equal with area under the curve $\sigma = f(r)$, as shown in figure 13.

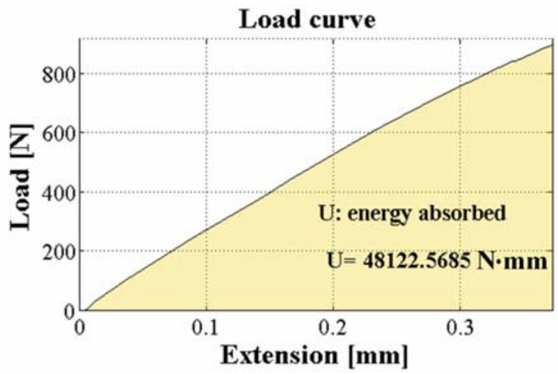

Fig. 13. Determining the energy absorbed by the specimen during tensile tests

Tests have shown that the energy absorbed by the specimens reinforced with particles of size between 0.4 ÷ 1 mm is greater. The average values of energy absorbed for the three types of specimens can be seen in figure 14.

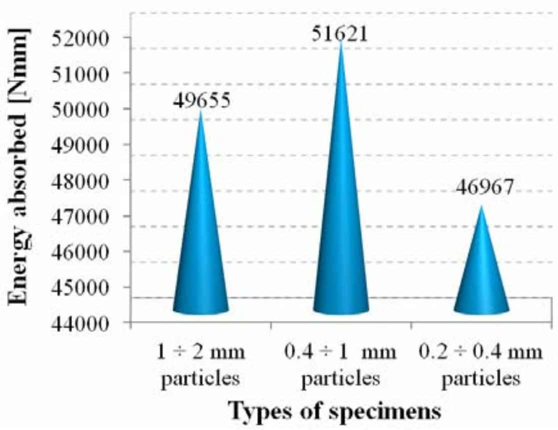

Fig. 14. Average values of energy absorbed for the three types of specimens

Other properties such as tensile strength and elongation at fracture are also higher for the specimens reinforced with particles of size between 0.4 ÷ 1 mm, as can be seen in figure 15 and 16.

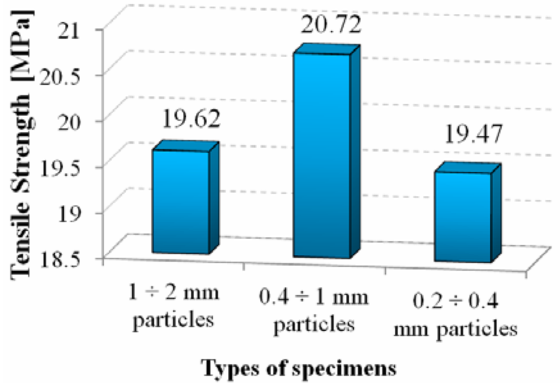

Fig. 15. Average tensile strength for the three types of specimens

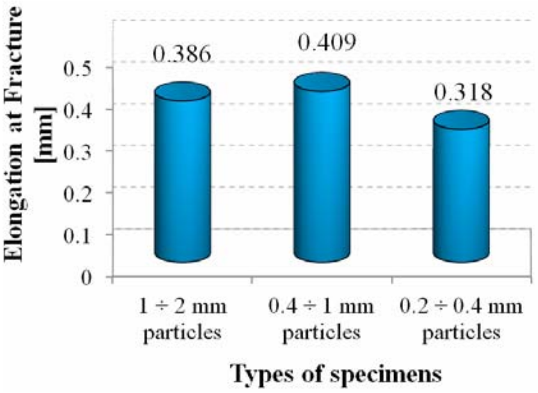

Fig. 16. Average elongation of fracture for the three types of specimens

Although the use of smaller particles typically leads to an increase in mechanical properties, in this case it was found that particles of size between 0.4 ÷ 1 mm have a greater length than particles of other sizes and this makes the tensile strength for this category to be greater.

4. CONCLUSION

- With increasing of oak particles sizes, density decreases after the law:

$$y = -0.16\ln(x) + 1.032 \quad (2)$$

- Oak particles sizes of 0.4 ÷ 1 mm obtained by sawing are the majority representing a percentage of approx. 58% from the total amount of sawdust. This percentage varies from one species to another and depends on several factors such as wood density, moisture content at the processing, cutting regime etc.

- Experimental tests have shown that long particles lead to increased resistance compared to those with comparable sizes (spherical or rectangular).
- Maximum strain energy resulted for specimens reinforced with particles sizes between 0.4 ÷ 1 mm.

5. ACKNOWLEDGEMENTS

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SOLUTION BASED PROCESSING FOR NANOCARBIDES

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Abstract: *A metal alkoxide polymer precursor for carbothermal reduction was synthesized by a sol-gel method. Solution-based processing was used to achieve a fine dispersion of the reactants. Complexing agent acetylacetone was used as additive component for controlled polymerization during the sol-gel process. Titanium-(IV)- and zirconium-(IV)butoxides were used for precursor preparation. Mixture of titanium and zirconium carbides (TiC-ZrC) was synthesized by carbothermal reduction at temperature of 1500 ^{o}C. The structural transformation of the polymeric materials into the carbides was characterized by SEM, X-ray diffraction analysis, and energy dispersive X-ray spectroscopy (EDS or EDX) and Raman spectroscopy*.

Key words: sol-gel process, carbide solid solution, carbothermal reduction, grain size

1 INTRODUCTION

Single-phase titanium carbide (TiC) and zirconium carbide (ZrC) as well as the binary solid carbide mixtures (ZrC–TiC) are of interest for ultrahigh temperature applications because of their extremely high melting points and stable mechanical properties at high temperatures. Therefore, these compounds have been broadly termed ‘‘refractory carbides”. ZrC–TiC systems have attracted considerable attention due to their high hardness, high melting temperature, low thermal expansion, good thermal shock resistance, relatively good oxidation resistance in extreme environments, suitable chemical inertness and comparatively high electrical and thermal conductivities. As a consequence these composites are widely used for cutting tools, wear-resistant coatings, aerospace materials, as reinforcement in composites, structural components in chemical and electronic industries [1-4]. Formation of the heterogeneous finely dispersed structures in ZrC–TiC mixtures also are of a great interest because their possible contribution into development of superplastic ceramic-based composites [5-6].

The binary solid carbide compounds are classically synthesized by carbothermal reduction of metal oxides (ZrO_2, TiO_2) and amorphous carbon mixture in controlled atmospheres at a very high temperature (above 2000 ^{o}C). Another method to synthesise the binary solid carbides compounds is high-energy milling of ZrC and TiC which reduces crystallite size to achieve almost amorphous powders exhibiting quite low transition temperature around 1500 ^{o}C. The conventional methods are energy and time consuming and a final product suffers from impurities and is inhomogeneous because the powders are mixed together on a relatively coarse scale (e.g., micrometer-scale) and attrition of milling media increase content of impurities [1]-3][7]. The single phase carbides can be obtained at much lower temperature by the sol–gel method [8-12]. Sol–gel process is a well-known chemical route to prepare oxide-based powders, fibres, films and microtubes [13-16].

The present study is aimed at elaboration of a novel way to synthesize the binary solid carbide mixture (ZrC–TiC) precursors of corresponding metal alkoxides using sol–gel method. The powder mixtures should be suitable for fabrication of bulk specimens. The main advantage of the sol-gel process developed in this study is reduction of the kinetic barriers between the formed metal oxide and the carbon particles created in pyrolysis of metal alkoxide polymer due to the homogeneous dispersion of reactants in the precursor material. The increased contact area of the nanograins results in a complete reaction between the metal oxide and carbon. Temperatures needed for the process to start are lower than temperatures required for conventional powder. Titanium and zirconium carbides were synthesized by carbothermal reduction out of metal alkoxide polymer at 1500 ^oC in vacuum (Carbon + Metal oxide → Metal carbide + CO_2).

2 EXPERIMENTAL

Fig. 1. presents a schematic flow chart describing preparation of the carbide precursors in this work. Titanium(IV)-butoxide, $Ti(OC_4H_9)_4$, and a 80% solution of zirconium(IV)- butoxide, $Zr(OC_4H_9)_4$, in butanol were used as the starting reagents. Hydroquinol was used as the carbon source. Acetylacetone was used as chelating ligands to reduce reactivity of metal alkoxide.

Firstly, 0.01 mol of $Ti(OC_4H_9)_4$ and 0.01 mol of $Zr(OC_4H_9)_4$ were mixed together and dissolved in 10 ml n-butanol under argon (Ar) in Schlenk glasswares, and the solutions were heated at 50 ^oC for 1 h. Then 0.044 mol of acetylacetone (AcAc) was drop wise added at 50 ^oC while stirring

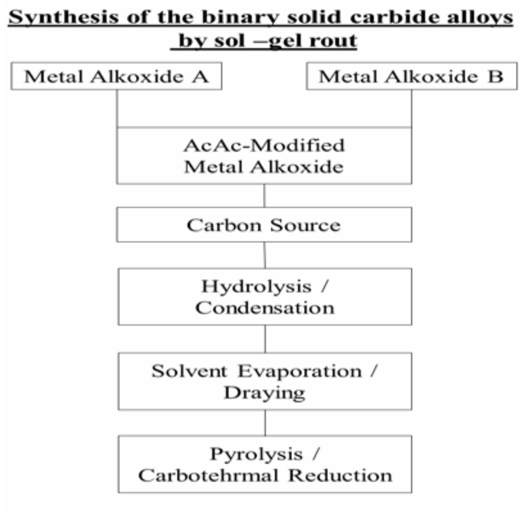

Fig. 1. Flow chart for synthesis of the binary carbide compounds from sol–gel precursors.

for another 1h. After the stirring the temperature of the solutions was increased up to 80 ^oC, hydroquinol was added, which changed the colour of the solutions into deep red. Afterwards the solutions were heated up to the reaction temperatures (120 ^oC) and concentrated at this temperature by evaporation of solvents. Following step was drying of the solution at 150 ^oC resulting in formation of the deep red polymeric gel powder.

2.1 Heat treatment

The dried ZrC-TiC precursors were annealed in graphite boats using an alumina tube furnace (Nabertherm HTRH) at 40 – 1500 ^oC, in inert (argon or vacuum) atmosphere. The heating rate was adjusted to 200 ^oC/1h and the annealing time at the maximum temperature was 1 h.

2.2 Characterization methods

X-ray diffractometry was used to determine the crystalline phases in heat treated samples. Microstructure was characterized by a scanning electron microscope Helios 600 equipped with an energy-dispersive spectroscopy. X-ray diffraction (XRD) analysis of the powders was performed using a Smarlab diffractometer. Raman spectroscopy was performed by a Renishaw micro-Raman set-up using a 514,5 nm continuous mode argon ion laser. The Raman spectra were recorded in the range between 100 and 1800 cm^{-1} with an acquisition time of 3×30 s.

3 RESULTS AND DISCUSSION

Precursor material for TiC-ZrC mixture was synthesised using corresponding metal alkoxides (Titanium(IV)-butoxide and zirconium(IV)- butoxide). Carbon scourge (hydroquinol) was chosen as to give an optimal stoichiometric carbon/metal ratio [11]. In our work we have used analogy reaction mechanism as described elsewhere [10-11]. The difference is that we mix together two different metal alkoxides (Titanium-(IV)-butoxide and zirconium-(IV)-butoxide), to synthesise homogenously dispersed titanium and zirconium carbide particles throughout the mixtures.

It is well known that in sol-gel process, moisture from ambient environment gives spontaneous hydrolysis and condensation reactions, which result in uncontrolled participation of material. In order to avoid premature gelataion of a metal alkoxide mixture complex agent AcAc was added (before adding the carbon source in to the metal alkoxides mixture) to decrease the metal alkoxide reactivity with water.

To study annealed powder composition and

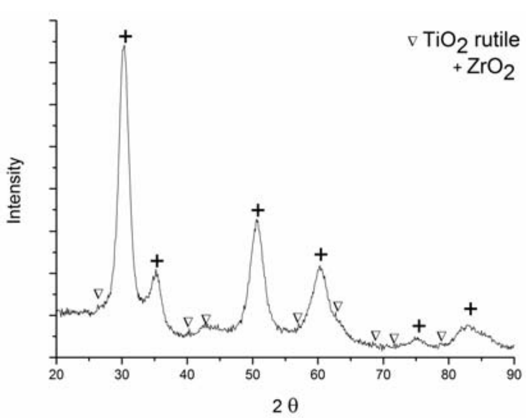

Fig. 2. X-ray diffraction patterns of ZrC-TiC precursor heated at 800 ^{o}C in vacuum.

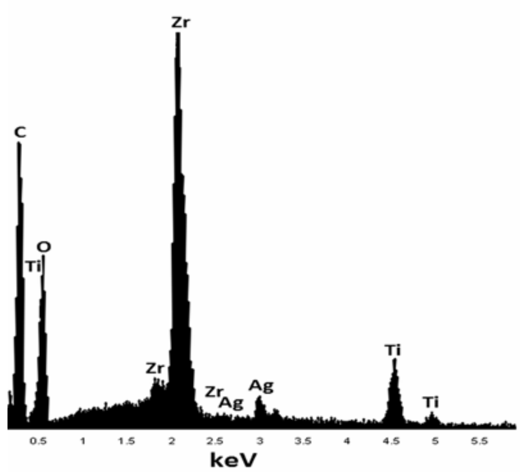

Fig. 3. EDX spectrum of ZrC-TiC precursor heated at 800 ^{o}C in vacuum. Silver (Ag) is present because of silver paste used for gluing objects on the electron microscope stub.

crystallite size we carried out X-ray diffraction analysis. Fig. 2. show X-ray diffraction (XRD) results for as heat treated sample (1h at 800 ^{o}C in vacuum). After annealing at 800 ^{o}C the sample must consist of pure metal oxides and amorphous carbon. The XRD pattern (Fig. 2.) for a sample pyrolyzed at 800 ^{o}C (1h) shows strong and broad diffraction peaks that are due to cubic zirconia dioxide (+ ZrO_2) and shows also weak diffraction peaks which might be due to titanium dioxide (TiO_2 rutile). EDX measurement of the same sample confirms our assumptions and shows (Fig. 3.) titanium (Ti) presented in equal concentrations compared to zirconia (Zr) at the final blend. Also, EDX measurements show some amount of carbon in the samples. Carbon is found to remain amorphous without any of diffraction peaks. For ZrO_2 crystallite size calculations from the broadening of the XRD peaks the Scherrer equation [17] has been used. That average ZrO_2 crystallite size is comparatively small and is around 10 nm. SEM images of the samples after pyrolysis at 800 ^{o}C reveal the presence of agglomerates of about 50µm, EDX and X-ray diffraction patterns indicate that these structures are composed of ZrO_2, TiO_2 nanoparticles and amorphous carbon. The

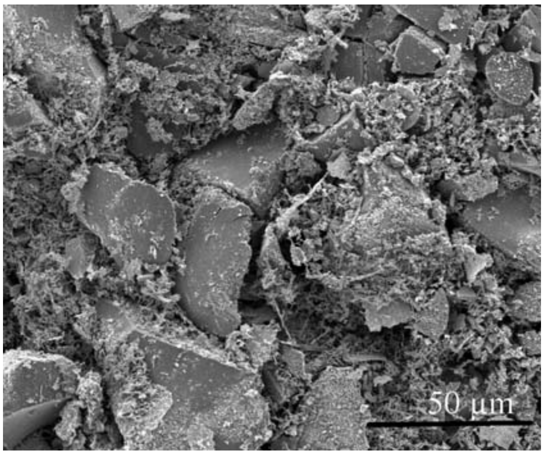

Fig. 4. SEM images of ZrC-TiC precursor heated at 800 °C in vacuum.

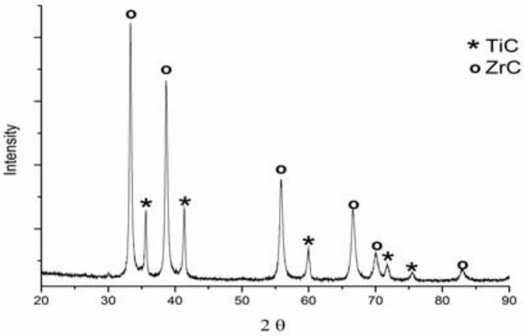

Fig. 5. X-ray diffraction patterns of ZrC-TiC precursor heated at 1500 °C in vacuum.

characteristic microstructure of agglomerates is shown in Fig. 4.

The carbothermal reduction in the current work was done at 1500 °C. Fig. 5. shows the XRD pattern of the sample annealed at 1500 °C (1h) revealing only ZrC and TiC crystalline phases. ZrC and TiC crystallite sizes were calculated with Scherrer equation [17] and the crystallite size were of around 27 nm and ~35 nm, respectively. Fig. 6. demonstrates a SEM image of the sample pyrolysed at 1500 °C. The sample for SEM analysis was prepared by dispersing a small amount of solid powder in ethanol and using an ultrasonic bath to break up agglomerates.

We also have used Raman spectroscopy to clarify the ZrC-TiC mixed carbide synthesis mechanism. Very little has been reported on the use of Raman spectroscopy

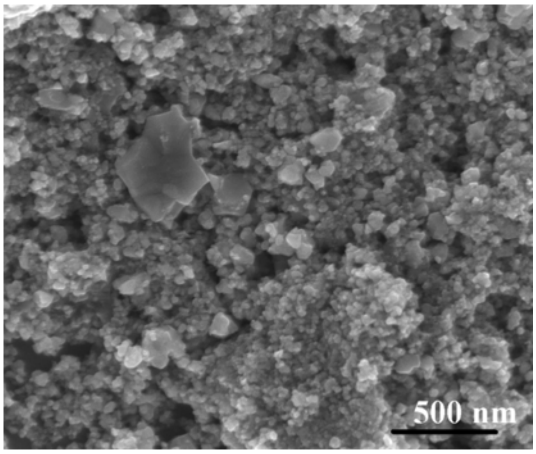

Fig. 6. SEM images of the ZrC-TiC precursor heated at 1500 °C in vacuum.

to study metal carbides. The literature states that stoichiometric TiC has no active Raman scattering due to the disorder induced by vacancies [19][20]. Fig. 7b shows Raman spectra of the sample of the ZrC-TiC precursor heated at 800 °C in vacuum. In the spectra Fig. 7b two strong peaks at approximately 1340 and 1590 cm^{-1} are clearly recognized. These peaks are associated with the A_{1g} and E_{2g} vibrational modes of graphite[19]. The spectra in Fig. 7b also show five broad peaks at approximately 153, 288, 340, 421, 640, and 767 cm^{-1},which are similar to those for the spectra in Fig. 7a the ZrC-TiC precursor heated at 800 °C in air. The latter spectrum consists of eight broad peaks at

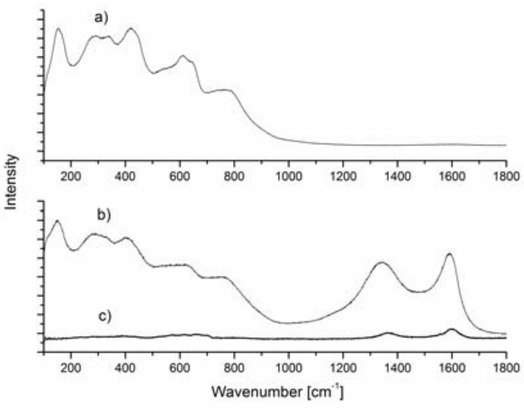

Fig. 7. Raman spectra of a) ZrC-TiC precursor heated at 800 °C in air; b) ZrC-TiC precursor heated at 800 °C in vacuum and c) ZrC-TiC precursor heated at 1500 °C in vacuum.

approximately 153, 288, 340, 421, 538, 609, 640, and 767 cm^{-1}. These peaks are comparable to reported Raman spectra of titanium and zirconium binary oxides (TiO_2-ZrO_2) in Rasmin database [21] and the literature [22][23]. Therefore, we can conclude that sample of the ZrC-TiC precursor heated at 800 ^{o}C in air consists of pure TiO_2-ZrO_2 mixed oxides.

As we assumed previously the ZrC-TiC precursor heated at 800 ^{o}C in vacuum consists of ZrO_2, TiO_2 and amorphous carbon. The XRD analyses of the sample have revealed weak peaks corresponding to TiO_2.This may be because TiO_2 particles detected by Raman spectroscopy are too fine to be detected by XRD analysis or the volume fraction of TiO_2 is too small to produce XRD peaks that are discernible above the background signal. Fig. 7c presents Raman spectrum of the sample of the ZrC-TiC precursor heated at 1500 ^{o}C and the peaks in range of 100 -1000 cm $^{-1}$ and the amorphous carbon peaks are reduced and the spectrum is almost linear. We can see that the ZrC-TiC mixture powders still consist of a little amorphous carbon. Also we can assume that the peaks in the range of 100-1000 cm^{-1} belong to TiO_2-ZrO_2 and the ZrC-TiC mixture in addition consist of TiO_2-ZrO_2 or those peaks are related to the vibration of C-Ti-C bonds as reported by Lohse et al.[19] and Amer et al.[20] and the synthesis product is no stoichiometric ZrC-TiC mixture.

4 CONCLUSIONS

Method for preparation of ZrC-TiC binary compound polymer precursor by sol-gel method for carbothermal reduction was elaborated. ZrC-TiC compounds were synthesized by carbothermal reduction at 1500 ^{o}C from polymer precursor. Characterizations of ZrC-TiC samples show that the polymer precursor is suitable for the preparation of ZrC-TiC binary compound with crystallite size of around 27 nm and ~35 nm and low amorphous carbon content. Further studies are needed for synthesis a carbon free TiC-ZrC binary compound.

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DESIGN OF GLASS CANOPY PANEL

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Abstract: *The main objective of the current study is to design point supported glass panel with prescribed stiffness/ strength properties.The maximal deflection of glass panel and maximum stress around fixing holes are two objectives considered above.*
Structural analysis of the point supported glass panel is performed by applying FEM (geometrically nonlinear plate theory). Based on FEA results the mathematical model is composed using artificial neural networks (ANN). Optimal set of design variables is determined by employing evolotionary algorithms.
Key words: design of glass canopy, Taguchi DOE, FEA, evolutionary algorithms.

1. INTRODUCTION

Over a last couple of decades, glass as a building material has undergone a transformation from being used as a building envelope to also being used as part of the load-carrying structure and elements [1-2]. For example glass floors, roofs, canopies etc. Application of the point supported glass and FEM analysis have been the main reason of the rapid progress in this area. Safety, failure issues of the concerning glass panel structures are studied in [3-5].
The point supported glass canopy panel design considered involve large and relatively thin lites of glass with certain amount of bolt holes. The critical problems are high stresses around fixing holes and large deflection of the panel. In the current study behaviour of these quantities is characterised by introducing ANN based mathematical model.
Artificial neural network (ANN) modeling is inspired by the biological nerve system and is being used to solve a wide variety engineering problems. [6,7].
ANN approach is known as a successful analytical tool for response modeling and is used by many researchers to predict the mechanical, thermal and electrical properties of materials and structures [8-10].
The main goal of the current study is to determine optimal canopy panel thickness and also locations and dimensions of the fixing holes to minimize maximal deflection and maximum stress. The posed problem can be solved by use of multi-criteria optimization approach described in [11-13]. An analysis of the objective functions has been performed and based on In order to manage local extremes and the design variables with discrete values the hybrid genetic algorithm is applied [14-15].

2. PROBLEM FORMULATION

The current paper is concentrated on design of point supported glass panel for canopy (see Figure 1). Designing of glass constructions is a special challenge because of the material behavior of glass. Main criteria considered herein are maximum stress around fixing holes and deflection of glass panel. These criteria are depending on the glass panel thickness, fixing holes location and diameter.

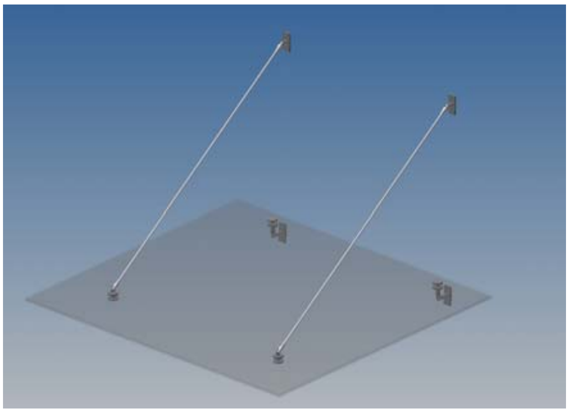

Fig. 1. Glass canopy with four point supports.

Width and length of the panel are given by the manufacturer, which are 1700 mm and 2000 mm accordingly. Main task is to search for an optimal set of design variables X1, X2, X3, X4 and X5 (see Figure 2) determining geometry of the supports. Panel is made of structural glass. In the current study it is assumed to be monolithic solid glass panel.
Panel is loaded by gravity and design load caused by snow (up to 2 kN/m^2).

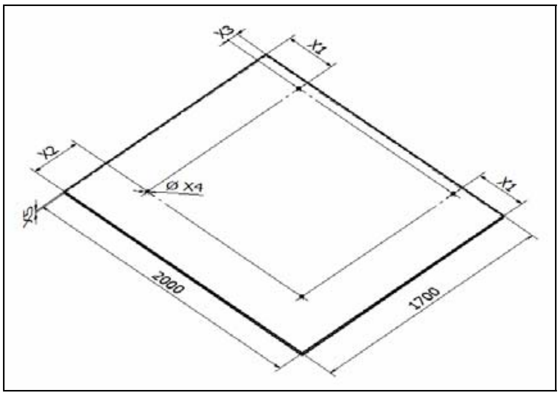

Fig. 2. Glass panel (X1, X2, X3, X4 and X5 are design variables).

Thus, X1,X2 and X3 stand for coordinates of the holes, X4 is diameter of the hole and X5 is thickness of the panel.

3. FINITE ELEMENT ANALYSIS

The only way to analyse a glass plate with point-bearings in a satisfying manner is by means of a threedimensional-FEM software system [1]. When glass panel subjected to the snow or wind load, it usually deforms more than its thickness. Under this situation, its behavior cannot be modeled accurately by linear theory[2]. Therefore a non-linear plate theory is employed.The stress-strain state of the glass panel is analysed by use of FEA (ANSYS). The FEA model with solid elements for analysis of the glass lite has been developed.
Because of the glass panel relatively large dimensions FE model general mesh elements size is 20 mm to avoid long calculation time. Maximum stresses are concentrated around the fixing holes. Therefore to get precise results of maximum stresses in mentioned locations, elements size is reduced to 3 mm. This is applied in 40 mm diameter sphere around the holes (see Figure 3).

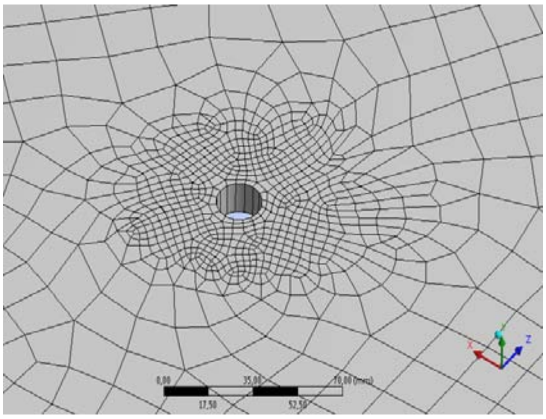

Fig. 3. FE mesh in hole region

Five design variables have been used for analysis of the panel. In order to reduce the computational cost the design of experiment (DOE) is performed.
First values for every variable were assigned according to manufacturing and structural limitations (see Table 1). Four level for each variable are considered.

Independent variable	Levels			
	1	2	3	4
X1	300	350	400	450
X2	300	350	400	450
X3	65	75	80	85
X4	18	24	30	36
X5	12	14	16	20

Table. 1. Levels of design variables

N	Design variable values					Results	
	X1	X2	X3	X4	X5	Max. Str., Mpa	Max. Def., mm
1	300	300	65	18	12	286,2	7,6
2	300	350	75	24	14	156,3	3,3
3	300	400	80	30	16	102,6	1,6
4	300	450	85	36	20	110,2	1,4
5	350	300	75	30	20	161,0	4,4
6	350	350	65	36	16	160,8	4,4
7	350	400	85	18	14	78,3	1,0
8	350	450	80	24	12	117,6	2,6
9	400	300	80	36	14	100,9	2,7
10	400	350	85	30	12	82,7	1,5
11	400	400	65	24	20	147,5	4,2
12	400	450	75	18	16	92,2	2,3
13	450	300	85	24	16	59,1	1,4
14	450	350	80	18	20	78,6	2,4
15	450	400	75	36	12	105,8	3,0
16	450	450	65	30	14	118,8	4,0

Table. 2. Taguchi DOE, L16 orthogonal array

Parametrical model according to variables (X1, X2, X3, X4 and X5) was created in ANSYS Workbench.

The Taguchi's design of experiments (DOE) is applied in order to reduce the number of computational experiments (computational time). Taguchi's L16 ortogonal array is employed and corrsponding values of the design variables as well as objective functions considered are given in Table 2.

The distribution of the maximal stress near fixing hole is depicted in Figure 4.

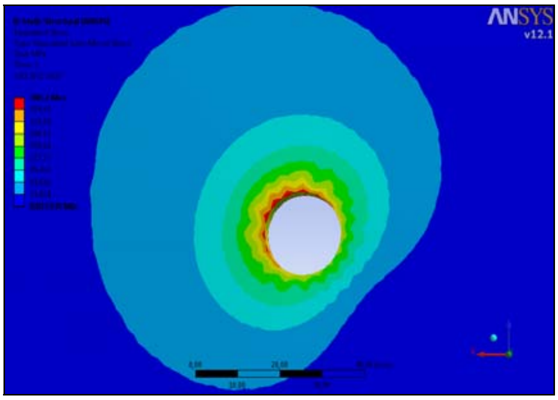

Fig. 4. Max. stress distribution around fixing hole

In can be seen from Figure 4 that the maximal stress near fixing hole is not symmetric and has values up to 300 Mpa.

The distribution of the deflection of glass panel is depicted in Figure 5.

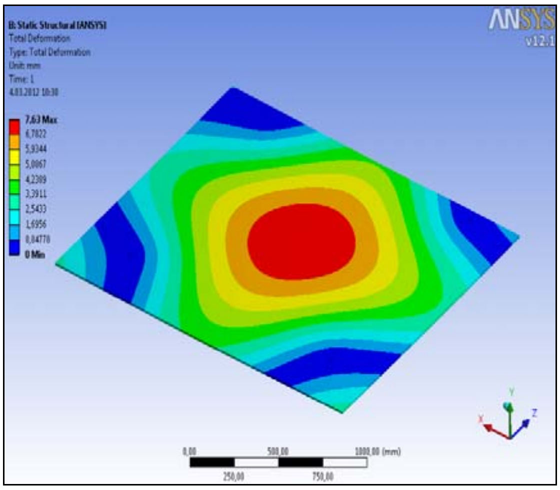

Fig. 5. Distribution of the deflection of glass panel

It can be seen from Figure 5, that the distribution of the deflection can be characterized by symmetry and has values up to 8mm.

4. MATHEMATICAL MODEL

In the current study, the artificial neural networks (ANN) technique was used for prediction the values of the maximal deflection and maximum stress. The inputs to the network are geometrical parameters describing locations of the fixing holes, holes diameter and thickness of the panel. The output data sets of the ANN are formed using values of the maximal deflection and maximum stress obtained from series of FEA simulations (structural analysis of the panel).

Data pre-processing has been applied for both input and output data of the ANN model since the range and unit in one sequence may differ from the others. The original input and output sequences can be normalized by use of formulas (1) and (2), respectively.

$$x_i = \frac{X_i - \min X_i}{\max X_i - \min X_i}, \qquad i = 1,...,n, \quad (1)$$

$$f_j(\bar{x}) = \frac{F_j(\bar{x}) - \min F_j(\bar{x})}{\max F_j(\bar{x}) - \min F_j(\bar{x})}, \quad j = 1,...,k. \quad (2)$$

In (1) X_i and x_i stand for original and normalised input sequences (design variables), respectively. In (2) $F_j(x)$ and $f_j(x)$ stand for original and normalised output sequences (objective functions), respectively and $\bar{x}$ is vector of input variables. As result the values of the both, both input and output sequences remains in interval [0,1]. The ANN employed comprise of three layers: input, hidden and output layers. The number of neurons in hidden layer is determined from simulation results. The transfer functions applied in hidden and output layers are radial basis and linear functions, respectively. The back propagation learning-algorithm is used. The model was trained with Levenberg–Marquardt learning algorithm which has second-order converging speed [18]. The update rule of the Levenberg–Marquardt algorithm is a blend of the simple gradient descent and Gauss-Newton methods and is given as

$$x_{i+1} = x_i - (H + \lambda diag[H])^{-1} \Delta f(x_i)\ . \qquad (3)$$

where H is the Hessian matrix evaluated at x_i, λ and Δ stand for the scaling coe-ficient and gradient vector, respectively. the Levenberg–Marquardt algorithm is faster than pure gardient method and is less sensitive with respect to starting point selection in comparison with Gauss-Newton method.

5. MULTICRITERIA OPTIMISATION

For above posed multicriteria optimisation problem can be formulated as

$$f(\bar{x}) = \min(f_1(\bar{x}), f_2(\bar{x})), \qquad (4)$$

subjected to linear constraints

$$x_i \le x_i^*, \qquad -x_i \le x_{i*}, \ , \qquad i = 1,...,n\ , \qquad (5)$$

In (4) $f_1(\bar{x})$ and $f_2(\bar{x})$ stand for the normalised maximum stress and deflection of glass panel, respectively (see formula (2)). In (5) x_i^* and x_{i*} stand for the upper nad lower limit of the i-th design variable, respectively.

In the case of multicriteria optimization problem with conflicting objectives the Pareto optimality concept can be considered as one of the most powerful and general approach. However, an analysis performed in the case of posed problem shows that the objectives considered are not conflicting. Such an result is not surprising, since both objectives are related to stiffness/strength of the structure [12-13].

As result, the use of the simpler multicriteria optimisation strategy is reasonable. Mostly these strategies are based on combining objectives into one objective function and solving latter problem as a single criterion optimization problem.

In the following the weighted summation technique is employed. According to this technique the optimality criteria given by (2) are multiplied by weights and summed into general objective f_s as

$$f_s = \sum_{i=1}^{m} w_i f_i\ . \qquad (6)$$

where m is the number of optimality criteria used, w_i is weight of the i-th criteria and

$$\sum_{i=1}^{m} w_i = 1, \qquad 0 < w_i \le 1\ . \qquad (7)$$

The constrained optimization problem has been solved by use of hybrid GA algorithm [14-15]. An advantage of the hybrid GA with respect to GA is higher convergence speed and reduced computing time [19].

6. DISCUSSION

The main conclusions can be outlined as

- The objectives considered are not conflicting, thus use of physical programming techniques is justified;
- In the case of considered objective functions the optimal thickness of the plate is equal to upper limit and can be fixed (not considered as a design variable). The situation will be changed when problem formulation is completed with third objective function – cost of the panel (planned as future study).
- The initial robust optimal design is determined by row of Taguchi dataset with best value of the objective function (6)
- The initial robust optimal design can be improved in range of 20-30% (decrease of objective function) depending on design space used.
- Larger data set is needed in order to improve ANN model (future study). The dataset based on Taguchi's DOE technique does not consider complex interactions between design variables.

7. CONCLUSION

The Taguchi's DOE method has been applied for design of data sets for structural analysis of the glass canopy panel. Based on FEA results the mathematical model for prediction of the values of objective functions is developed. The artificial neural network and evolutionary algorithms are employed for response modeling and search for optimal design. Finally, the sensitivity analysis has been performed. The objective function (6) appears most sensitive with respect to the thickness of the glass panel. However, in the case of objective function (6) the thickness corresponding to optimal solution reaches the upper value (boundary of the design domain) and thus can be fixed. This result can be expected, since glass panel with maximal thickness has highest stiffness/ strength properties. As mentioned in section 6, the situation can be changed by introducing new additional objective – cost of the panel.

8. ACKNOWLEDGEMENTS

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SINTERING ROUTES FOR ZIRCONIA DOPED HARDMETALS.

Voltsihhin, N.; Cura, M.E.; Hussainova, I.; Hannula, S-P.

Abstract: *Three sintering routes (hot isostatic pressing; vacuum pressureless sintering; and spark plasma sintering were used for fabrication of zirconia doped hardmetals to reveal the optimum conditions for manufacturing of the final product with improved mechanical properties. The effect of fabrication parameters on the microstructure development and properties of WC-Ni based and yttria-stabilized zirconia doped hardmetals was studied. Each sintering technique has its own impact on the formation of the chemical compounds and mechanical properties of the material. The SPSed specimens had ultra-fine grained microstructure in combination with high hardness and density close to theoretical. HIPed and vacuum sintered materials although have low porosity suffer from the abnormal grain growth that influences their mechanical properties.*

Key words: Hardmetals, Sintering, Zirconia, Hot Isostatic Pressing, Spark Plasma Sintering, Vacuum Pressureless Sintering

1. INTRODUCTION

Production of cemented carbides has been rapidly developed over the past six decades and hardmetals are found in different applications for example, wear resistant parts, automotive components, can tooling, metal forming tools and etc. The most representative member of this group of materials is a well known cobalt-bonded tungsten carbide (WC-Co cermets) that is widely used in situations where high wear resistance is needed [1,2,3].

Zirconium dioxide is one of the most studied ceramics and one of the most versatile materials commercially available today [4]. It resists high temperatures, corrosion, wear and impact, is chemically inert in the presence of most substances and one of the most intriguing oxide ceramics for investigation due to stress-induced tetragonal-to-monoclinic (martensitic) phase transformation, which is characterized by a large volume change (3 - 5%) and shear deformation (1 - 7%) [5]. Addition of zirconia to the cemented carbides matrix (or using zirconia as matrix) has been intensively studied [6-9]. Nevertheless development and optimization of such kind of materials is far away from its final point.

There is a great influence of the processing conditions on the formation of microstructure and mechanical performance of sintered materials [10-12].

Cemented carbides can be produced either by conventional sintering methods with or without isostatic pressure or by spark plasma sintering (SPS), which is one of the best ways to densify ultra-refractory compounds [13].

In this work vacuum pressureless sintering (VPS), hot isostatic pressing (HIP) and spark plasma sintering (SPS) routes were employed to produce WC-8wt.% Ni-6wt.% ZrO_2 bulk bodies for their further investigation and optimization. Usually SPS technology is compared to hot pressing (HP) technology because of the similarity of the furnaces construction and difficulty of producing near-net shape complex details. The aim of the present study was to reveal features of microstructure development during different routes of processing and their influence on mechanical properties of the composites.

2. EXPERIMENTAL

2.1 Materials

The raw materials used in the production of $WC/Ni/ZrO_2$ multiphase cermets were fine grained WC (Wolfram GmbH, Austria), micro-scale Ni powders as binder materials and 3 mol. % yttria partially stabilized zirconia (PSZ-ZrO_2) nanopowders (TOSOH, Japan*)*. Because of possible η-phase formation during sintering of these mixtures revealed in the previous study [10] 1 wt.% C was added to eliminate the formation of unfavorable phases. Table 1 lists the characteristics of the raw powders to be mixed based on the data from the suppliers and analyzes conducted in the laboratory of Tallinn University of Technology using Fritsch Particle Sizer analysette 22.

2.1 Mixing and compaction

Mixing of the bellow mentioned powders was carried out in a rotary ball mill device of a vertical rotation direction. Process duration was 72 hours.

Grinding was made using WC-Co balls with a diameter of 12mm. Ball to powder ratio was 7:1 and 100ml of ethanol together with 3g of PEG (Polyethylene-glycol) were added as a PCA (process control agent). PEG also serves as a plasticizer during compaction. After milling powders were dried in air. Then powders were compacted in a single

Powder	WC	Ni	ZrO_2	C
Particle size	0.9[a] µm	5-7 µm[b]	25 nm[a]	6.5µm[a]
Purity %	≥99.0	99.7	98.2	-
Grade	WC	Ni	PSZ	KS6
Supplier	Wolfram GmbH	-	TOSOH	TIMCAL

a-suppliers data, b-measured data

Table 1 The characteristics of the starting powders

ended press under pressure of 8.5MPa with a die having dimensions of 15mmx10mmx5mm. Green bodies were then held at 700°C in hydrogen for 30 min to burn plasticizers off. SPS procedure does not require the green bodies.

2.2 Sintering

The green bodies were sintered in HIP furnace at a pressure of 200 MPa using capsule free method and vacuum furnace under medium vacuum conditions, which varied slightly during heating from 20 Pa to 5 Pa. Maximum temperature for both processes was 1450°C and in both cases specimens were held at a maximum temperature for one hour.

The conditions of SPS sintering for the present materials are of special consideration and need to be optimized. Review of the literature [10,13-15] has shown the theoretical temperature parameters to be chosen and the first trial sintering was held under the specified parameters; then the process was re-considered and specified parameters were applied to the sintering process. A schematic of the sintering cycles are illustrated in Figure 1. Maximum temperature of the SPS cycle was 250°C lower than in the case of HIP and VPS and was 1200°C. Dwell time at maximum temperature during SPS cycle was 1 minute and the pressure applied to punches was 50 MPa.

2.3 Characterization

The microstructure was investigated by SEM (Zeiss EVO MA-15). The bulk Vickers hardness was measured using Indentec 5030 SKV at the load of HV20 or 200N according to ISO 6507. The density was measured using Archimedes method. Fracture toughness was measured using IFT (indentation fracture toughness) technique from the Vickers indent imprint. Toughness evaluation was made for both Palmquist and median crack systems on the base of some researches and equations [17-19].

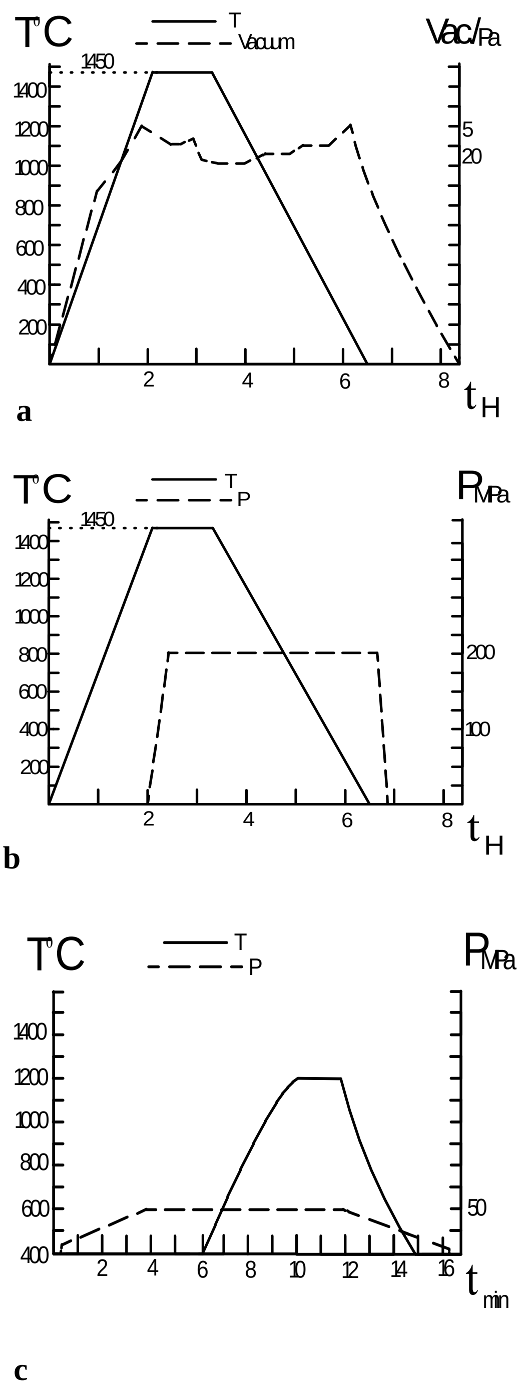


Fig.1 Diagrams of the sintering processes. a) Vacuum cycle, b) HIP cycle, c) SPS cycle

3.RESULTS AND DISCUSSION

3.1 Microstructure

SEM analysis revealed a great difference in the microstructures of the SPSed specimens and specimens sintered under pressure and pressureless conditions. SPS process is unique because the most significant parameters influencing grain grows (i.e. sintering temperature and time) are reduced to minimum.

Main three phases are indicated with arrows on the Figure 3a. Tungsten carbide grains are bright white grains, zirconia particles are rounded black clusters and nickel phase is in a view of grey shapeless spots. Grain coarsening of the HIPed and VPSed specimens can be clearly seen from Figures 3 b and c. However, reducing dwell time during HIP and VPS as microstructure optimization parameter does not perceptibly result in grain refinement while it could influence unfavorably the densification process and porosity level. The temperature was also chosen to prevent simultaneous zirconia particles transformation from tetragonal to monoclinic crystal lattice state during cooling after sintering. Some grain growth inhibitors can be used to prevent the WC grain growth (e.g. Cr_3C_2, VC), though they were not added deliberately in order to compare the effect of different techniques on the behavior of WC grains under different conditions. Nevertheless, the composites produced are of low porosity as it can be proved by SEM analysis. SPSed microstructure is ultra-fine grained with submicron WC grains of different shapes and sizes. The boundaries of the WC grains cannot be clearly determined from the images made of SPS specimens, but the compact grain structure is indisputable. The refinement of the WC grains after ball milling should also be mentioned here. Although the initial particle size of WC is 0.9 µm in average, after SPS sintering there are many grains, which are smaller in size, which means that grain growth was minimal. Zirconia grains can be also determined as ultra-fine in the range of 0.2-0.5µm. Usually it is difficult to get zirconia particles of this size because their tendency to agglomerate due to a great surface area of the initial nanoparticles.

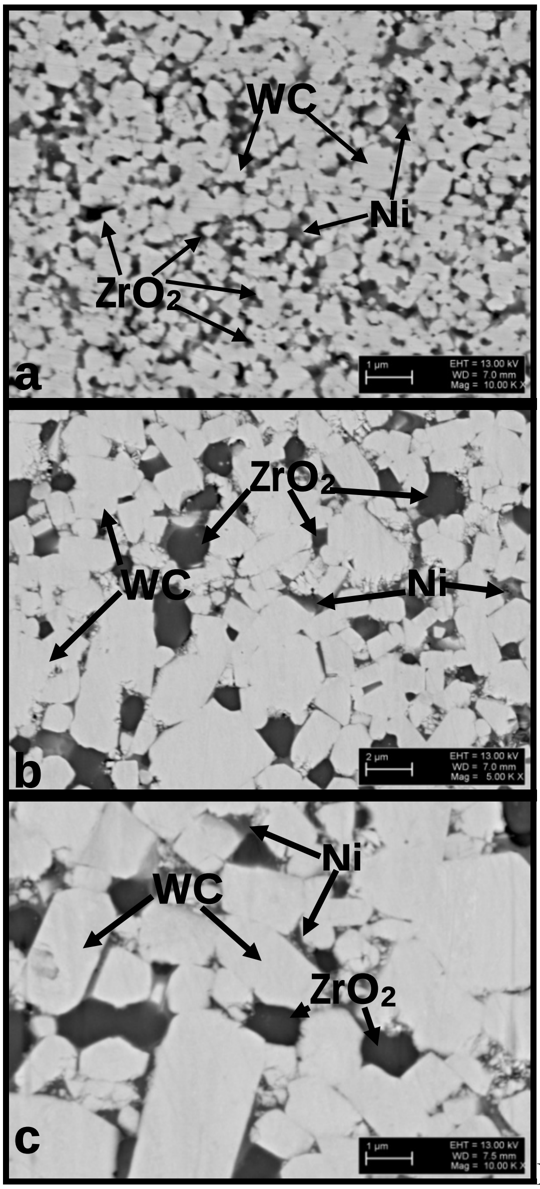
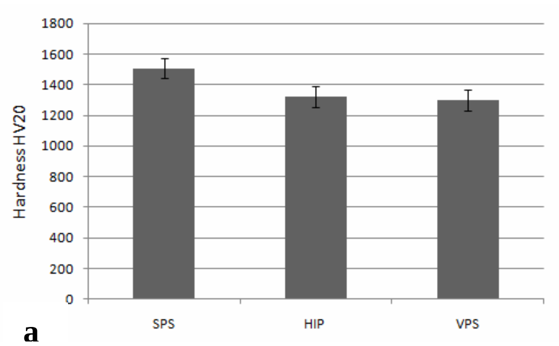


Fig.3 SEM micrographs of the sintered specimens. a-SPS, b-Vacuum, c-HIP

3.2 Density, hardness and fracture toughness

Densities of the sintered compacts were compared to theoretical densities calculated with the rule of mixtures on



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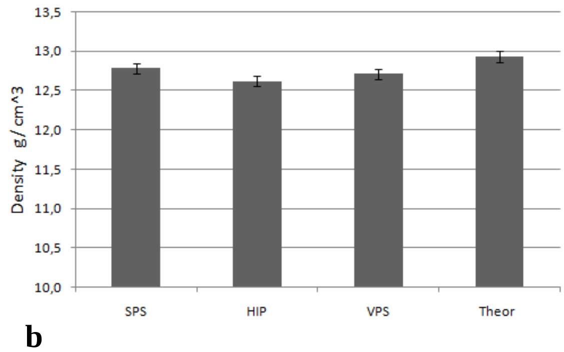

b

Fig.4 Graphs of a) hardness and b) density

SPS MPaxm$^{1/2}$		VPS MPaxm$^{1/2}$		HIP MPaxm$^{1/2}$	
PLQ	MED	PLQ	MED	PLQ	MED
7.73	9.06	10.20	13.11	9.67	12.46

Table 2 Fracture toughness results

the basis of the starting nominal compositions assuming no impurities and no reactions and transformations during processing.

Two graphs representing hardness and density values of the sintered bulk bodies are shown in Figure 4. Hardness of the specimens produced by HIP and pressureless sintering are lower than that of the sample produced by SPS route. The main reason for the lowered hardness is most probably grain coarsening of the HIP and VPS grades. It is a known fact that hardness is inversely dependent on the grain size.

The specimen sintered by SPS has also the highest density. Higher densification degree of the grade sintered with SPS is also likely to contribute to higher hardness shown in Figure 4.

Fracture toughness of the specimens sintered in pressureless conditions is higher than sintered in SPS. It is a common rule that if a material has high hardness it is more brittle and less fracture resistant than a similar material having a lower hardness. Lower fracture toughness can most likely be attributed to higher hardness and smaller porosity of the SPS processed samples, becauese in some cases fracture toughness can be enhanced by the presence of pores in the microstructure of the material.

4. CONCLUSIONS

Tungsten carbide based ZrO_2 doped cemented carbide was sintered using vacuum pressureless sintering, hot isostatic pressing and spark plasma sintering techniques. The production process has shown that temperature needed for the densification of material during SPS sintering cycle can be 200°C lower than for comparable technologies. The microstructure generated by the SPS technique can be defined as submicron and ultrafine grade, while HIP and vacuum sintered microstructures refer to submicron and micronized grains. As a consequence of fine and preferable microstructural parameters the materials produced by SPS had higher hardness in the range of 1500 HV20 units. As a result of high hardness the fracture toughness of the SPS grade was lower than grades sintered by HIP and VPS furnaces.

Although the results obtained by SPS are impressive a more detailed comparison and investigation on the effects of sintering technologies on the properties of cemented carbides are needed. In the near future further studies on the SPS sintering of different cemented carbides will be carried out.

5. ACKNOWLEDGMENTS

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EFFECT OF CARBON CONTENT ON SINTERABILITY AND PROPERTIES OF ZrO_2 DOPED WC-CERMETS

Cura M.E.; Voltsihhin, N.; Hussainova, I.; Viljus, M.; Hannula, S-P.

Abstract: *The control of carbon amount has an important role in controlling the mechanical properties of cemented carbides. In this study an integral effect of adding different carbon amounts in combination with three different sintering techniques was investigated. Graphite was used as carbon source and was added to the WC - 8 wt.% Ni - 6 wt.% ZrO_2 mixture in 0 wt.% C, 0.2 wt.% C, 0.4 wt.% C, 0.7 wt.% C and 1 wt.% C in order to reveal influence of carbon amount on the mechanical properties and microstructure of the composites. The composite with 0.2 wt. % C showed the highest density and hardness, ~ 100 % T.D. and 1700-1800 HV20 respectively, for all sintering techniques. Increasing the amount of carbon further caused clear grain growth during hot isostatic pressing and vacuum sintering. In spark plasma sintering the grain growth was suppressed regardless of carbon addition.*

Keywords: Cermets, Sintering, Carbon, Microstructure, Zirconia

1. INTRODUCTION

Cermets are heterogeneous combination of metals or alloys with one or more ceramic phase with a relatively low solubility between metallic and ceramic components [1]. The largest category of cermets is called hardmetals and they are mostly referred to cemented tungsten carbides which are extensively used in cutting tools and wear parts. Nickel is one of the metallic binders used in liquid phase sintering of WC and offer better stability over other binders in presence of oxide additives, e.g. ZrO_2 [2]. Doping by yttria stabilized zirconium dioxide is used as a grain growth inhibitor and improves the fracture toughness of cemented tungsten carbides [3-5]. Zirconia is well known for its high toughness owing to stress-activated tetragonal to monoclinic transformation which started a new class of ceramics combining ceramics properties with improved toughness [6].

Carbon content in cemented carbides has a significant influence on the physical and mechanical properties of the materials. Carbon deficiency in the microstructure yields to formation of lower carbides which are brittle, such as the η-phase in tungsten carbide. On the other hand carbon precipitates when it is excessive in amount [7,8]. Since the carbon content can be changed substantially during sintering by reactions with oxygen-containing phases and by carbon exchange reactions with the metallic content in the initial material, control of the composition of the starting powder as well as the furnace atmosphere is essential to produce high-quality P/M parts. If an excessive amount of carbon is present in the material the free carbon will appear along the grain boundaries as a separate phase. This carbon rich pocket like structures will disrupt the WC-Ni matrix and affect the properties of the material. Excessive carbon content is also determined by ASTM as C type porosity [9].

In this study effect of carbon content on the densification, mechanical properties and microstructure of WC-Ni containing partially stabilized ZrO_2 (PZT) as a toughening agent was investigated. The composites were sintered by applying Vacuum Pressureless Sintering (VPS), Hot

Isostatic Pressing (HIP) and Spark Plasma Sintering (SPS) techniques and their effect on the material properties is also evaluated.

2. EXPERIMENTAL PROCEDURE

WC - 8 wt.% Ni - 6 wt.% (ZrO_2/3mol.%Y_2O_3) composite powders (referred as WC/Ni/PZT later in the text) were prepared by rotary ball milling of the commercial powders in ethanol for 72 h. The prepared compositions and milling parameters are given in Table 1. The particle sizes of WC (Wolfram GmbH, Austria), 3 mol. % yttria partially stabilized zirconia (TOSOH, Japan) and nickel (Russia) powders were 0.9-1.1 μm, 25 nm and 5-7 μm respectively and measured by Fritsch Particle Size Analyzer. Throughout the experiments the same powder composition was used for WC/Ni/PZT and in one of the composites, 0.4 wt.% of Cr_3C_2 (2-3 μm, Tokyo Tungsten Co.) was added as a grain growth inhibitor. KS6 grade graphite (TIMCAL) with a particle size of 5.5 μm was used as the carbon source and it was added in amount of 0.2, 0.4, 0.7 and 1 wt.%. After the milling the powder mixtures were dried at 60 °C in air and granulated by a 1 mm sieve. A pre-compaction was made before VPS and HIP by uniaxial pressing with a pressure of approximately 10 MPa.

Prior to the sintering processes removal of the organic binders in the precompacts (powder in case of SPS) was carried out at 700 °C for 1h under hydrogen. Compacted green bodies and as milled powders were consolidated by VPS, HIP and SPS respectively. Parameters of sintering are described in Table 2.

Composition	86WC-8Ni-6ZrO_2				
C wt.%	0	0.2	0.4	0.7	1
Ball to powder Ratio	6:1	10:1	6:1	6:1	7:1
Milling balls	ZrO_2	WC-Co	ZrO_2	ZrO_2	ZrO_2
Ball dia., mm	10	12	10	10	10
Milling t, h	72				
PCA, plasticizer	3g PEG & 100ml ethanol				

*Contains Cr_3C_2

Table 1 Powder compositions and milling parameters.

C content, %	Technique	T, °C	Pressure MPa	Heating rate, °C/min	Cooling rate, °C/min	Dwell time, min
0-1.0	HIP	1450	200	12	8	60
0.2-1.0	VPS	1450	$2x10^{-5}$	10	10	60
0.2-1.0	SPS	1200	50	100	~150	1

Table 2. Sintering parameters for the applied techniques.

After the sintering the densities of the sintered composites were measured using Archimedes method. The Vickers hardness was measured by Indentec 5030 SKV with a load of 20 kg or 200N according to ISO 6507. Fracture toughness was measured using IFT (indentation fracture toughness) technique from the Vickers indent imprint. Toughness evaluation was made for both Palmquist and median crack systems on the base of equations given elsewhere [12-14]. The microstructure of the sintered compacts was investigated by SEM (Zeiss EVO MA-15. Phase identification was carried out using X-ray diffraction (XRD) with Cu-K_α radiation (Bruker AXS D5005).

3. RESULTS AND DISCUSSION

3.1 Physical and Mechanical Properties

When no carbon was added to the material presence of so called η-phase was observed for HIPed material. Ni_2W_4C was detected in XRD studies up to 20 wt.% in materials HIPed without any graphite (Fig. 1a). High hardness of this carbide phase was reported in various sources [15,16] which is known for X_nW_yC type of structures (X: Ni, Co, Fe, B etc.). Despite its relatively high hardness the formation of this phase is not favorable since it promotes brittleness and unpredictable behavior during wear. The formation of η-phase was prevented by adding different amounts of graphite and in XRD studies ternary carbide phases were not observed in presence of additional carbon.

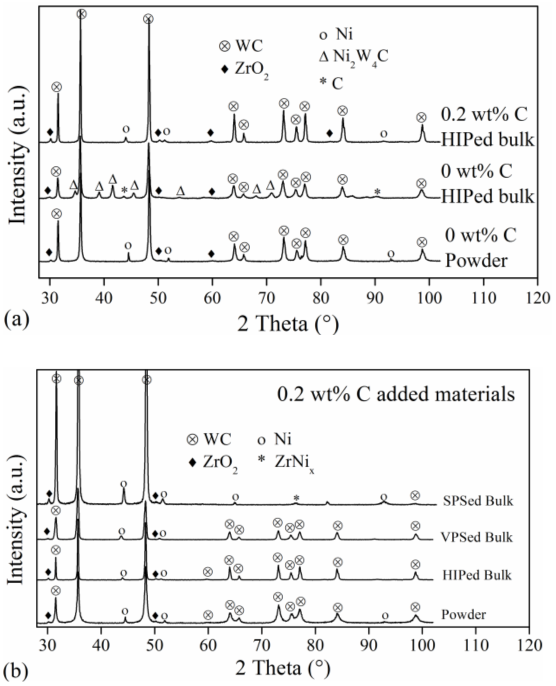

Fig.1 The effect of a) C content and b) sintering method on the composition

A comparison of XRD measurements of the powder and the compacts with 0.2 wt.% C for different sintering methods are given in Fig. 1b.

The densities of the carbon containing composites are given in Fig. 2a. The upper curve represents the theoretical densities of the studied compositions and the curves below it represents the densities of the compacts consolidated with different techniques. In presence of 0.2 wt.% graphite the measured density of the material is very close to its theoretical density, which indicates almost full densification. In other compositions with or without additional carbon the densities are slightly lower than the theoretical density values. Even though there is no evidence of η-phase in the XRD results of 0.2 wt.% C grades, the amount of this phase can be below the detection limits of XRD, which will also yield a lower relative density. The measured density of the HIPed material was 13.40 g/cm^3 and it increased slightly in presence of 0.2 wt.% C to 13.43 g/cm^3. When the carbon amount was 0.4 wt.% densities of all the compositions regardless of the production technique were dropped significantly, to 12.77, 13.10 and 12.54 g/cm^3 for HIPed, VPSed and SPSed samples respectively. The major cause for this drop is the effect of additional carbon on composition and the formation of η-phase which has a much higher density. When the carbon content was further increased the densities of the materials showed some variation depending on the sintering method. Measured densities of SPSed materials were increased first to 12.64 g/cm^3 and then to 12.78 g/cm^3 for additions of 0.7 and 1.0 wt.% C. Density of HIPed samples showed a continuous drop with the increasing C content while the density of VPSed sample was slightly increased with 1.0 wt.% C addition.

Hardness of the tested cermets was lowered to some extent by the increasing amount of graphite additive (Fig. 2b) Materials with 0.2 and 0.4 wt.% C addition had higher hardness when they were sintered by VPS. Similar behavior was observed with the density change, the hardness of SPSed samples first dropped from 1722 HV20 to 1382 HV20 when the C content went up from 0.2 to 0.4 wt.% and it increased first to 1386 HV20 and

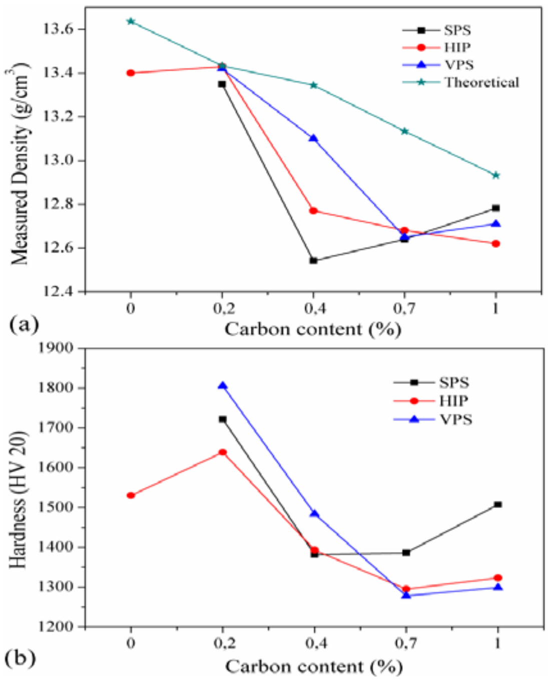

Fig. 2. Effect of carbon content on the a) density and b) hardness of the samples.

then to 1507 HV20 for 0.7 and 1.0 wt.% C, respectively. SPS technique has the unique advantage of suppressed grain growth over other sintering methods. This is probably the main reason for the increase in hardness with higher C content along with better densification compared to HIPed and VPSed samples.

Fracture toughness of the materials showed evident variation (Fig. 3). Fracture toughness of HIPed materials was in a declining regime when the carbon amount was increased. VPSed materials on the other hand had an increase in their fracture toughness up to 0.7 wt.% C which was dropped when C amount was 1 wt.%. SPSed materials showed a more unique behavior and almost no difference was observed for 0.2 and 1.0 wt.% C addition. Fracture toughness had a small increase at 4 wt.% and remained almost the same for 0.7 wt.%. SPSed materials had an inverse relation between their hardness and fracture toughness. Presence of additional carbon not only hindered η-phase formation but also made some improvement on the densification overall. In the grades produced by HIP IFT was very high especially for low carbon content grades. In general higher fracture toughness is assumed to be a result of synergetic influence of microstructure and zirconia transformation toughening effect. However behavior of HIPed specimens was not very clear.

3.2 Microstructure

Difference in the microstructure development and morphology with increase in carbon content and effect of different sintering techniques were observed by SEM studies. The images in Fig. 4 represent the microstructures of the materials with various carbon contents and sintered with different techniques. The carbon content in Fig. 4 a-d is 0.2-1.0 wt.% of C and the materials were sintered by VPS. In Fig. 4 e-g is for the same carbon content but obtained using SPS. The HIPed materials had almost the same

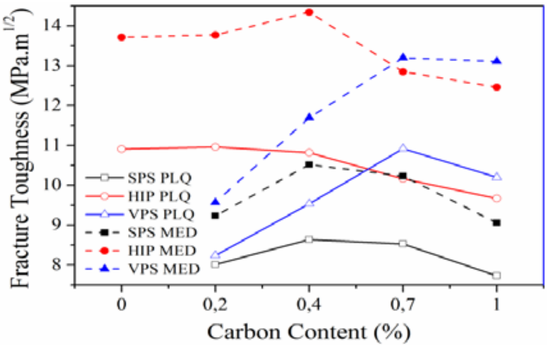

Fig. 3. Fracture toughness values for Palmquist and median crack systems.

microstructures with those consolidated by VPS. A significant difference in the microstructure was the grain growth in the materials sintered by VPS and HIP compared to SPS as a result of much shorter sintering cycle for the latter. The change in the carbon content had a clear influence on the grain size evolution, where 0.2 wt.% C grade had a finer microstructure and the change was in an increasing manner for 0.4, 0.7 and 1.0 wt.% C grades. The increase was observed both for WC and ZrO_2.

The specimens with 0.2 wt.% C were doped by Cr_3C_2 and as a result the grain growth was less compared to other grades when they were sintered by VPS and HIP. Coarser grain structure for 1 wt.% C grade samples compared to 0.4 and 0.7 wt.% grades indicates the enhanced discontinuous grain growth namely the effect of carbon addition on the microstructure. The microstructure of SPSed materials showed almost none or very little grain growth and seemed to be unaffected by the graphite addition. WC grains were in submicron range and ZrO_2 particles were in the range of ultrafine to nanoscale.

The microstructure of Cr_3C_2 containing grade was more preferable for both VPS and HIPed samples as it had more homogeneous distribution of the submicron size grains. WC demonstrated a tendency of grain elongation and having a rectangular shape with the increasing carbon content (Fig. 4 c-d). This type of

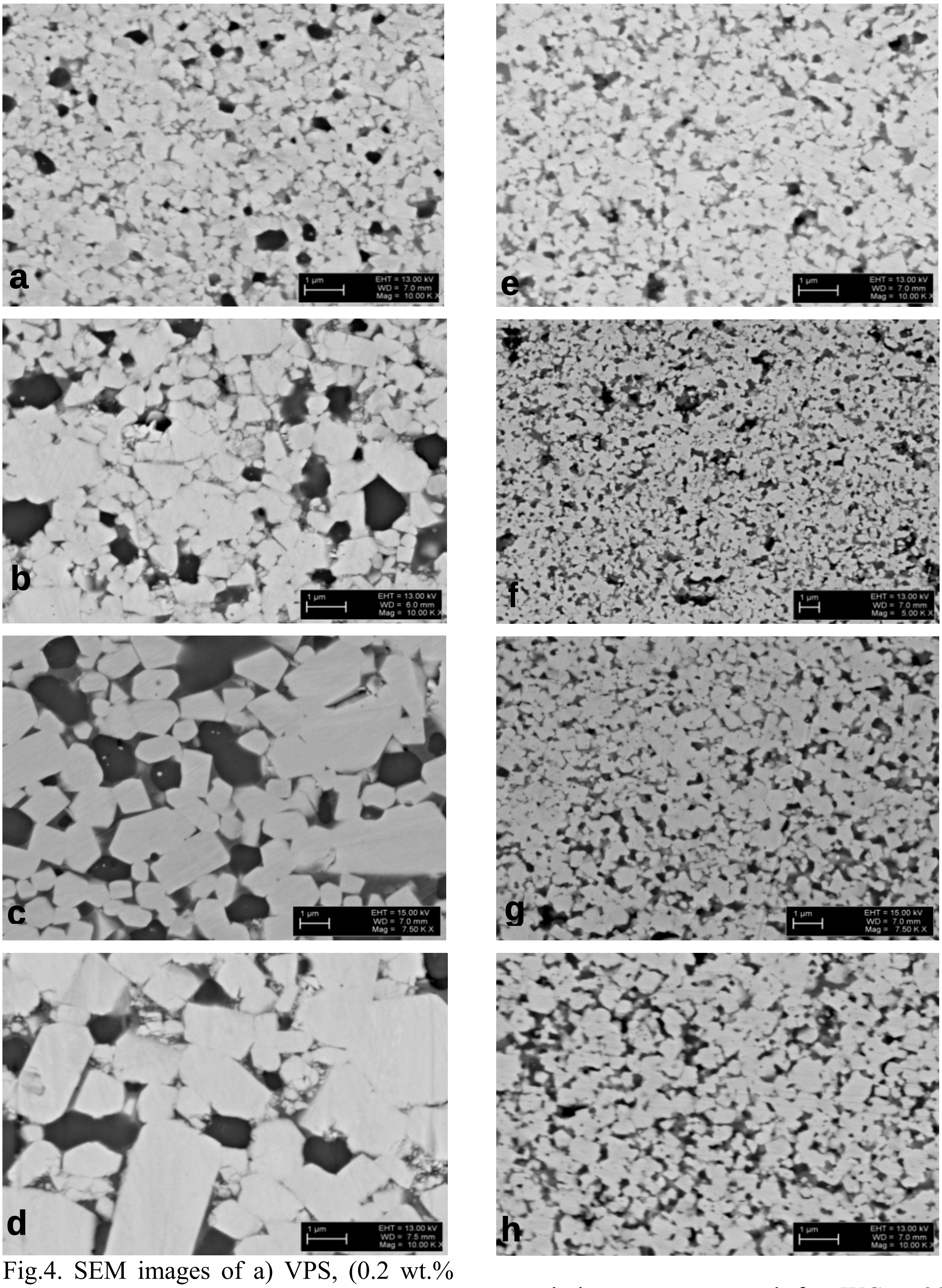

Fig.4. SEM images of a) VPS, (0.2 wt.% C) b) VPS, (0.4 wt.% C) , c) VPS, (0.7 wt.% C), d) VPS, E (1 wt.% C) e) SPS, (0.2 wt.% C) f) SPS, (0.4 wt.% C) g) SPS, (0.7 wt.% C) h) SPS, (1 wt.% C)

morphology was reported for WC - 30 wt.% Co composites when the carbon content was increased from 0.1 to 1.0 wt.% [17].

4. CONCLUSION

Effect of carbon content in combination with various sintering techniques on the microstructure and mechanical properties of the WC-Ni hardmetals with 6 wt.% of PZT was investigated. The microstructure of the VPSed and HIPed materials was changed significantly by the addition of extra carbon. There was almost no grain growth in SPSed materials due to shorter process duration. The hardness of the composites were decreased in presence of extra carbon up to 0.7 wt.% for VPS and HIP and 0.4 wt.% for SPS. Fracture toughness of the materials was consistent with their hardness with some deviation.

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CHEMICAL PRE-TREATMENT OF MECHANICALLY MILLED RECYCLED HARDMETAL POWDERS

Zikin, A., Yung, D., Hussaionova, I. & Ilo, S.

Abstract: *The present research concentrated on chemical pre-treatment of recycled powders bathed in acid media. Influential factors including concentration, submerging time, solution composition, cleaning conditions (magnetic or ultrasonic agitation) and temperature were studied in detail. Results showed the importance of chemical pre-treatment process. Sulphuric acid was selected as a suitable reagent as it is readily available, affordably priced and highly reactive. Furthermore, sulphuric acid did not dissolve the cobalt binder in WC-Co as compared to many other concentrated acids. Hardfacings produced from pre-treated recycled powders showed an improved quality with almost no surface defects.*

Key words: chemical treatment, powder surface cleaning, WC-Co, pta hardfacing

1. INTRODUCTION

Tungsten carbide hardmetal is one of the most renowned powder metallurgical products, mainly used for manufacturing machine tools operating under severe wear stress conditions. When alloyed with different elements including Fe, Co or Ni, tungsten carbide's superior hardphase properties provides high wear resistance for materials used in cutting, mining, drilling tools and other industrial equipment [1-3]. However, the high marked requirements lead to permanently increasing prices and wastage of cemented tungsten carbide. Therefore, research and development into alternative solutions to reuse or recycle hardmetal scrap containing tungsten carbide has become economically important in recent years.

The technology to recycle hardmetal scraps from worn and damaged cermets requires application of different processes for the breakup, disjunction and purification of hardmetal particles. One effective mechanical method for recycling of cermets and hardmetal scrap is disintegrator milling [4-5] which yields powders of uniform particle size and shape. However, disintegrator milling hard and dense hardmetals also wears the mechanical grinding medium, contaminating the derived powder.

Surface contamination, especially by oxides, can significantly influence quality, properties and performance (decrease weldability; increase porosity) of recycled hardmetal powder [6-7]. During the Plasma Transferred (PTA) hardfacing, contaminants can cause CO_2 or other gases to form resulting in pores. This hindrance factor affects the eventual surface quality of nickel-based compositions. To produce reliable pore-free coatings, the quality of recycled powders needs to be improved.

The present study is focused on chemical pre-treatment of the powders produced from WC-Co scrap. The process of hardmetal scarp cleaning has been developed based on the commercially cheapest method of chemical pre-treatment and simplicity of experimental procedure that allows quick, efficient and effective treatment of the recycled hardmetal powders to be used for PTA hardfacing process.

The main objectives of the present research are as follow: (1) to remove iron contamination from the surface of recycled

WC-Co powder particles; (2) to optimise the parameters for chemical treatment; (3) to improve quality of the weld transferred from the recycled WC-Co scrap.

2. EXPERIMENTAL

2.1 Powder preparation and characterisation

Recycled WC-Co hardmetal powders were produced from hardmetal scrap by disintegrator milling as described elsewhere [4]. The milling blades as well as disintegrator device frame are constructed from steel. Therefore, as expected, some of the steel (namely iron and iron based particles) would contaminate the resulting surface as shown in Fig. 1. Chemical composition and grain size distribution of the recycled WC-Co powder are listed in Table 1.

It should be noticed that coarse hardmetal particles represent fine (3-5 µm) tungsten carbide grains bonded together by Co-binder. Some trace amount of titanium nitrite (2-3µm layer thickness) was found in the grinded and milled powder mixture (see Fig. 1) as the WC-Co scarp was sourced from cutting tool elements.

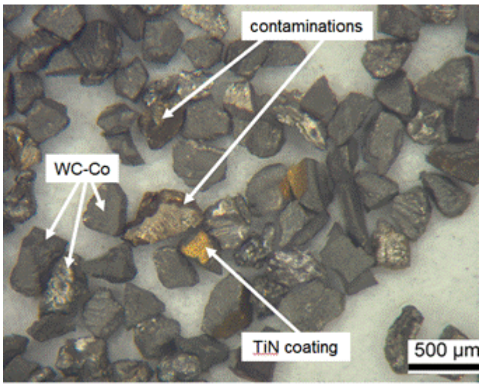

Fig. 1. Optical microscopy image of recycled carbide powder after disintegrator milling

Material	Grain size, µm	Chemical composition, wt %
WC-Co	-150+315	10-12 Co, 6-10 Fe, 2-4 Cr, rest WC*

** Various due to wear of grinding media*

Table 1. Characterisation of recycled powder

2.2 Chemical pre-treatment procedure

Standard laboratory reagents were used in all tests: H_2SO_4 stock was 95% and the reagent was serially diluted to 50%, 40%, 30%, 20%, and 10% for the experiments using distilled water.

The main parameters influencing the process of surface cleaning were studied: time, concentration (diluted acids), ultrasonic energy and temperature.

Hardmetal powder (20 g) was placed into a pyrex flask with 3 ml of acid under consideration. Magnet stirrer was used to continuously and thoroughly mix the acid with the powder during the reaction time. The stirrer ensured a constant flow of acid between individual particles. Magnetic stirrer was used for every experiment with exception of ultrasonic agitation experiments.

In some tests, ultrasonic energy was introduced into the acid bath instead of magnetic agitation. The water was kept at room temperature, however, vibrational energy from the ultrasonic bath quickly increase the temperature to ~35°C. Experiments were performed with H_2SO_4 of 10%, 20%, and 30% based on the results from magnetic agitation research.

For further optimization of the process, the temperature of solution treatment was varied in the range 20–80° C while other variables were fixed.

To stop acid reactions at the specified time, water was slowly poured to quench the reaction. Water washing was repeated until the mixture became clear. This step was followed by ethanol washing to remove impurities and remaining acids. Isopropyl alcohol was the next to sensitized any water and sulphuric acid products. Finally, benzene was added in the mixture and then poured out to help with drying. All samples were dried overnight in a 45°C oven to remove all traces of moisture.

Dried, chemically treated powders were weighted using analytical balance. Percent weight lost was calculated when compared to an initial weight. Pycnometer method measured the density of powders.

Surface of the powders before and after cleaning process was studied by scanning electron microscopy (SEM). Chemical composition was analysed by energy dispersive X-ray spectroscopy (EDS) and X-ray fluorescence (XRF).

3. RESULTS AND DISCUSSION

3.1 Time factor

SEM images of recycled WC-Co powder are presented in Fig. 2 clearly showing powder surface contamination. EDS and XRF analysis revealed iron and iron oxide residues.

To evaluate the effect of cleaning procedure duration, 95% concentrated H_2SO_4 acid has been used for an adjusted time with 10 min intervals between 0 (initial powder without any treatment) and 60 min. Fig. 3 exhibits quantitative data for the weight percentage of some main elements found on the sample surface. The total weight lost due to the acid treatment is between 0.9 - 1.3 % that means carbide dissociation rate even after 60 minutes of exposure in the acid bath stays constant. With increased time of treatment degradation of Co binder from surface takes place. Cobalt content decreases from its pre-treatment level of approximately 11 % to about 3 % post-treatment.

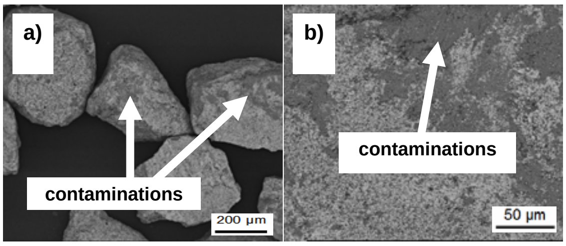

Fig. 2. SEM micrographs of recycled WC-Co powder surface: a) BSE, magnitude 100x; b) BSE, magnitude 500x

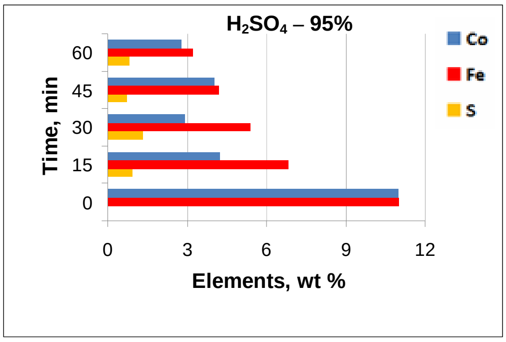

Fig. 3. Surface analysis based on EDS measurements - constant sulphuric acid concentration of 95% at different time scales

Furthermore, the use of strong sulphuric acid also left unfavourable sulphur residues on particle surface. The speculation is that sulphur presence on hardmetal grains could lead to problems (mainly the formation of pores) during the PTA process. Some iron contamination remains after 60 minutes exposure to concentrated H_2SO_4 acid as indicated by backscattering SEM images (see Fig. 4). Based on in-experiment observations, the reaction of concentrated H_2SO_4 significantly decreases contaminations after just 30 minutes; however, the process also removes Co-binder with increasing exposure time.

3.2 Diluted acids

Fig. 5 corresponds to the surface analysis results based on the diluted acids with concentration decreasing from 50 % to 10 % at 15 minutes exposure time.

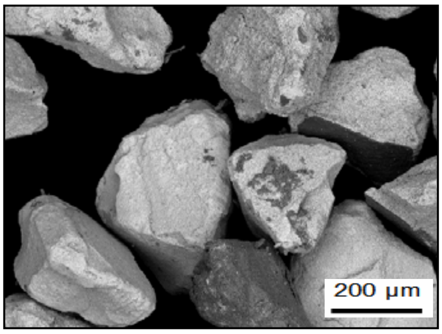

Fig. 4. SEM micrograph of recycled powders after pre-treatment 95 % H_2SO_4, T – 60 mins

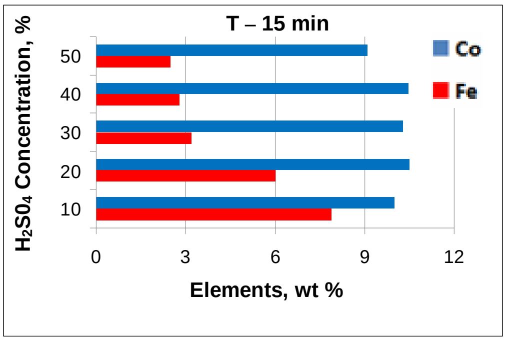

Fig. 5. Surface analysis based on EDS measurements - different acid concentration at 15 min experiment

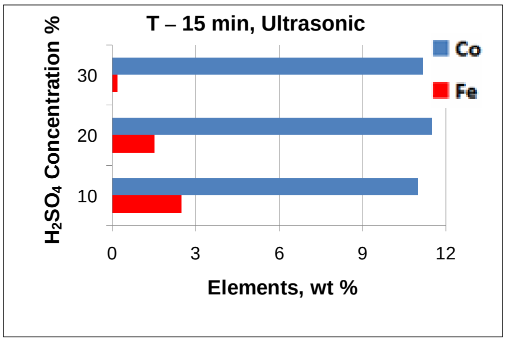

Fig. 7. Surface analysis based on EDS measurements - ultrasonic energy at different concentration with constant time

With increasing acid concentration a trend of decreasing iron weight percentage is observed. This indicates a decrease in superficial iron and iron oxide contaminations on the hardmetal grains. Co wt% remains at a constant level of about 10% for all acid concentrations, except for experiments with 50% H_2SO_4 acid where Co wt% slightly drops to 9%. Furthermore, probably due to lower acid concentration, no sulphur contamination is detected. SEM observations (see Fig. 6) confirm that certain amount of surface impurities remains on the material. The total weight loss is observed at between 1.2 - 2 % for 15 min tests.

3.3 Ultrasonic cleaning

Promising results (see Fig. 7) are achieved by using ultrasonic bath and vibration energy. Even 10% concentration of H_2SO_4 is able to significantly remove Fe-based contaminants, without dissolving Co binder

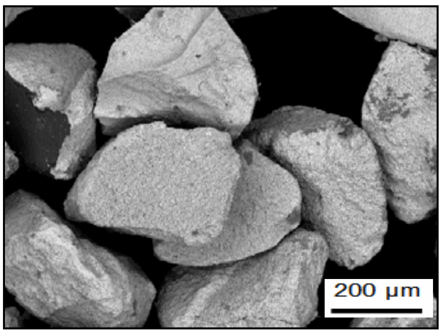

Fig. 6. SEM micrograph of recycled powders after pre-treatment; 30 % H_2SO_4, T – 15 mins

metal and not adversely affect the surface of the grain and structure.

After 15 minutes cleaning with 30% concentration H_2SO_4 under ultrasonic bath iron content on the surface becomes negligible and no oxides can be detected (Fig. 8). The amount of free iron also appears to be reduced significantly compared to any other previous results. Co is maintained at 11%.

3.4 Temperature

Increasing temperature during chemical cleaning does not seem to affect refinement quality of the grains until > 80° C (see Fig. 9). Reaction with 30% concentrated H_2SO_4 at temperatures 23°, 40° and 60° C are found to be similar at removing the contamination from the surface of hardmetal grains. Nevertheless, below 80°C, temperature treatment has a detrimental effect compared to ultrasonic cleaning.

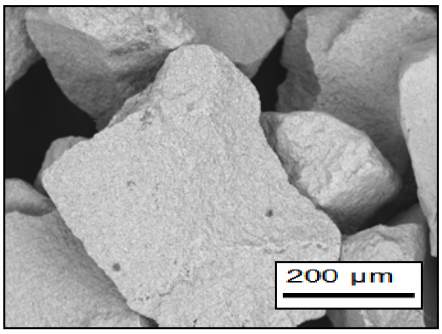

Fig. 8. SEM micrograph of recycled powders after pre-treatment; T - 15 mins in ultrasonic bath

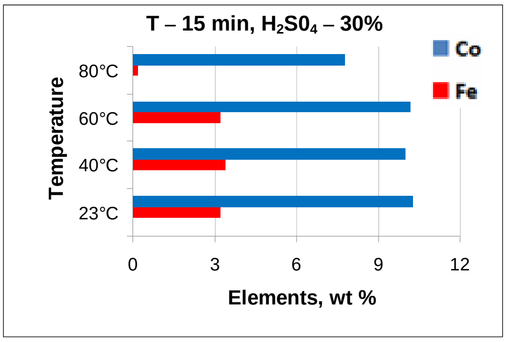

Fig. 9. SEM micrograph of recycled powders after pre-treatment; different temperatures with constant time and constant acid concentration

Between room temperature and 60° C, Fe concentration and Co concentration are constant when using 30% H_2SO_4. Once the temperature hits 80° C both concentrations (Fe and Co) decrease significantly. Iron and iron oxides are fully removed from the grain surfaces (Fig. 10); however, Co binder metal is also removed. Therefore, changing temperature is counterproductive to maintaining elemental Co in the hardmetals. To protect the cobalt binder, treatment temperature should not be artificially raised above 60° C.

3.5 Pre-treatment effects

SEM analysis of the treated particles with different acid concentrations indicates that surfaces of hardmetal grains after cleaning become finer with higher acid concentration (Fig. 11). It is assumed the acid starts to penetrate between phases of WC and Co-binder while dissolving both. This "etching effect" leads to increased

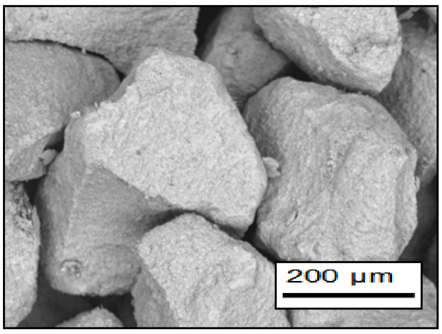

Fig. 10. SEM micrograph of recycled powders after pre-treatment; T - 15 mins at 80°C

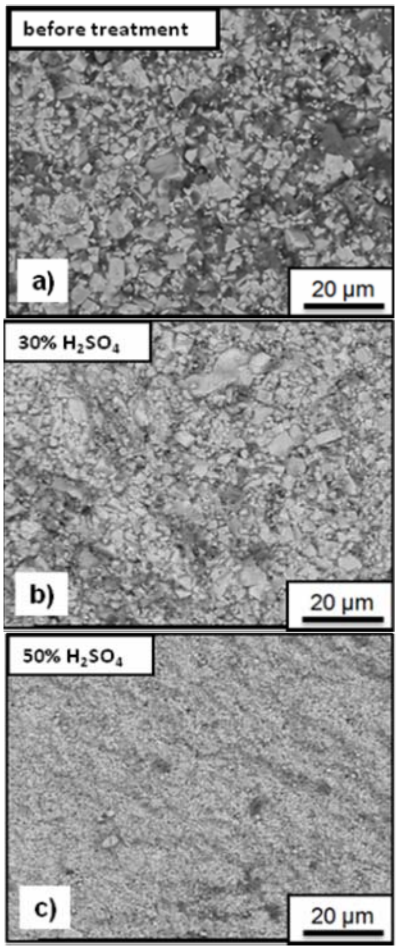

Fig. 11. SEM backscattering images of recycled grains surface: a) before chemical treatment; b) after treatment with 30% H_2SO_4 and 15 min; c) after treatment with 50% H_2SO_4 and 15 mins

weight loss and refined carbides. Similar effect was observed also for cleaning at temperature of 80°C.

Based on experimental analyses, the recommendations for increasing quality of recycled powders using pre-treatment are as follow: 30 % H_2SO_4, ultrasonic bath, 15 minutes cleaning time. For further evaluation, initial powder is welded with the same parameters as pre-treated powder. Cross-section image of both weld deposits and SEM micrograph of treated hardfacing are presented in Fig. 12. The results indicate significant improvement of weld deposit quality. No porosity is found in either cross or longitude sections for pre-treated weld. This chemical pre-treatment method has demonstrated to significantly improve the quality of recycled powders,

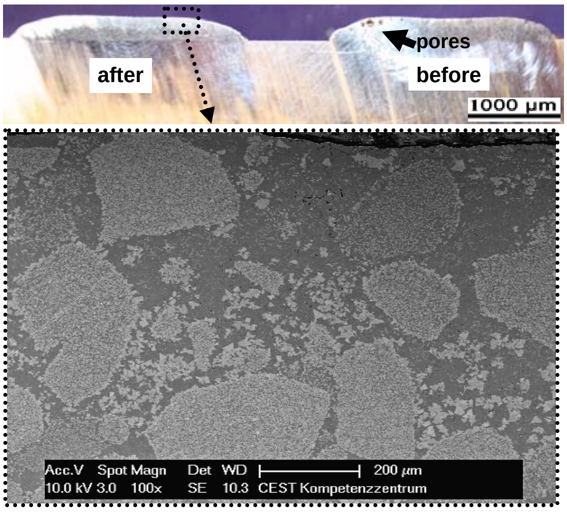

Fig. 12. Cross-section of weld deposit and SEM image of hardfacing

and should be employed for future processing of contaminated WC-Co powders.

4. ACKNOWLEDGEMENT

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5. CONCLUSION

Based on the study within this work, the following conclusions can be drawn:

1. The chemical pre-treatment method, used in the present study was successfully applied for improving the quality of recycled WC-Co powders.
2. 15 minutes of reaction time and ultrasonic energy could be enough to remove all iron and iron oxide residues from powders surface.
3. Application of chemically pre-treated recycled hardmetal powders by PTA hardfacing has revealed high improvement of weld deposit quality and the main problem of welds porosity was solved.

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REACTIVE SINTERING OF ZIRCONIUM CARBIDE BASED SYSTEMS

Yung, D.; Kollo, L.; Hussainova, I.; & Zikin, A.

Abstract: *The high cost of commercial ZrC nanopowder has spurred the development of cost-efficient and low-energy approaches for carbide synthesis. Mechanical activation synthesis (MAS) by high-energy ball milling technology and reactive vacuum sintering was used to synthesize ZrC powder from zirconia (ZrO_2) at the low temperature of 1500°C.*

However, a major drawback for structural ZrC powder made from MAS was the relatively low fracture toughness, and difficulty ensuring adequate hardness and densification when vacuum sintered below 2000°C. ZrC combined with 20% weight molybdenum was sufficient to yield a cermet of 96.1% densification, hardness of 17GPa, and fracture toughness of 5.23-6.08MPa$m^{1/2}$. This present study was able to achieve a genuinely homogenous ZrC-Mo cermet in vacuum sintering temperatures not exceeding 1900°C.*

Key words: mechanical activation, reactive vacuum sintering, cermets, carbides, ZrC-Mo

1. INTRODUCTION

Zirconium carbide (ZrC) belongs to a class of ultra-high temperature ceramics, which possesses high melting temperature (~3400°C), decent refractory hardness (~25GPa), and good corrosion and oxidation resistance [1-4]. ZrC is typically produced by fusing zirconia with carbon in an electric-arc furnace at temperatures >2500°C [5]. However, densification, hardness, and fracture toughness are evident weaknesses in eutectic ZrC. Various research attempts have signalled the use of molybdenum as a viable binder agent for liquid sintering in the effort to boost the mechanical properties of ZrC. Research into ZrC-Mo cermets synthesised in pressureless or non-carburizing environments have used temperatures in excess of 2000°C [1-5]. Flexure strength and fracture toughness increased with increasing Mo content from 1.0 to 6.6MPa*$m^{1/2}$ respectively [5].

Mechanical activated synthesis (MAS) is achieved during high-energy ball milling, a process that mechanically increases the specific surface area of particles as well as homogenously mixes substrates allowing for chemical reaction and sintering at lower temperatures [6-7]. Previous studies performed by the authors of this paper have shown ZrO_2 and graphite undergoing 10 hours of high-energy milling (HEM) and subsequent reactive vacuum sintering at 1500°C can yield cubic ZrC up to >98% purity [8].

This study aims to further optimise the initial findings of synthesising ZrC from zirconia in an effort to increase the yield and efficiency of the process involving MAS and vacuum reactive sintering. In regards to HEM, the milling time and ball-powder (BP) ratios are factors taken into account. And then to improve upon the mechanical quality of ZrC, this study produces a series of experiments to determine the adequate amount of Mo needed to amend the densification, hardness, and fracture toughness of ZrC-Mo cermets at temperatures no more than 1900°C. In this case, the percent weight of Mo and sintering temperatures are factor taken into account. The experimental methods of high-energy (HEM) and low energy (LEM) ball milling will be compared as these proven methods have shown to decreased the required sintering temperature for bulk samples.

2. EXPERIMENTAL

2.1 Optimising ZrC Synthesis

We used un-stabilised zirconia (with the absence of yttrium) to characterise HEM milling parameters regarding the milling time and BP ratio. The first parameter was BP ratio during HEM. In our milling container, the amount of starting substrates was increased by 50% in each of three experiments. The original starting material amount was 40g weight at 1:1 molar ratio of ZrO_2 and graphite (see equation 1), which was subsequently increased to 60g and then 80g.

$$ZrO_2 + C \rightarrow ZrC + CO_2 \qquad (1)$$

All stoichiometric weights of the zirconia and graphite were held constant as well as the milling time set to 10 hours and the number of milling balls. The milling liquid was topped off proportionally. The BP ratio consequently decreased from 12:1 to 9:1 to 6:1 as only more substrate was added.

In all experiments, the ideal milling time was set to 10 hours. However, given the wear and tear inflicted on the machines with such long milling times, the goal was to reduce the needed time, but still homogenously mix the reactant substrates where reactive sintering will continue to yield quality ZrC. To evaluate milling time, the BP ratio was reset to 12:1 and using the original 40 grams of starting materials, milling time was set to increase from 3 hours to 10 hours. All samples underwent vacuum, reactive sintering at 1500°C for at least 1 hour. XRD and SEM/EDX of bulk samples were used to analyse the resulting ZrC.

2.2 Creating ZrC-Mo

The second phase of experiments centred on mechanical enhancing the ZrC cermets. Just as in our previous research, we compared ZrC(TUT), synthesised from zirconia by MAS and HEM undergoing reactive sintering, with commercial grade ZrC(CP). With specific focus on ZrC-Mo composites, the goal was to improve upon the brittle, low fracture toughness starting material of ZrC as well as densification and hardness.

The first set of experiments looked at the stand point of using stoichiometric 1:1 molar weights in the following reaction scheme.

$$ZrC + Mo \rightarrow ZrC\text{-}Mo \qquad (2)$$

A series of LEM involved using only ZrC(CP) and Mo at decreasing Mo concentrations from 54.5% - 20% wt. All samples were added ~1% binding agent, a mixture of 1:1 weight organic liquid rubber and paraffin wax during milling. This would ensure quality mould pressing at 100 MPa for making green bulk samples. All green samples were pre-sintered at 1500°C for at least 1 hour before final sintering step. Final sintering up to 1900°C took place at 4°C/min and held for 30 minutes at final temperatures. Sintered samples were polished and examined with scanning electron microscopy energy (SEM) and dispersive X-ray spectroscopy (EDX); density measured with Archimedes' method; and fracture toughness determined using Palmqvist & Median crack equations based on Vickers' indentation under light microscope [9].

3. RESULTS AND DISCUSSION

3.1 ZrC Synthesis

Changing the BP ratio or the milling time for HEM powders of ZrO_2 and graphite and then undergoing subsequent reactive sintering up to 1500°C show no discernable difference in the yield of ZrC(TUT).

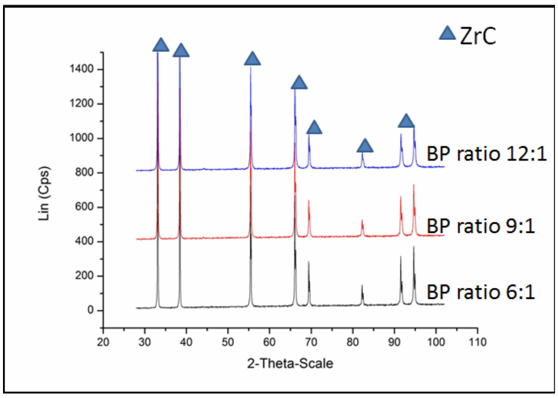

Fig 1: XRD of ZrC(TUT) due to varying BP ratio

XRD patterns (Fig 1) show strong peaks for cubic ZrC even when BP ratio is dropped from 12:1 to 6:1. Fig 2 shows promising results to streamline the synthesis and manufacturing of ZrC, potentially decreasing the amount of energy and time needed to make ZrC. Ideally, the results could indicate ZrC can be manufacture using a parameter of BP ratio 6:1 and in as little as 3 hours HEM.

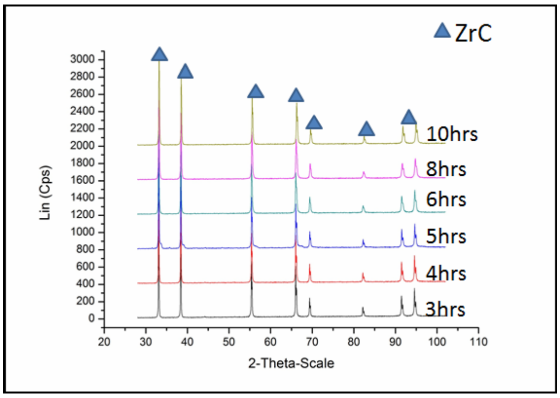

Fig 2: XRD ZrC(TUT) due to increasing milling time

ZrC(TUT) has densified up to ~88% at 1900°C and hardness ~13GPa (Table 1). Adding 1:1 molar Mo does not improve the densification when using HEM, although the results do show evidently higher hardness. This factor may be attributed to the titanium carbide (TiC) and tungsten contaminations from using WC-Co milling container and TiC balls during high-energy milling. However, ZrC(TUT) shows more stability at higher temperatures as it exhibited 25% more densification compared to ZrC(CP). The propensity of Mo to react with the carbon molecule in ZrC makes predicting densification more difficult.

Sintered Cermets	Composition ZrC - Mo	Sintering Temp	Measured Density	Theoretical Density	Densification	Fracture Strength	Vickers' Hardness
elements	*wt%*	*(°C)*	*g/cm ^{3}*	*g/cm ^{3}*	*%*	*MPa*m $^{1/2}$*	*GPa*
ZrC(TUT)	100%	1800	5.68	6.56	86.5	--	13.9
ZrC(TUT)	100%	1900	5.76	6.56	87.8	--	12.7
ZrC(CP)+Mo	45.5% : 54.5%	1800	6.51	8.15	79.8	3.69 , 4.62	16.2
ZrC(CP)+Mo	45.5% : 54.5%	1900	5.06	8.15	62.1	--	4.0
ZrC(TUT)+Mo	45.5% : 54.5%	1800	4.36	8.15	53.4	--	3.0
ZrC(TUT)+Mo	45.5% : 54.5%	1900	6.65	8.15	81.6	1.33 , 1.90	14.4

Table 1: High-energy milled ZrC and ZrC-Mo bulk samples comparing ZrC(TUT) and ZrC(CP); note that fracture toughness is given as palmquist and median crack measurements respectively

Sintered Cermets	Composition ZrC - Mo	Sintering Temp	Measured Density	Theoretical Density	Densification	Fracture Strength	Vickers' Hardness
elements	*wt%*	*(°C)*	*g/cm* ^{3}	*g/cm* ^{3}	*%*	*MPa*m* $^{1/2}$	*GPa*
ZrC(CP)+Mo	45.5% : 54.5%	1800	7.48	8.15	91.8	--	10.1
ZrC(CP)+Mo	60% : 40%	1800	7.27	7.66	94.8	3.55 , 4.32	11.8
ZrC(CP)+Mo	70% : 30%	1800	6.95	7.35	94.5	--	14.2
ZrC(CP)+Mo	80% : 20%	1800	6.67	7.07	94.3	2.98 , 3.70	13.6
ZrC(CP)+Mo	45.5% : 54.5%	1900	7.41	8.15	90.9	--	12.8
ZrC(CP)+Mo	60% : 40%	1900	7.29	7.66	95.2	3.27 , 4.50	15.6
ZrC(CP)+Mo	70% : 30%	1900	7.08	7.35	96.3	--	14.7
ZrC(CP)+Mo	80% : 20%	1900	6.79	7.07	96.1	5.23 , 6.08	16.9

Table 2: Low-energy milling using commercial grade ZrC and decreasing Mo wt% concentrations; note that fracture toughness is given as palmquist and median crack measurements respectively

3.2 ZrC-Mo Synthesis

Since HEM samples have proven to give inconsistent results mostly due to contamination from the milling media, switching to LEM gave more consistent results. Table 2 indicates densification of ZrC-Mo actually increases with decreasing Mo concentration where no more than 40% wt Mo should be used for optimal densification. As well, final sintering temperature also plays a role in densification, hardness, and fracture toughness with the higher 1900°C setting improving all three parameters by 2%, 40%, & 20% respectively.

The inability to achieve full densification is most likely attributed by the lack of liquid formation during sintering [2], which requires temperatures in excess of 2000°C. Fig 3 shows that only 20% wt Mo is enough to create an impressive microstructure with high hardness, 17GPa and densification reaching >96%. Adding more Mo results in a more porous microstructure and lowers overall hardness (Fig 4). Depending on the integrity of ZrC, Mo can compete for the carbon molecule in ZrC to form Mo_2C creating a third phase and leaving spots of free zirconium.

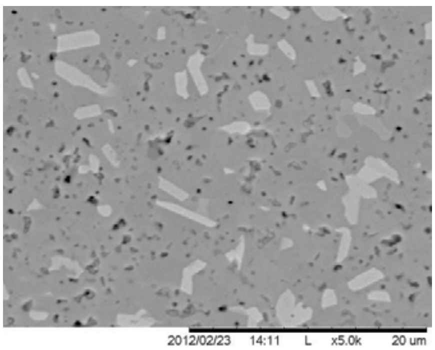

Fig 3: SEM image ZrC-Mo (80%, 20% wt respectively) sintered at 1800°C

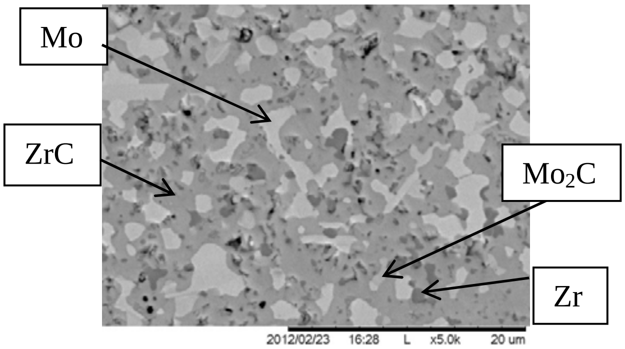

Fig 4: SEM image of ZrC-Mo (70%, 30% wt respectively) sintered at 1900°C

Contrary to previous studies where researchers show fracture toughness increases up to 6.6MPa*m$^{1/2}$ with increasing Mo concentration [4], results in this study seem to conclude the opposite effect. Mo concentration at 20% wt gives a mid-range fracture toughness of ~5.7MPa*$m^{1/2}$. Fracture toughness would actually decrease due to increasing Mo concentration as evident by macro-fractures appearing on all polished samples surface with Mo greater than 20% wt.

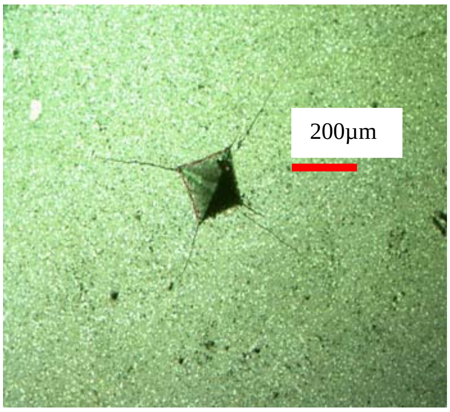

Fig 5: ZrC-Mo (80%, 20% wt respectively) sintered at 1800'C only exhibited microfractures only after indentation impact testing

Fig 5, with ZrC 80% and Mo 20%, displays a typical, expected fracture lines that terminate before reaching a pre-existing grain boundary. However, raise the concentration Mo by just half to 30% wt and macro-fractures become prevalent (Fig 6).

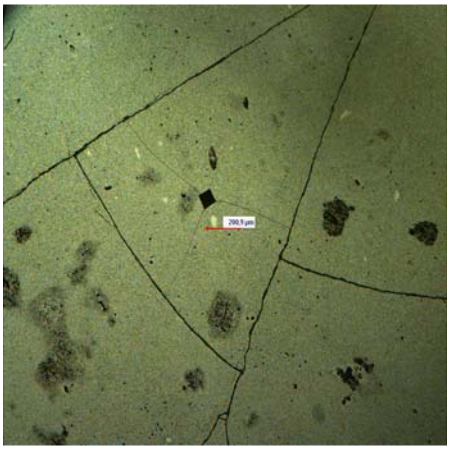

Fig 6: ZrC-Mo (70%, 30% respectively) sintered at 1800'C with easily visible macro-fracture cracks under light microscope with 5X.

It maybe the formation of Mo_2C and resulting remnants of Zr that causes grain boundaries to enlarge during the cooling process after sintering leading to macro-fractures visible to the naked eye.

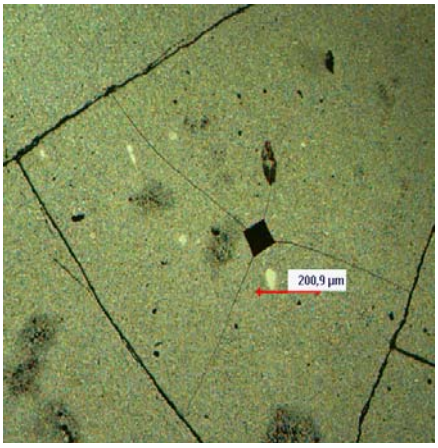

Fig 7: Zoomed in picture of Fig 6. The fractures created by Vickers' indentation extend and terminate at pre-existing boundaries

4. CONCLUSIONS

Based on the study within this work, the following conclusions can be drawn:

1. Synthesising ZrC from ZrO_2 and graphite can be done using high-energy milling and reactive sintering using parameters of 6:1 ball-powder ratio, 3 hours milling time, and 1500°C.
2. Synthesising ZrC-Mo, using low-energy milling and sintering at 1900°C improves densification, hardness, and fracture toughness by 2%, 40%, and 20%, respectively, from 1800°C.
3. To avoid macro-fracture and improve fracture toughness and hardness, using 80%wt ZrC and 20%wt Mo gives the most optimal result.

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