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# METALURGIJA
## METALLURGY

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**60 godina proizvodnje bešavnih cijevi u Hrvatskoj (1952.-2012.)**
**60 years of production of seamless pipes in Croatia (1952-2012)**

51st year

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# THE THEORETICAL AND EXPERIMENTAL RESEARCHES OF PB-AL COMPOSITE MATERIALS EXTRUSION

Received - Prispjelo: 2011-07-18
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Original scientific paper - Izvorni znanstveni rad

The work presents the analysis of the character of a simultaneous plastic flow of composite material of a hard core-soft sleeve structure. Experimental research work using model composite material Aluminium-Lead and theoretical analysis allowed to identify the initial cracking conditions, its character and localization, depending on geometrical parameters of the composite materials and the extrusion ratio value. It has been shown that the higher the parameters' values are, the longer the flawless extruded product is (cracking appears in the further stages of the process).

*Key words:* extrusion, composite Pb - Al, fracture of composite, plastic flow

**Teorijska i eksperimentalna istraživanja ekstruzije Pb-Al kompozitnog materijala.** Članak daje analize karaktera simultane ojačane jezgre i mekše vanjske strukture. Eksperiment je rabio model kompozitnog materijala olovo-aluminij a teorijske analize omogućavaju utvrditi uvjete početnih pukotina, njihov karakter i lokalizaciju, ovisno o geometrijskim parametrima kompozitnih materijala i veličine ekstruzije. Ustrojene su maksimalni parametri vrijednosti ekstruzije bez pojave pukotina (napukline se pojavljuju u idućim stadijima procesa)

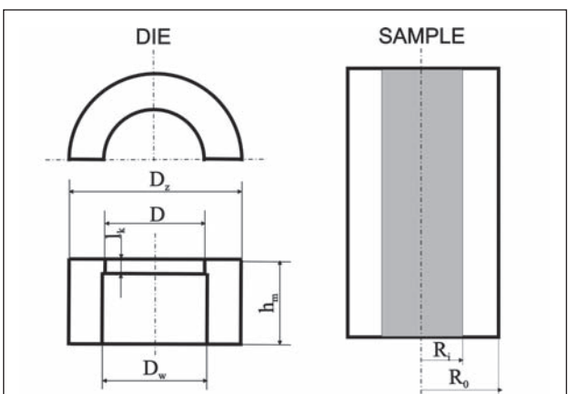
*Ključne riječi:* ekstruzija, kompozit Pb-Al, prijelom kompozita, krivulja plastičnosti

## INTRODUCTION

A fracture phenomenon is a basic factor reducing the material ductility while plastic processing it. Finding out the conditions conducing fracture in given process conditions allows to indicate the method of avoiding the fracture. This problem is of particular importance in the analysis of more complex processes, e.g. simultaneous plastic extrusion of materials of different properties in order to obtain composite material of expected properties [1-3]. The extrusion process of core-sleeve composite materials, such as rods, bars or wire, makes it necessary to search for the possibility of an appropriate core- or sleeve- fracture prognostication. In the simultaneous extrusion process of materials having different properties, deal with diverse component ductility, which cannot be entirely leveled by matching the process parameters because the components' values are so different [4– 6].

## EXPERIMENTAL RESEARCH

Test extrusions, with the use of composite metallic materials, were carried out at a test bench consisting of a hydraulic press equipped with force sensors, ram displacement sensors, a set of tools and a measurement and recording system. A complete set of dies included flat dies to obtain three different reduction degrees of extrusion ratio λ (see Figure 1). The research of the metallic composite extrusion concurrent process was conducted with the use of two-ply samples. The test samples had the form of a core (Al) with a concentric sleeve (Pb). Outer dimensions of the sample are: $D_0$ =36mm, h=72 mm (fastening between core and sleeve -interference fit). Seven kinds of complex extrusion samples have been prepared (Figure 1).




| Parameter | Value |
|---|---|
| $R_i/R_0$ | 0,17; 0,22; 0,28; 0,33; 0,39; 0,44; 0,50 |
| $D_z$ / mm | 36 |
| D / mm | 20,78; 14,70; 10,38 |
| $h_m$ / mm | 20 |
| $l_k$ / mm | 2 |
| $\lambda=D_z^2/D^2$ | 3; 6;12 |

**Figure 1** Geometric arrangement of the dies and samples

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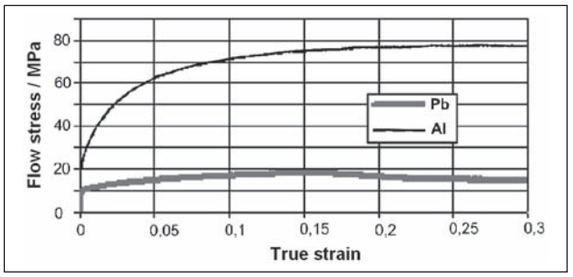


**Figure 2** Stress – strain curves for researched materials indicated in uppsetting test of different geometric parameters samples

Dependence between flow stress and true strain for both materials used in research are shown in Figure 2.

Prior to the extrusion process, the samples were cleaned and sterilized with acetone. In this way, it was possible to determine comparable friction conditions between a container and a batch for all kinds of samples.

## EXPERIMENTAL RESULTS

After the extrusion process was completed, the obtained results were presented in the form of a force versus ram displacement plot. As a result of complex billet extrusion, various products were obtained, which were further cut along their axis in order to enable the observation of inner processes. Exemplary results are shown in Figures 3 to 5. Visible core fracture is caused by the difference between plastic flow speeds of individual composite elements, and a result of which is exceeding acceptable tensile stress of the core material. Performed experimental results of composite material extrusion enabled to determine the beginning of fracture for all examined specimen's geometrical variants depending on the die used, which determined the reduction level of cross section, and also characteristics and information on possible core fracture in the composite being extruded. The results were composed in tabular form (Table 1).

The achieved cross section image correlation of extruded product along with the ram displacement course enables to evaluate:

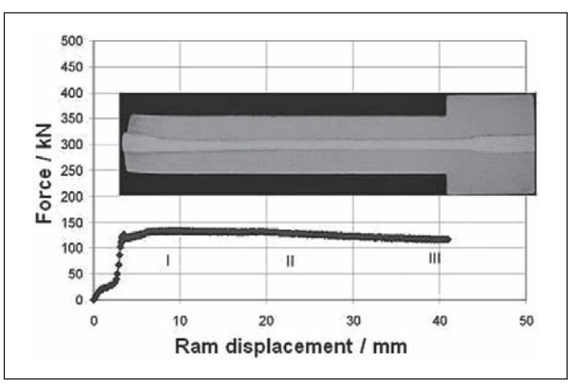


**Figure 3** Force – ram displacement curve. Extrusion of composite Pb-Al, $R_i/R_o$=0,17 λ=3

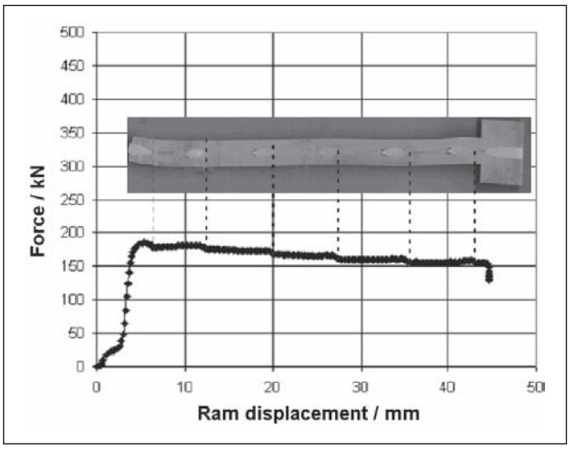


**Figure 4** Force – ram displacement curve. Extrusion of composite Pb-Al, $R_i/R_o$=0,17 λ=6

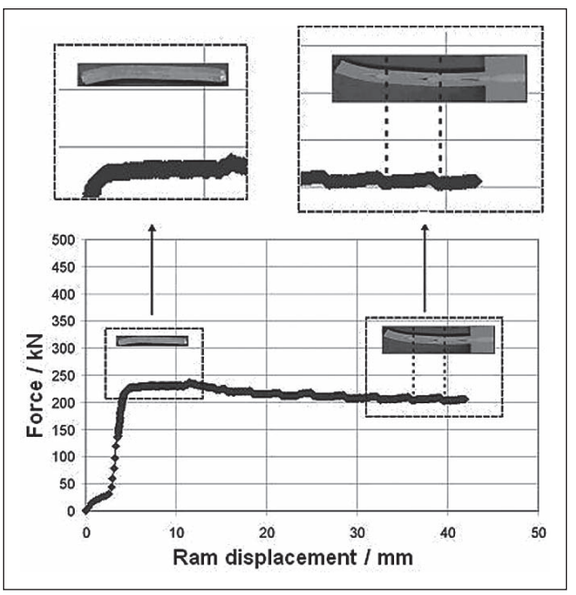


**Figure 5** Force – ram displacement curve. Extrusion of composite Pb-Al, $R_i/R_o$=0,17, λ=12

- the phenomenon of fracture periodicity,
- the values of relevant parameters (a, b, c, d, α ,β, γ c', e, f, $F_H$-$F_L$), which describe the fracture effect (Figure 6).

The experiment revealed that the fracture occurred in average once the 10 % of initial sample length is extruded. The core fracture was not observed in products made with the die of an extrusion ratio λ=3. Based on extruded and cross cut longitudinally composite specimens, the following length measurements were performed: an initial length of core part (a), core fragment length (b) and the distances between them (c, d). The images of the composite samples, extruded and cut along the axis, were compared with the extrusion force versus ram displacement diagrams for individual samples. As a result, a correlation was obtained between parameters describing individual dimensions of the core fragments and the distances between them (a, b, c, d)

Table 1 **Fracture in experimental research. Relative length of extruded sample for beginning of fracture depending on extrusion ratio λ and geometric arrangement of samples**

| λ | $R_i/R_o$ | Relative length of extruded sample /% |
|---|---|---|
| 3 | 0,17 | - |
| 3 | 0,22 | - |
| 3 | 0,28 | - |
| 3 | 0,33 | - |
| 3 | 0,39 | - |
| 3 | 0,44 | - |
| 3 | 0,5 | - |
| 6 | 0,17 | 8,70 |
| 6 | 0,22 | 10,09 |
| 6 | 0,28 | 11,55 |
| 6 | 0,33 | 11,09 |
| 6 | 0,39 | 11,59 |
| 6 | 0,44 | 11,59 |
| 6 | 0,5 | 9,88 |
| 12 | 0,17 | 17,8 |
| 12 | 0,22 | 6,88 |
| 12 | 0,28 | 7,77 |
| 12 | 0,33 | 7,95 |
| 12 | 0,39 | 8,10 |
| 12 | 0,44 | 5,24 |
| 12 | 0,5 | 10,49 |

with the corresponding parameters presented on the extrusion plot (e, f ,c', $F_H$-$F_L$). Next, the parameters measurements were performed, as presented in Figure 6. The measurements were made on a real object, the measurements on graphs were made proportionally in X and Y direction.

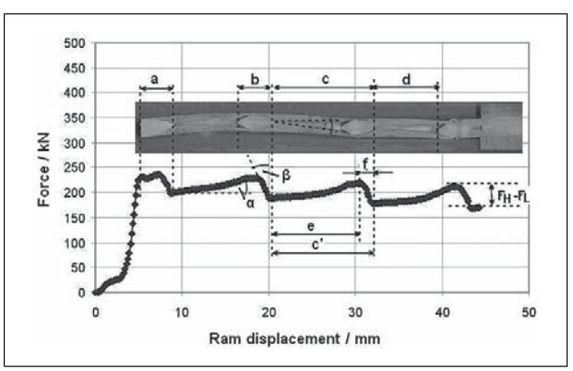


**Figure 6** Scheme of the measurement procedure of the distances between the split core parts, dimensions of the core elements a, b, c, d, and the corresponding distances in the extrusion plot e, f, c', $F_H$-$F_L$

The parameters *b, c, d* clearly increase along with $R_i/R_o$ value increase, in contrary to parameter a (λ=12), which decreases along with $R_i/R_o$ value increase. For the lowest $R_i/R_o$ values the highest values of this parameter were achieved (Figure 7).

Measured extrusion force drops for core fracture in the composite vs. $R_i/R_o$ value reveal that $F_H$-$F_L$ value

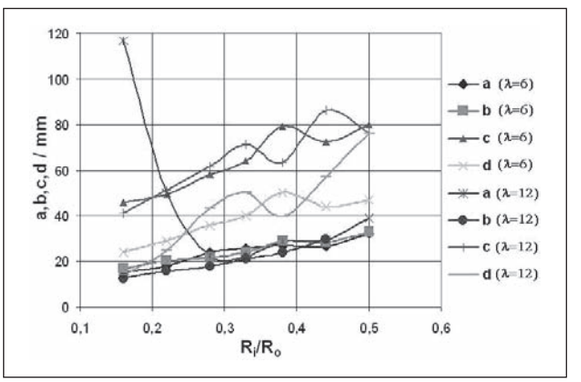


**Figure 7** Dependence between a,b,c,d parameters and $R_i/R_o$ ratio (λ=6, λ=12)

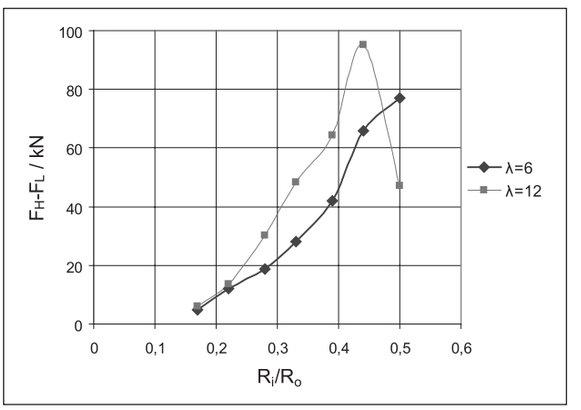


**Figure 8** Dependence between $F_H$-$F_L$ and $R_i/R_o$ ratio (λ=6, λ=12)

(Figure 8) increases along with the core volume ratio expressed as $R_i/R_o$ value.

The c', e, f parameters measurements performed based on extrusion force vs. ram displacement diagram enable to plot the relation of these parameters on the core volume ratio in composite (Figures 9 and 10) expressed as $R_i/R_o$ value. Achieved maximum values of parameters c' and e overlap $D/D_w$ value (presented as a dashed line on figure). The parameter f has an increasing trend.

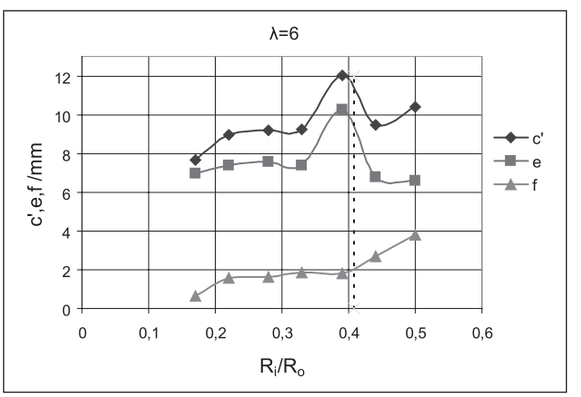


**Figure 9** Dependence between c', e, f parameters and $R_i/R_o$ ratio (λ=6)

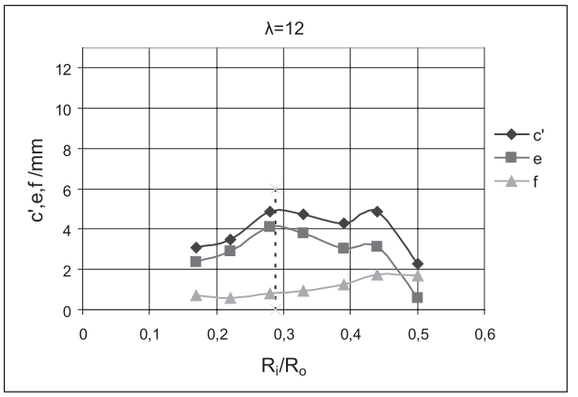


**Figure 10** Dependence between c', e, f parameters and $R_i/R_o$ ratio (λ=12)

Corresponding angles on specimens (α and β - see Figure 6) and on extrusion force vs. ram displacement diagram (γ) were measured and related to $R_i/R_o$ value. These relations were presented on Figure 11. The explicit increasing trend of α angle along with $R_i/R_o$ ratio increase and decreasing trend of β angle were observed. Thę values of γ angle are not changing.

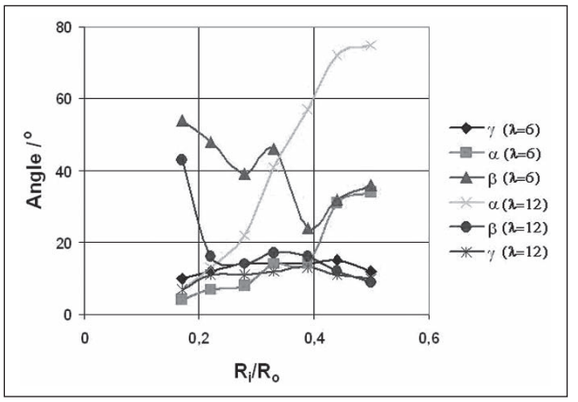


**Figure 11** Dependence between α, β, γ angles and $R_i/R_o$ ratio (λ=6, λ=12)

The researches on composite specimen extrusion revealed force vs. ram displacement data. The experiment performed revealed certain data on beginning of fracture (Table 1) for all examined specimen geometrical variants depending on die used, which determines the reduction level of cross section. Data on characteristics and location of possible core fracture in the composite being extruded were also achieved. It was revealed that the fracture occurred in average once the 10% of initial length of sample is extruded. The used die of extrusion ratio λ=3 allowed to deliver products without core fracture. For other cases, the core fracturing in products was observed. Achieved characteristics of force vs. ram displacement enabled also, comparing to longitudinal section images of products, to gain the correlation between distinctive points of diagram and their image in form of corresponding product parts (Figure 6). Based on extruded and cross cut longitudinally products, the following length measurements were performed: an initial length of core part, core fragment length and the distances between them, relating these values to $R_i/R_o$ parameter value. The relation of parameters a, b, c, d – measurements performed on specimen – to $R_i/R_o$ value (the measure of core volume ratio in composite material) was achieved, which were compared against corresponding parameters measured on an extrusion diagram (e, f, c', $F_H$-$F_L$). Gained characteristics of parameter relations (b, c, d) has an increasing trend. The length of individual core fragments in composite increases along with increasing core volume ratio, thus increases also the distance between these fragments.

The function $F_H$-$F_L$ ($R_i/R_o$) has an increasing trend. This means that an increase of core volume ratio causes an increase of core forming ratio comparing to extrusion force.

The c', e, f parameter measurements performed based on extrusion force vs. ram displacement diagram enabled to plot the relation of these parameters on $R_i/R_o$ value. Achieved relation reveals the maximum (for parameters c', e), which exists for $R_i/R_o$ value convergent to $D/D_w$ value. This means that c' and e parameter value increases in a stepped way for the core diameter convergent to the die orifice, and then further decreases.

Measurements of corresponding angles on each specimen enabled to plot charts depicting the relation of these parameters vs. core volume ratio in the composite. The increasing trend of α angle and decreasing trend of β angle were observed. Along with $R_i/R_o$ value increase, γ angle value stays almost unchanged. The α angle increase is combined with $F_H$-$F_L$ value. The lower the forming force of entire composite (the sleeve and core) and the sleeve, the higher α angle. High β angle indicates slow core separation.

## CONCLUSIONS

The analysis of the character of a simultaneous plastic flow of composite material of a hard core- soft sleeve structure allowed to identify the initial cracking conditions, its character and localization, depending on geometrical parameters of the composite materials, and the elongation ratio value. It was proved that the higher the parameters' values are, the longer the flawless extruded product is (cracking appears in the further stages of the process). The results of this work may substantially improve the modeling of layered composite extrusion processes.

The characterizations of the force curve in the ram displacement function in comparison with the corresponding images of the longitudinal cross-sections of the extruded products allowed for the correlation of the characteristic points in the extrusion plots and their images in the form of the corresponding product parts. Introduced parameters: a, b, c, d, c', e, f, $F_H$-$F_L$ (a, b, c, d – values determined experimentally on the extruded product, c', e, f, $F_H$-$F_L$ – values in the extrusion plot)

allow for an adequate description of the cracking core phenomenon in the extruded composite material.

It was proved that there is a characteristic disturbance in the composite material flow, which results in the tendency to change parameters (c', e) as presented in the extrusion plot. The obtained dependence of parameters c' and e on the $R_i/R_o$ values shows the maximum which occurs for the $R_i/R_o$ value, concurrent with $D/D_w$ value. It shows there is a correlation between the way the composite flows and the batch geometry, in relation to the die opening's dimension.

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# APPLICATION OF THE FLOTATION PROCESS IN THE SILVER RECOVERY FROM THE WASTES GENERATED DURING THE SILVERY SEMI-PRODUCTS MANUFACTURING

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Original Scientific Paper – Izvorni znanstveni rad

In this work, the results of the flotation process application in the silver recovery from the wastes generated during the silvery semi-products manufacturing, are shown. The flotation process parameters, i.e. time of process, rotation frequency, gas flow rate and flotation reagents, were optimized.

*Key words:* silver, flotation, waste, silver, recycled

**Primjena flotacijskog procesa u dobivanju srebra iz otpada nastalog tijekom proizvodnje poluproizvoda od srebra.** U ovom su radu prikazani rezultati primjene flotacijskog procesa u dobivanju srebra iz otpada nastalog tijekom proizvodnje poluproizvoda od srebra. Parametri flotacijskog procesa, tj. vrijeme procesa, frekvencija rotacije, protok plina i flotacijski reagensi bili su optimizirani.

*Ključne riječi:* srebro, flotacija, otpad, srebro, reciklaža

## INTRODUCTION

Lately, the significant development of the technologies dealing with the noble metals recovery from the secondary raw materials, is being observed. Such approach is the economical and ecological necessity, due to the rare occurrence of noble metals' primary raw materials and high energy consumption of their ore mining. Since there exist large diversity of secondary raw materials varying in both metal content and physical form, i.e. electronic elements, joints, catalysts, jewelry wastes, the recovery technique has to be customized for each material type separately [1 - 5].

The flotation process is used in the separation of the grains that posses different wetting ability under the gas, usually air, flow. The main product of this process is the concentrate with higher, comparing to feedstock, content of the desired component [6 -10].

In this work, the results of the investigation of the flotation process as a technique for the silver recovery from the wastes coming from the silver-containing semi-products manufacturing are presented. In the course of work the flotation process parameters, i.e. time of process, rotation frequency, gas flow rate and the type of the flotation reagents were optimized

## EXPERIMENTAL PART

The wastes coming from the final treatment of silver-containing semi-products were investigated. Their

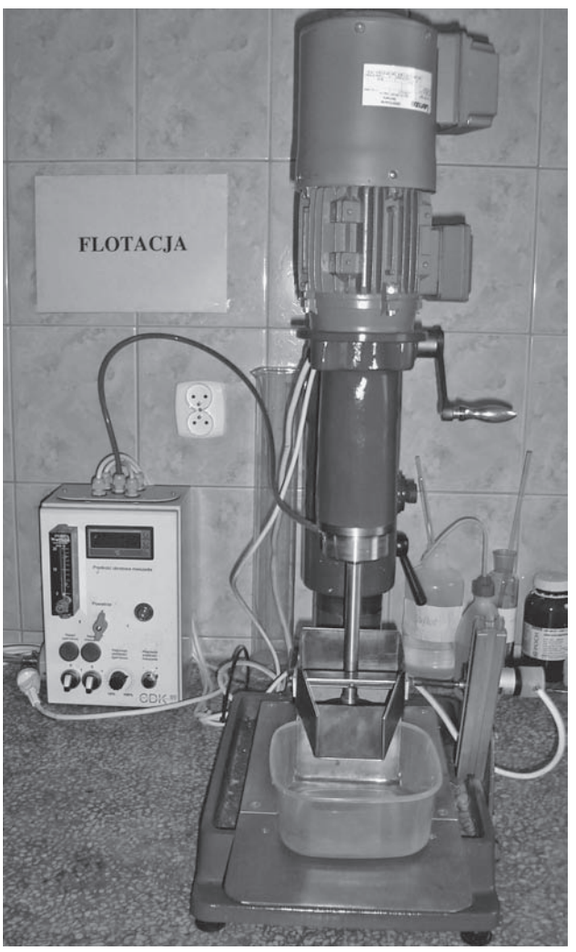


**Figure 1** Laboratory-scale flotation process equipment [1].

B Oleksiak, G. Siwiec - Silesian University of Technology, Department of Metallurgy, Katowice, Poland
A. Blacha – Grzechnik - Silesian University of Technology, Department of Chemistry, Gliwice, Poland

Table 1 **Selected flotation reagents**

| Foaming agent | Collecting agent | pH regulator |
|---|---|---|
| α-terpineol | X-23 | $CuSO_4$ |
| Pine oil | Paraffin oil | |
| Ethyl alcohol | Oleic acid | |
| $Na_2S$ | Sodium amyl xanthogenate | |
| Corflot | Potassium etyl xanthogenate | |
| 4-methyl-2-pentanol, Potassium | | |

composition was determined qualitatively and quantitatively by means of chemical methods. The main components were $Al_2O_3$, $SiO_2$ and silver with the mean content of 10,5 % wt.

The flotation laboratory scale set-up (Figure 1.), that consists of the flotation chamber of 1 $dm^3$ volume, made from the acid-proof steel and height-control rotor with engine, was applied for the wastes components separation. The liquid phase was mixed by both rotor and the air introduced by the compressor connected to the rotor. The rotation frequency was varied between 100 - 1 500 rot/min. The final product was collected mechanically from the surface of the liquid in the chamber during the process.

The effectiveness of the process was checked by monitoring the silver content in the final product and in the residues remaining in the flotation chamber. The analysis was conducted by means of Atomic Adsorption Spectrometer Unikam.

In order to optimize the flotation process parameters, several preliminary tests were run [11 - 13] analyzing the influence of the process time, rotation frequency, air flow rate, type and amount of the flotation reagents, on the final product properties. It was found that the process was the most effective when the rotation frequency

Table 2 **Results of the flotation process conducted on waste coming from silver-containing semi-products for rotation frequency equal to 500 rot/min**

| Flotation agent | Air flow rate / $dm^3$/min | Ag content in flotate / % wt. | Ag content in chamber residues / % wt. |
|---|---|---|---|
| Corflot, oleic acid | 2 | 35,48 | 0,96 |
| | 4 | 47,20 | 0,68 |
| | 6 | 30,74 | 1,22 |
| Pine oil, oleic acid | 2 | 23,99 | 4,06 |
| | 4 | 27,75 | 3,01 |
| | 6 | 25,36 | 3,32 |
| α-terpineol, oleic acid | 2 | 24,73 | 5,61 |
| | 4 | 30,72 | 4,21 |
| | 6 | 26,17 | 5,47 |
| Corflot, Sodium amyl xanthogenate | 2 | 23,17 | 3,74 |
| | 4 | 40,58 | 1,96 |
| | 6 | 20,45 | 3,87 |
| Corflot, Sodium amyl xanthogenate | 2 | 24,41 | 3,74 |
| | 4 | 25,56 | 4,81 |
| | 6 | 18,12 | 6,01 |
| Corflot, X-23 | 2 | 16,31 | 9,71 |
| | 4 | 18,00 | 8,97 |
| | 6 | 16,42 | 8,84 |
| Corflot, paraffin oil | 2 | 18,97 | 10,32 |
| | 4 | 18,99 | 9,30 |
| | 6 | 18,21 | 9,55 |
| 4-methyl-2-pentanol, Potassium / Sodium metyl and ethyl xanthogenate | 2 | 15,32 | 10,17 |
| | 4 | 15,12 | 9,39 |
| | 6 | 13,55 | 9,28 |
| α-terpineol, X-23 | 2 | 16,51 | 9,57 |
| | 4 | 17,08 | 10,06 |
| | 6 | 16,90 | 10,11 |
| Ethyl alcohol, X-23 | 2 | 16,74 | 8,97 |
| | 4 | 17,09 | 8,61 |
| | 6 | 16,62 | 9,74 |
| Corflotu, acrylonitrile | 2 | 16,79 | 9,74 |
| | 4 | 16,97 | 9,39 |
| | 6 | 16,62 | 9,41 |

Table 3 **Results of the flotation process conducted on waste coming from silver-containing semi-products for rotation frequency equal to 700 rot/min**

| Flotation agent | Air flow rate / $dm^3$/min | Ag content in flotate / % wt. | Ag content in chamber residues / % wt. |
|---|---|---|---|
| Corflot, oleic acid | 2 | 23,45 | 0,98 |
| | 4 | 37,54 | 0,54 |
| | 6 | 23,16 | 8,26 |
| Pine oil, oleic acid | 2 | 21,21 | 5,11 |
| | 4 | 24,44 | 3,12 |
| | 6 | 20,38 | 3,72 |
| α-terpineol, oleic acid | 2 | 23,87 | 5,99 |
| | 4 | 28,00 | 4,97 |
| | 6 | 27,10 | 5,06 |
| Corflot, Sodium amyl xanthogenate | 2 | 33,85 | 0,85 |
| | 4 | 31,17 | 1,04 |
| | 6 | 13,43 | 5,07 |
| Corflot, Sodium amyl xanthogenate | 2 | 19,01 | 5,77 |
| | 4 | 20,15 | 5,99 |
| | 6 | 17,12 | 6,28 |
| Corflot, X-23 | 2 | 15,02 | 9,62 |
| | 4 | 14.97 | 9.97 |
| | 6 | 14,07 | 9,09 |
| Corflot, paraffin oil | 2 | 18,00 | 8,97 |
| | 4 | 17,45 | 9,23 |
| | 6 | 17,03 | 9,87 |
| 4-methyl-2-pentanol, Potassium / Sodium metyl and ethyl xanthogenate | 2 | 15,01 | 9,98 |
| | 4 | 15,22 | 9,72 |
| | 6 | 14,55 | 9,38 |
| α-terpineol, X-23 | 2 | 16,43 | 9,06 |
| | 4 | 16,28 | 9,99 |
| | 6 | 15,19 | 9,42 |
| Ethyl alcohol, X-23 | 2 | 17,62 | 8,21 |
| | 4 | 17,21 | 9,84 |
| | 6 | 17,33 | 9,41 |
| Corflotu, acrylonitrile | 2 | 17,23 | 9,09 |
| | 4 | 17,72 | 9,08 |
| | 6 | 17,12 | 9,04 |

was equal to 500 or 700 rot/min, while the air flow rate was between 2 and 6 $dm^3$. The highest silver content in the final product, in comparison to the initial material, was obtained after 15 min of flotation. The further increase in the process time leads to the decrease in the silver content.

The flotation reagents, given in the Table 1, were selected in the preliminary tests as the most promising. In the course of this work, it was found that the best results, i.e. stable foam, were obtained when 2 $cm^3$ of foaming agent was introduced into flotation bath. The formation of the foam was ineffective or too excessive, when the amount of the reagent was reduced or increased, respectively. Moreover, the amount of the collecting agent was balanced to 0.2 $cm^3$ and pH to 8, so the appropriate amount of pH regulator was introduced.

## RESULTS

Tables 2 and 3 present results obtained during the flotation process of the wastes coming from silver-containing semi-products manufacturing.

## CONCLUSIONS

Based on the presented results, we can state that for this type of silvery wastes generated during the semi-product polishing, the highest silver recovery was obtained by applying flotation process with the rotation frequency equal to 500 rot/min and air flow rate equal to 4 $dm^3$/min, with one of the following mixtures of the flotation reagents employed:

- corflot- oleic acid,
- α-terpineol – oleic acid,
- corflot- sodium amyl xanthogenate

The highest silver content in the final product was equal to 47,2 % wt., which was almost fivefold increase in comparison to initial silver concentration. Such product was obtained with corflot as a foaming agent, oleic acid as a collecting agent and process parameters: 500 rot/min and air flow rate equal to 4 $dm^3$/min.

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# BEHAVIOUR OF COARSE GRAIN HEAT AFFECTED ZONE (HAZ) DURING CYCLE LOADING

Received – Prispjelo: 2011-09-27
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Original Scientific Paper – Izvorni znanstveni rad

This paper presents results of a study on martensitic coarse grain heat affected zone that can appear in welded joints. Mechanical properties of martensitic coarse grain heat affected zone and its microstructure were investigated. Special attention was given to its behaviour during the cycle loading under stress concentration. Stress concentration was similar to the one in real welds. The S-N curve and the fatigue limit were determined. The Paris curve and the threshold for crack propagating were also determined.

*Key words:* Weld, coarse grain HAZ, microstructure, mechanical properties, fatigue limit, Paris curve

**Ponašanje grubozrne zone utjecaja topline (ZUT) zavara tijekom cikličkog opterećenja.** U radu se istražuje martenzitna grubozrnata zona utjecaja topline koja se može pojaviti pri zavarivanju. Istražena su mehanička svojstva i mikrostruktura ove zone. Posebna je pažnja posvećena njenom ponašanju tijekom cikličkog opterećenja kada je prisutna koncentracija naprezanja. Koncentracija naprezanja je slična onoj kod realnog zavarivanja. Određena je S-N krivulja i granica umaranja. Također je određena i Parisova krivulja i prag propagacije pukotine.

*Ključne riječi:* Zavar, grubozrnata ZUT, struktura, mehanička svojstva, granica umaranja, Parisova krivulja

## INTRODUCTION

A material is heated locally during an arc welding. Consumable material and a part of a base material are melted and solidified into weld metal during the cooling. The heat input needed for welding increases material temperature in the vicinity of the weld metal. Some microstructure changes appear in high heated area which is not melted. This region is called the heat affected zone (HAZ).

Part of the HAZ that is heated the most is found nearby the weld metal, therefore crystal grains are coarsening during the heating. The coarse grain microstructure, called the coarse grain heat affected zone (CG HAZ), results from this process; see Figure 1.

In some cases, martensitic microstructure can appear in the HAZ, if material contains enough carbon or other elements which increase hardness. The martensitic microstructure is usually hard and brittle with low impact toughness, and is therefore not always convenient for welded joints.

In order to achieve better microstructure, preheating is used before welding and higher heat input is used during welding to reduce cooling speed of heated material. Result of such process is less hard and less brittle microstructure. Heat input does not need to be too high because of grain coarsening and reduce of the HAZ impact toughness. Post weld heat treatment is also used to improve the microstructure, but some types of material do not allow post weld heat treatment like micro-alloyed steels. This is the reason why in some cases martensitic microstructure stays in the HAZ. Taking this into account, stress concentration can appear in welds due to weld toe's shape where inconvenient coarse grain microstructure exists. This region could cause problems especially when welded joint is loaded by cycle loading.

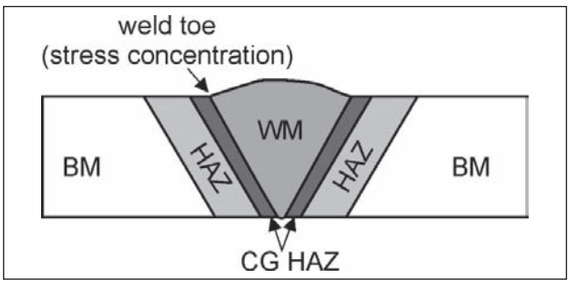


**Figure 1** Welded joint; BM (base material), HAZ (heat affected zone), WM (weld material)

The aim of this study was to assess the 17CrNiMo7 CG HAZ microstructure and properties, and to determine its behaviour during the cycle loading under stress concentration.

## MATERIAL

The steel 17CrNiMo7 was used to prepare samples of CG HAZ microstructure. Chemical composition and

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Table 1 **Chemical composition of the steel (weight / %)**

| C | Si | Mn | P | S |
|---|---|---|---|---|
| 0,18 | 0,22 | 0,43 | 0,012 | 0,028 |
| Cr | Ni | Cu | Mo | Al |
| 1,56 | 1,48 | 0,15 | 0,28 | 0,023 |

Table 2 **Mechanical properties of the steel**

| $R_{p0.2}$ / MPa | $R_m$ / MPa | $A_5$ / % | $Z$ / % | Hardness / HV 10 |
|---|---|---|---|---|
| 489 | 633 | 26 | 72 | 217 |

mechanical properties of the steel are shown in Tables 1 and 2.

## EXPERIMENTAL PROCEDURE

GMAW welding process with low heat input was simulated. The CG HAZ microstructure was investigated. It was prepared by using a weld thermal cycle simulator. The applied weld thermal cycle is shown in Figure 2.

The peek temperature was 1300 °C, the holding time was 3 s on the 1300 °C and cooling time between 800 °C to 500 °C was 5 s. The crystal grains coarsened till 200 μm during simulation. Short cooling time ensured the martensitic transformation.

Fifteen cylindrical specimens with a groove were prepared for rotation bending fatigue tests. The groove in the middle of the specimen causes the stress concentration during loading like a weld toe at real weld [1]. Other authors reported that the stress concentration due to the weld toe was approximately 1,74 [1,2,3] for gas metal arc welding. In order to obtain the same stress concentration in the specimens, the specific geometry of the groove was used.

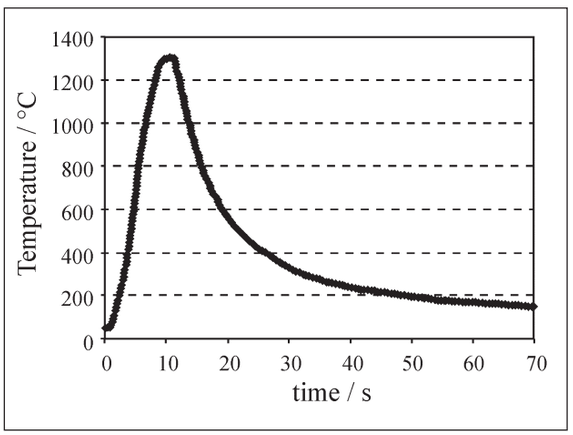


**Figure 2** Influence of weld thermal cycle on CG HAZ material

The groove was designed according to equations suggested by Peterson and Young [4,5]; in that way the theoretical stress concentration factor was calculated by using the equations 1 and 2, when the specimen was loaded by bending.

$$K_t = K_1 + K_2 \cdot \left(\frac{2 \cdot h}{D}\right) + K_3 \cdot \left(\frac{2 \cdot h}{D}\right)^2 + K_4 \cdot \left(\frac{2 \cdot h}{D}\right)^3 \quad (1)$$

The factors $K_1$, $K_2$, $K_3$ and $K_4$ depend on the type of loading (tension, bending, torsion, etc.), $h$ is depth of the groove $(D - d)/2$, $D$ is specimen diameter, $d$ is inside diameter of the groove. In the case of bending loading $K_1$, $K_2$, $K_3$ and $K_4$ are calculated by equation 2 [5].

$$\begin{aligned} K_1 &= 0{,}455 + 3{,}354 \cdot \sqrt{(h/r)} - 0{,}769 \cdot (h/r) \\ K_2 &= 0{,}891 - 12{,}721 \cdot \sqrt{(h/r)} + 4{,}593 \cdot (h/r) \\ K_3 &= 0{,}286 + 15{,}481 \cdot \sqrt{(h/r)} - 6{,}392 \cdot (h/r) \\ K_4 &= -0{,}632 - 6{,}115 \cdot \sqrt{(h/r)} + 2{,}568 \cdot (h/r) \end{aligned} \quad (2)$$

Geometry of the grooved specimens used for this investigation is shown in Figure 3. The groove causes the stress concentration of 1,74 during bending loading.

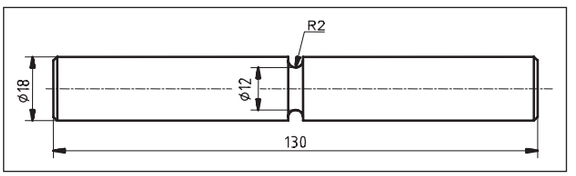


**Figure 3** Specimen for rotation bending fatigue testing

Fatigue tests were done on the rotation bending machine (Amsler UBM 200) in order to obtain a fatigue limit and behaviour of CG HAZ material during cycle loading. Fatigue crack growth tests were done on the Amsler cracktronic machine in order to obtain threshold for crack propagation and Paris curve, and finally, analysis of the microstructure was performed on light and TEM microscopes. Preparation of the samples for TEM microscope is shown schematically in Figure 4. The

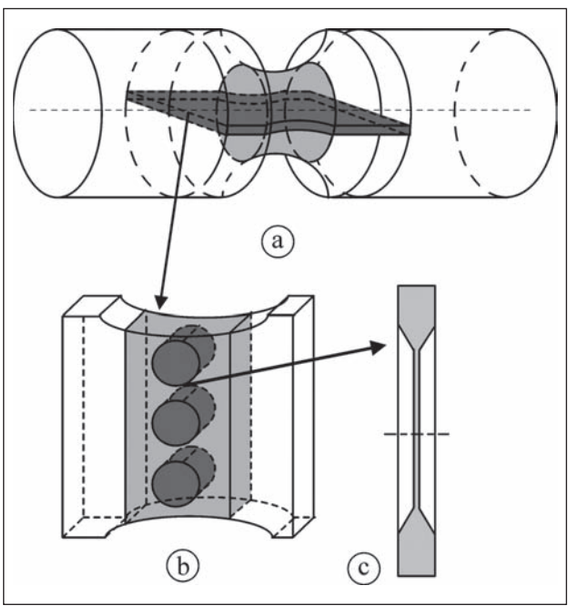


**Figure 4** Preparation of the samples for TEM microscope

CG HAZ material is only in grey region of the specimen (see Figure 4). The samples for the TEM microscope were prepared from this region of the specimen.

## RESULTS AND DISCUSSION

Microstructure was analysed by the light microscope at magnification of 100×. The microstructure consists of laths martensite, as shown in Figure 5. The size of crystal grains is approximately 200 μm.

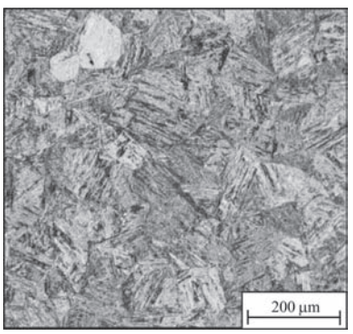


**Figure 5** Microstructure of CG HAZ material; light microscope 100 ×

Details of the CG HAZ microstructure were analysed by the TEM microscope. Builds-up are of long martensitic laths. Their thickness is from 0,25 to 2,5 μm. Laths being 0,6 to 1,1 μm thick predominate, but some small regions of thicker or thinner laths also exist. The martensitic laths are shown in Figure 6a, and the boundary between them is shown in Figure 6b. Dislocation density was measured by a secant method and by using diffraction images from the TEM microscope. Dislocation density is high especially in the vicinity of grain boundary, where $8{,}5\ 10^{14} \pm 2{,}5\ 10^{14}$ m/m$^3$.

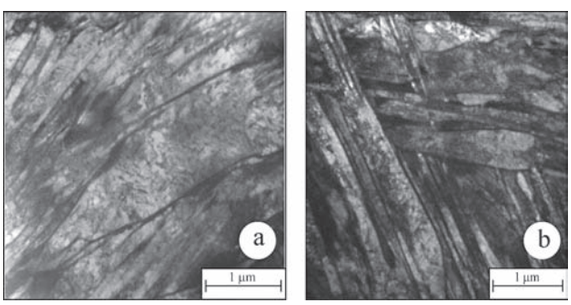


**Figure 6** Martensitic laths microstructure; martensitic laths (a) and grain boundary (b)

## Mechanical properties

Vickers' hardness was measured by using load of 98,1 N on instrumented Zwick machine. Hardness was 455 HV10. Results are shown in Figure 7, presenting the curve force versus depth.

It was not possible to measure the tensile strength and a yield stress by mechanical testing, because simulated HAZ region was too small. They were calculated

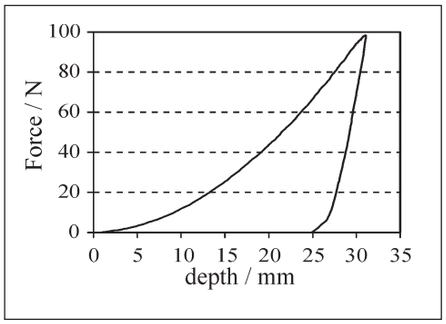


**Figure 7** Curve force versus depth during Vickers indentation

approximately from the hardness by applying equations from the BS 7448-2 [6] and equations proposed by Pavlina and Tyne [7], but in such cases error occurs up to 10%. Equations 3 and 4 refer to the BSI standard and equations 5 and 6 were proposed by Pavlina and Tyne.

$$R_{p0.2} = 3{,}8 \cdot \mathrm{HV} - 221 \quad (3)$$

$$R_m = 3{,}15 \cdot \mathrm{HV} + 93 \quad (4)$$

$$R_{p0.2} = 2{,}876 \cdot \mathrm{HV} - 90.7 \quad (5)$$

$$R_m = 3{,}734 \cdot \mathrm{HV} - 99.8 \quad (6)$$

(HV is the Vickers hardness number)

The yield stress and the tensile stress are presented in Table 3.

Table 3 **Yield stress and tensile strength CG HAZ and base material**

| Material | $R_{p0.2}$ / MPa | $R_m$ / MPa |
|---|---|---|
| CG HAZ | 1271 (1) | 1526 (1) |
| | 1218 (2) | 1599 (2) |
| Steel 17CrNiMo7 | 474 (1) | 761 (1) |
| | 519 (2) | 692 (2) |

(1) BSI 7448-2 standard (equations 3 and 4)
(2) proposed by Pavlina and Tyne (equations 5 and 6)

## Results of fatigue testing

Results of fatigue testing on the rotation bending machine are shown in Figure 8.

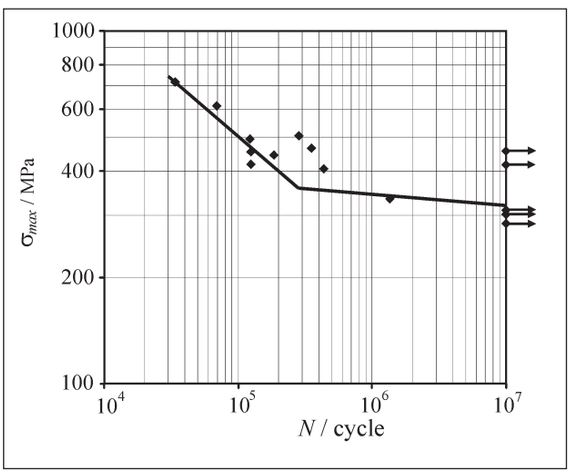


**Figure 8** S-N curve of the CG HAZ

Load ratio R was -1 due to rotation bending. The continuing line represented the S-N curve of the CG HAZ microstructure. The fatigue limit was relatively low, only 330 MPa. This was the lowest stress limit beyond which specimen did not break after 10 million cycles.

## Results of fatigue crack growth test

Specimens of 10 × 10 × 55 mm were used for the fatigue crack growth test. Before starting the experiment, special thin foil crack gauge was attached on one side of the specimen. It was used for measuring the crack propagation during the loading. The 2 mm-long precrack was prepared with the low $\Delta K$. The crack threshold was obtained step by step by reducing $\Delta K$ from $\Delta K$, which was used for precrack creation. Crack threshold was low, only 10,7 MPam$^{0.5}$. Test was continued by increase of $\Delta K$ until the breakage of specimens. Results are shown in Figure 9.

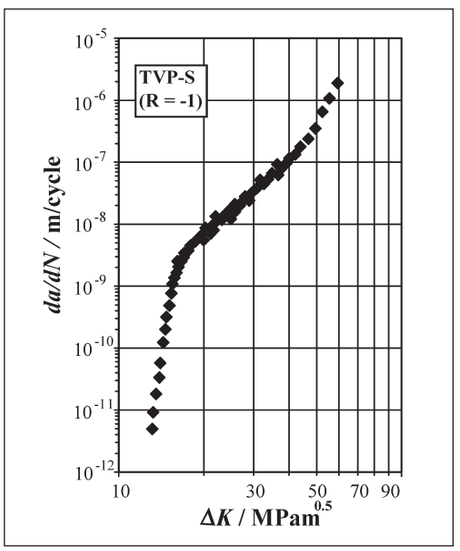


**Figure 9** Paris curve of the CG HAZ material

Obtained Paris curve represents CG HAZ material behaviour in case of crack and speed of eventual crack propagation. Paris law is valid in the middle liner part and is explained by equation 7.

$$da/dN = C \cdot \Delta K^m \quad (7)$$

The constant C is 1,7 $10^{-13}$ and the constant m is 3,6 for CG HAZ material.

## CONCLUSIONS

The CG HAZ microstructure consists of laths martensite. Its hardness is 455 HV 10. The dislocation density at the boundary of the martensitic laths is 8,5 $10^{14} \pm$ 2,5 $10^{14}$ m/m$^3$. The fatigue limit of the CG HAZ material is relatively low, according to its yield stress. It is only on one fourth of the yield stress. If compared to the unaffected base material, it is on two third of its yield stress, which is acceptable for welded joints, because base material fatigue limit will be lower. The threshold for crack propagation is low, being only 10,7 MPam$^{0.5}$.

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# THERMO-MECHANICAL CRACKING OF A NEW AND LASER REPAIR WELDED DIE CASTING DIE

Received - Primljeno: 2011-09-5
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Preliminary Note – Prethodno priopćenje

The paper presents the analysis of thermo-mechanical fatigue cracking of die casting die during industrial use. An innovative, production friendly approach to monitor the surface crack dimensions was introduced, which is based on measuring defect-fin on the casting part. A new four moulds die casting die was monitored 40 000 cycles in order to complete the production series. The production was stopped three times for laser repair welding of cracks since the defect-fins were not acceptable. The defect-fin heights were measured every 1 000 cycles on the castings before and after repair welding of die surface cracks. The in-service die life can be prolonged with laser repair welding for several times, even thought that in-service die life for a particular repair varies.

*Key words:* high pressure die casting, laser welding, thermo-mechanical fatigue cracking, casting defect-fin

**Termo-mehaničke pukotine uslijed toplinskog umora na novom i lasersko zavarenom alatu za tlačno lijevanje.** U radu je prikazana analiza termo-mehaničkih pucanja kalupa za tlačno lijevanje tijekom industrijske upotrebe. Inovativni pristup praćenja dimenzija pukotina je uveden, koji temelji na mjerenju defekata na odljevku. Četiri nova kalupa za tlačni lijev su promatrana 40 000 ciklusa tj. jednu proizvodnu seriju. Proizvodnja je zaustavljena tri puta zbog laserskog zavarivanje pukotina na kalupu, jer su defekti na odljevku bili neprihvatljivi. Visina defekta mjerena je svakih 1 000 ciklusa na lijevanim dijelovima prije i nakon popravka pukotina laserskim zavarivanjem. Životna doba kalupa za tlačno lijevenje može se produžiti s laserskim zavarivanjem više puta, iako produženje životne dobe kalupa zavisi od kvalitete laserskog zavarivanja.

*Ključne riječi:* Tlačno lijevanje, lasersko zavarivanje, termo-mehaničke pukotine uslijed umora, defekti na odljevku

## INTRODUCTION

The in-service life of die casting dies and injection moulding tools is correlated with the thermo-mechanical loads during production. The production of 300000 castings is a common series for die-casting industry and 1000000 mouldings for injection moulding industry [1, 2]. The in-service tool life is affected by (a) thermo-mechanical fatigue, which causes heat marks on the surface of the die, (b) corrosion and soldering of aluminium to the die surface, (c) erosion due to melt flow, and (d) catastrophic failures [1-8].

These defects are then reflected on casting parts as defects-fins, marks or burr. If these defects are in acceptable tolerances for the final product the die casting die is good even thought the surface has cracks or is eroded. If these defects are too extensive, each casting must be refurbished, or the die must be replaced by a new one or the die must be repaired by welding. The optimal choice depends on the series of castings to be produced, deadlines, costs of the new die and/or die repair, costs of workers, equipment, production space … The most economical is usually the repair of the die by weld cladding. The main advantages of repair welding are short downtime and cost efficiency compared to production of new tool part. Repair welding in general lowers the tool cost in the final part and enables higher added value to the die casting and injection moulding industry [9-12].

Good prediction of mould failure using numerical simulations is demanding due to many failure mechanisms that should be taken into account. An innovative industrial approach is presented, where monitoring of defect-fins on casting parts is done during production in order to predict the tool failure. A continuous monitoring of mould surface cracks is not possible during the production. But measuring the resulting defect-fin dimensions on castings is possible and already used during quality control to distinguish between good and bad castings. Measuring of these defect-fins growth could be used to estimate the size of mould defects like thermal fatigue cracks and consequently prediction of mould failure [13, 14].

The aim of this study was to monitor the defect-fins height on castings before and after repair welding of die casting die in order to predict the die in-service life time. A defect-fin height was measured and monitored at four locations on castings every 1000 cycles. Laser repair welding of mould surface cracks was done based on quality control personnel. A comparison between defect-fin growth for a new and laser repair welded mould

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Table 1 **Chemical composition of mould material, filler material and aluminium alloy [15-17].**

| EN | Chemical composition / mas. % | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | Cr | Mo | V | Fe | Cu | Mg | Zn | Ni | Al |
| X38CrMoV5-1 | 0,37 | 0,20 | 0,30 | 5,00 | 1,3 | 0,50 | rest | - | - | - | - | - |
| Filler material | 0,1 | 0,4 | 0,6 | 6,5 | 3,3 | - | - | - | - | - | - | - |
| AlSi9Cu3 | - | 8-11 | 0,55 | - | - | - | 1,3 | 3,0 | 0,5 | 1,2 | 0,5 | rest |

was done. The results show that the in-service life time varies and depends on many factors.

## EXPERIMENTAL WORK

### Die casting die and processing

A four nest die casting die was made of Cr-Mo-V hot work tool steel X38CrMoV5.1 (Table 1). Moulds were hardened at 990 °C and tempered three times at 620 °C, 590 °C and 570 °C to achieve the hardness of 46 HRc (Figure 1).

The dies have run on a 8 MN cold chamber machine in industrial environment. The aluminium alloy Al-Si9Cu3 with the chemical composition shown in table 1 was used for casting. The aluminium alloy AlSi9Cu3 was injected at temperature 680 °C into the mould. The die was closed for 25 s and opened for 35 s and the total cycle time was 60 s. The die was tempered to 200 °C. The die surfaces were lubricated before starting a new cycle. The weight of each casting was 332 g, the casting pressure was 50 MPa, filling time 23 ms and the entrance melt speed was around 52 m/s.

### Laser repair welding

When the quality control manager find defect-fins around 0,35 mm in height, the die casting stopped and dies were sent to repair shop. After cleaning the die, the cracks were either mechanically and laser grooved or only laser grooved in the case of repairing small cracks. During grooving, a special attention was taken in order to fully remove the crack.

Laser beam cladding was done using pulsed 200 W laser equipment (Lasag Easy welder SLS CL 60) and a 0,5 mm diameter filler wire with the chemical composition shown in Table 1.

A ramped down pulse with pulse peak power of 2 kW, repetition rate of 15 Hz, pulse duration of 10 ms and pulse energy of 12,5 J was used for cladding. The welding speed was 16 cm/min, the focal length 160 mm and the focus of laser beam was on the mould surface. The argon gas at 8 l/min was used for shielding. The filler wire was fed manually. After the welding the welds on refurbished mould were manually grinded and polished. The mould was than mounted on a machine where it produced castings to complete the desired series.

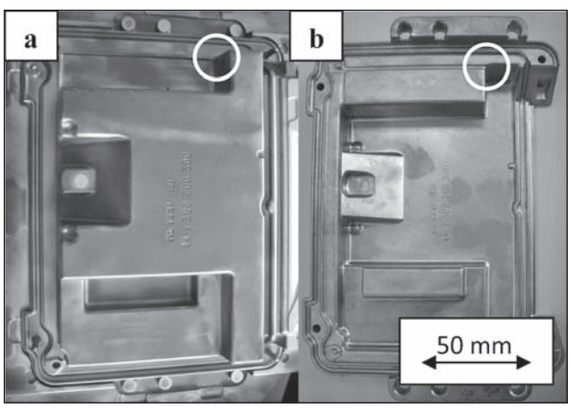


**Figure 1** a) Mould and b) casted part with indicated observed location.

### Defect-fin measurement

Casting defects-fins were measured using the profilometer Mitutoyo Contracer CV - 2000. The measurement stylus was dragged across the castings surfaces and the size and the shape of defect-fin cross-section was recorded (Figure 2). Maximum defect-fin heights (depths) were determined (Figure 2c).

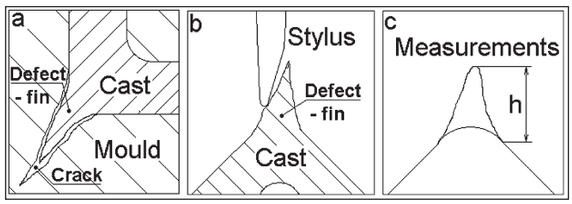


**Figure 2** Schematic presentation of (a) die casting mould and casting, (b) measurement stylus drag across the castings surfaces, and (c) defect's-fin's height.

The measurements were done every 1 000 cycles up to 40 000 cycles at four equal dies on the most critical location in order to get the relationship between crack height and the number of die casting cycles.

## RESULTS AND DISSCUSION

Measurement of the length of thermo-mechanical fatigue cracks on mould surfaces during the actual production run is practically impossible. Approx. measurement of crack length would be possible by sticking thin wires into the crack and measuring the penetration depth [8]. This could not be done without stopping the production. Another more precise way would be by cutting the tool and measuring the crack length on the prepared micro-sections (Figure 3). This is hardly affordable, since the die casting dies are very expensive [9]. Therefore, idea was to measure the defects-fins on the castings [7]. These defects-fins are basically the negatives of the cracks and other surface irregularities on the mould (Figure 1 – 5). The basis for this idea is that in industrial practice the tool fails when the mould starts to produce castings with defects-fins, which are no longer acceptable for the final product. In fact, the size of the casting defect-fin is a bit different from the corresponding mould defect-crack (Figure 3). The cause for this

deviance could be in detection possibility of relatively wide cracks that are filled with melt during die casting. The thinner parts of cracks that can not be filled up are undetectable by this method of monitoring (Figure 3). Nevertheless, our innovative monitoring method can be used to continuously monitor the condition of die casting die in order to estimate and predict the time for changing or repairing the mould.

Figure 4 shows a complete history of defect-fin depth over the in-service lifetime of monitored die casting die. The die casting process was stopped there times for laser repair welding during the production of 40 000 cycles. First repair welding was done after completion of 14 000 cycles on moulds two and three. The reason for stopping and repairing the die was because the defect-fin depth (height) exceeded the unacceptable limit by a factor of two. At this time the crack was also repaired on the mould 3, which experienced a fast crack growth i.e. defect-fin growth at the beginning of die casting (Figure 4). A second stop of production was done after completing 28 000 cycles (Figure 4). At this time the moulds one, two and four were subjected to a laser repair. Shortly after that at 34 000 cycles the production stopped and the mould four was refurbished for the second time, after only 5 000 cycles (Figure 4). The reason for that could be in joining of two adjacent cracks, which joined together and produced a surface material in-between to be removed (Figure 3b). This mechanism of tearing of material between the cracks due to closeness is schematically presented on the figure 3b and 3c. Figure 3b shows two adjacent cracks which are growing together. If such surface cracks are subjected to additional thermo-mechanical cycling, the two cracks meet and the material in-between is removed from the surface. This causes tearing of material between the cracks due to closeness, which is causing widening of surface crack (Figure 3c).

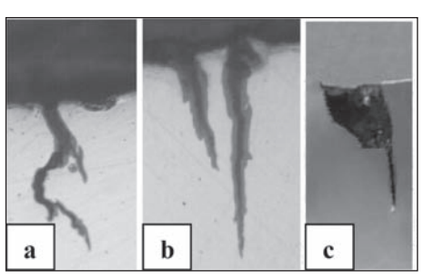


**Figure 3** Typical thermal fatigue cracks.

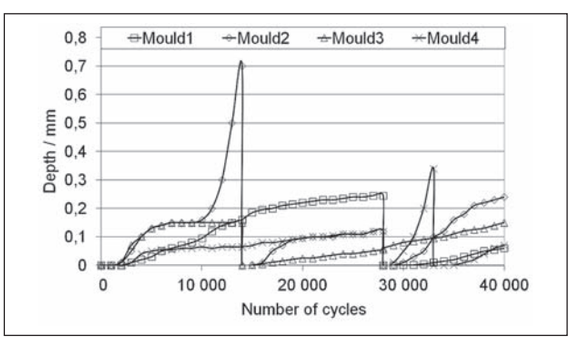


**Figure 4** The depth of defect-fins throughout the die lifetime.

Figure 5 shows defect-fins on castings after a) 9 800 cycles and b) after 22 500 cycles. The observed location on mould 2 experienced fast crack growth shortly after 10 000 cycles (Figure 4 and 5a). The reason for that is in widening of surface crack due to joining of two adjacent cracks seen on Figure 5a. At casting from mould 4 only one small defect-fin is observed (Figure 4 and 5a), whereas at castings from mould 2 two bigger defect-fins are observed at 9 800 cycles (Figure 5a and 4). The moulds 2 and 3 were laser repaired after 14 000 cycles. After 22 500 cycles the cracks on the mould 2 have grown fast at the beginning and than steadily proceeded with growth. On castings form mould 2 two defect fins can be observed (Figure 5b). The laser repair done at mould 3 was very good, since a slow and steady crack growth is observed (Figure 4). Even at casting (Figure 5b, mould 3) a defect-fin is hardly observed.

As we mentioned, there are many factors influencing the crack i.e. defect-fin growth and even a few more if we are considering laser repair welding of tools. Usually a fast crack growth is observed when crack widening appears, i.e. when two adjacent cracks joins or meet. On repair welded moulds a faster crack growth could appear due to a) fatigue material or b) faulty repair (Figure 6a). In both cases removing of more material would be beneficial. Faulty repairs could happen if the surface cracks are going zigzag (Figure 3a and 6a) or are long

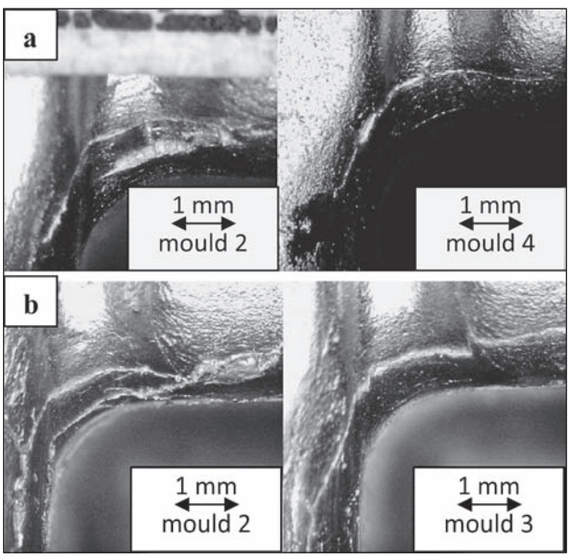


**Figure 5** Defect-fins on observed location on castings after a) 9 800 cycles (mould 2 and 4) and b) after 22 500 cycles (mould 2 and 3).

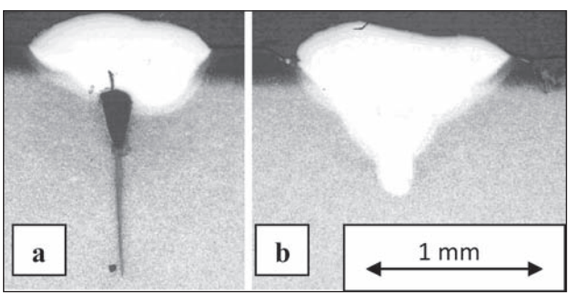


**Figure 6** a) Faulty and b) quality repaired surface crack.

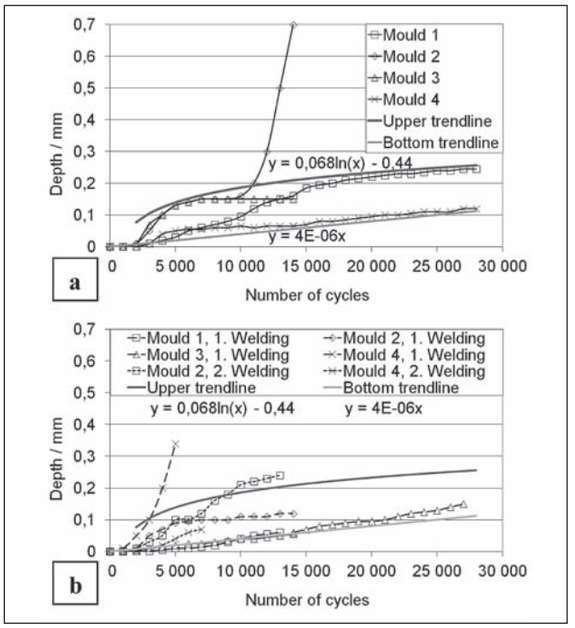


**Figure 7** Defect-fin growths vs. number of cycles for a) new and b) repaired die.

(Figure 3b). In both cases after grinding and before laser repair welding the crack is not visible. If laser repair welding is done on the filthy crack, small cracks or porosity could appear in the weld metal. If this is not observed during the repair, a crack could quickly be opened (Figure 7b, mould 4, 2 welding).

Figure 7 shows defect-fin growths vs. number of cycles for a) new and b) repair welded die casting die. In both plots upper and bottom trend line is drawn and their equations are written. The area between this two trend lines indicates the frame of crack growth rate, where the majority of cracks will appear (for this tool material, heat treatment, die casting parameters, mould design and particular location with notch effect). If the crack growth rate is closer to the bottom trend line, the crack grow is slower and the mould lasts longer. If the crack growth rate is faster, it is closer to the upper trend line. If the crack growth rate exceeds the upper trend line (very fast) two adjacent cracks has most probably grew together, which caused crack widening.

## CONCLUSIONS

Laser repair welding of damaged die casting die is appropriate technology for elimination of surface irregularities as cracks.

The following conclusions can be summarized:

- The crack growth rate for particular location and mould could be predicted to be between upper and lower trend line (Figure 7).
- If the crack grows at faster rates than indicated with upper trend line, two or more adjacent cracks joined and merged and caused the removal of surface material in-between the cracks.
- With the proper laser repair of damaged mould, the mould life could be extended for the same period or even more, and the repair could be done several times.
- If the repair is not done correctly, the extending of the mould lifetime is very short.

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**Note:** The responsible translator for English language is Urška Letonja, Moar.Prevajanje, Slovenia.

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# COMPARISON OF MECHANICAL PROPERTIES OF SURFACE LAYERS WITH USE OF NANOINDENTATION AND MICROINDENTATION TESTS

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Preliminary Note – Prethodno priopćenje

The objective of the paper is a mutual comparison of different methods for evaluation of mechanical properties of surface layers. Mechanical properties were tested with the use of nanoindentation and microindentation tests. Different loads and constant deformation speed were used in both cases. For the evaluation of mechanical properties, the AISI 304 type Chromium-Nickel steel commonly used in mechanical engineering industry was tested. Knowledge of relations and differences between nano and micromechanical properties is necessary for understanding of mechanical processes continuously occurring in surface layers during cutting processes.

*Key words:* nanohardness, microhardnesss, abrasive water jet, Chromium-Nickel steel

**Usporedba mehaničkih svojstava površinskih slojeva pomoću testova nano i mikro utiskivanja.** Cilj rada je međusobna usporedba različitih metoda za ocjenu mehaničkih svojstava površinskih slojeva. Mehanička svojstva su ispitivana pomoću testova nano i mikro utiskivanja. U oba slučaja su korištena različita opterećenja i konstantna brzina deformacije. Za ocjenjivanje mehaničkih svojstava je korišten krom nikl čelik (AISI 304 tip) koji se vrlo često primjenjuje u strojarstvu. Poznavanje međusobnih odnosa i razlika između nano i mikro mehaničkih svojstava je važno za razumijevanje procesa koji se događaju na površinskim slojevima tijekom procesa rezanja materijala.

*Ključne riječi:* nanotvrdoća, mikrotvrdoća, rezanje vodenim mlazom, krom-nikl čelik

## INTRODUCTION

With development of modern measurement methods [1-5], there is a growing demand for research on mechanical and tribological properties of surface layers of materials.

The trend is given by growing requirements for quality in engineering applications (final quality of prepared surfaces, tribology, contact loading, wear resistance, corrosion resistance, etc.). Nanoindentation and microindentation tests represent an important tool for evaluation of mechanical properties of surface layers. These measurements techniques are based on the principle of immediate load recording during the penetration of an indentation tip into a material surface (Figure 1). Based on the known geometry of indentation tip, it

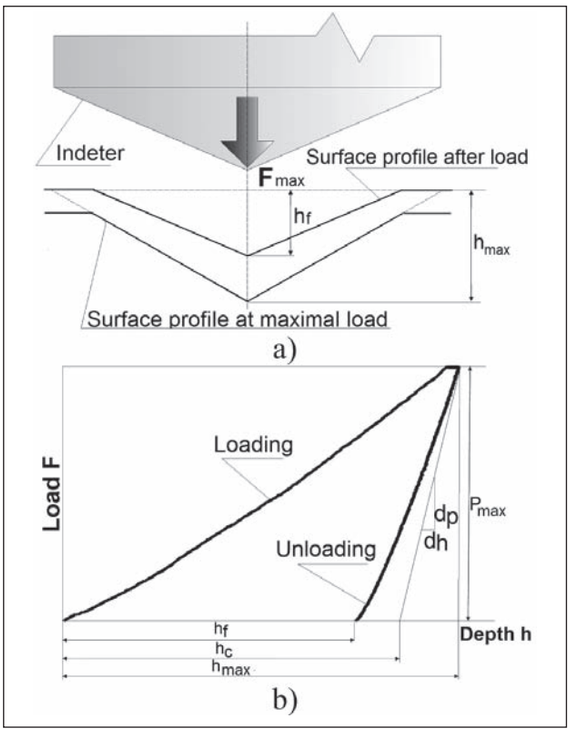


**Figure 1** Principle of indentation test a) penetration of indentation tip into material surface, b) courses of loading and unloading curves

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is possible to determine the elasticity modulus and hardness of surface layers.

Berkovich and Vickers indenters are commonly used indenters for indentation experiments. The Berkovich indenter is a three-sided pyramid with the same depth ratio as the four-sided Vickers pyramid. Typical geometry of both indenters is shown in Figure 2. The geometric relationship between the indenters is given in Table 1.

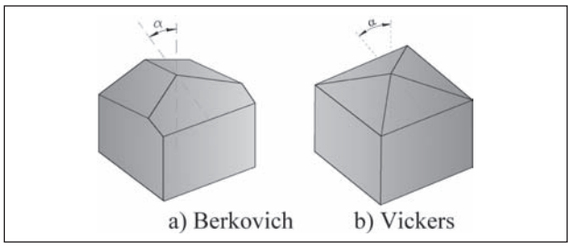


**Figure 2** Geometry of indenters

Table 1 **Geometric relationship of indentors**

| Indenter type | Projected area | Angle |
|---|---|---|
| Berkovich | A= 24,56.$h_c^2$ | 65,3° |
| Vickers | A= 24,504.$h_c^2$ | 68° |

Oliver and Pharr's metodology was used for evaluation of indentation hardness and elasticity. The hardness can be calculated using following formula for a Berkovich indenter [1]:

$$H_{INT} = \frac{P_{\max}}{A(h_c)}, \quad (1)$$

where $P_{max}$ is the maximum load, $A$ is the projected indentation area, $h_c$ represents the contact depth which is determined according to the Formula

$$h_c = h_{\max} - 0{,}75 \times \frac{P_{\max}}{S}, \quad (2)$$

where $h_{max}$ is the maximum indentation depth and, $S$ is the contact stiffness. The elastic modulus E of a material is calculated from $E_r$ using the reduced modulus of an indenter according to the formulas 3 and 4.

$$\frac{1}{E_r} = \frac{1-\nu^2}{E^2} \cdot \frac{1-\nu_i^2}{E_i^2} \quad (3)$$

$$E_r = \frac{\sqrt{\pi}}{2\beta} \cdot \frac{S}{\sqrt{A}} \quad (4)$$

where $\nu$ is the Poisson's ratio for the test material, and $E_i$ and $\nu_i$ are the elastic moduli and the Poisson's ratio of the indenter [1,3] .

## CURRENT STATE OF PROBLEM

The mechanical preparation of surfaces created by conventional methods of cutting is always accompanied by heat load, which can change the mechanical properties in surface layers. The subject of our research was a comparison of mechanical properties of surface layers by nanoindentation a microindentation tests. We try to use abrasive water jet technology for primary cutting of samples because this technology represents cold, precise and computer-controlled shape cutting without any thermal strain. Minimal heat loading of material to be cut is the main advantage of this technology. Surface of samples prepared by AWJT was subsequently grinded and polished using abrasive paper and diamond suspension. The measurement accuracy of the mechanical properties of surface layers usually depends on the quality of surface preparation and wear of an indentation tip [1-5].

## EXPERIMENTS

AISI 304 stainless steel was chosen as an initial material for the realization of experiments. This material is commonly used in various fields of industry and it is characterized by medium strength, good corrosion resistance, good maintenance and relatively low cost. The The chemical composition of the AISI 304 is given in Table 2.

Table 2 **Chemical composition of AISI 304 alloy, wt. / %**

| Element | C | Mn | Si | P | S | Cr | Ni |
|---|---|---|---|---|---|---|---|
| AISI 304 | 0,08 | 2 | 0,75 | 0,04 | 0,03 | 18,0<br>20,0 | 8,00<br>11,00 |

An AISI sample with a square cross-section of 10 x 10 mm and height of 5 mm was made by abrasive waterjet cutting technology with the use of a PTV Ltd. company device (Figure 3). After cutting, the sample was grinded and polished using the Struers Tegra Pol 35 device (Figure 4). Sandpapers with grain sizes of 320, 800, 1 000 and 1 200 μm were used for grinding. The pressure force was set to 10N and rotation speed of 200 $min^{-1}$ was used. Subsenquently the sample was polished using polishing diamond suspense with the grain size of 3μm and 1μm.

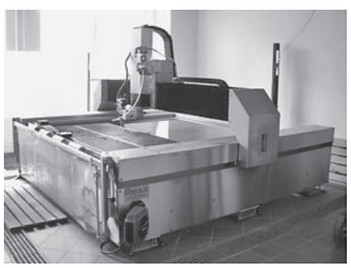

**Figure 3** PTV CNC WJ2020 device for sample cutting


**Figure 4** Struers Tegra Pol 35 device for sample grinding and polishing

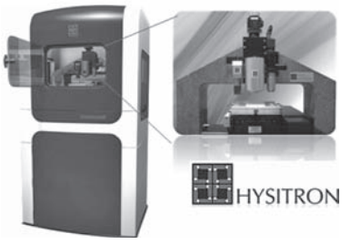


**Figure 5** Hysitron Triboindenter TI 950 device used for measurements of nanomechanical properties

**Figure 6** CSM Microhardness tester device used for measurements of micromechanical properties

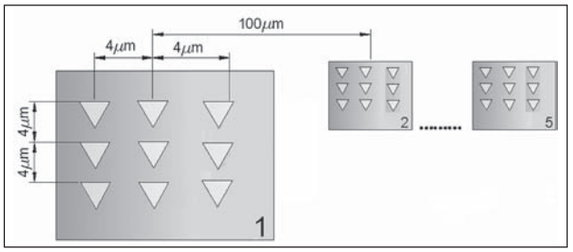


**Figure 7** Schematic plan of micro- and nanoindentation on surface of tested sample

Indentation tests were performed on the Hysitron Triboindentor TI 950 (Figure 5) and on the CSM microhardness tester instruments (Figure 6).

The nanoindentation tests were realized with a Berkovich tip and microindentation tests with a Vickers tip. The nanoindentation testing was performed with different forces of 1 000, 1 250, 1 500, 1 750 and 2 000 μN. Forces of 1 000, 1 250, 1 500, 1 750 and 2 000 mN were used in microindentation tests. Velocities of indenters penetration into the material surfaces were 400μN·min$^{-1}$ and 40 μN·min$^{-1}$. The total number of 45 indents in regular distances of 4 μm were done in 5 areas of testing in 100 μm distances. A schematic plan of indentation is presented in Figure 7.

## RESULTS

Calculations of the hardness and elasticity modulus were made using formulas (1-4) based on performed indentation tests, measured data and results of calibration. The analyses were made automatically in user's softwares which are parts of measurement devices. The calculation was carried out for selected indents, which were not influenced significantly by the quality of surface preparation. The resulting indentation curves are given in Figure 8 and Figure 9.

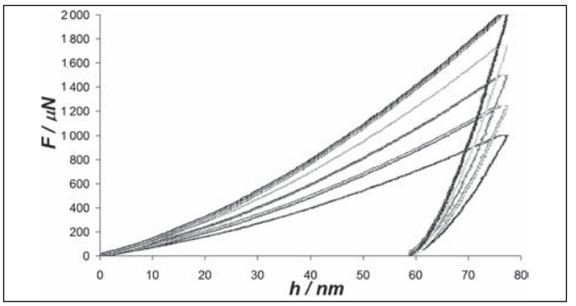


**Figure 8** Courses of nanoindentation curves

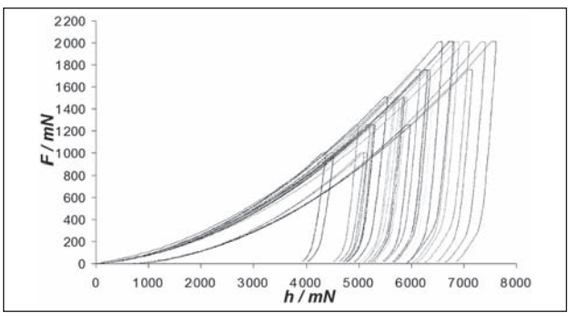


**Figure 9** Courses of microindentation curves

Good equality between loading and unloading curves by the same forces is illustrated in Figure 8 was achieved. Analysis of all forces was made according to the matrix consisting of 9 indentation imprints. The indentation depth differs from 58 to 60 nm. The courses of microindentation curves in Figure 9 show significant differences. They were caused by plastic deformation and size of applied forces (they were 1 000 x higher in comparison with nanoindentation tests). Possible reasons of these differences are various mechanical properties occuring in the middle and on the border of a grain with metallic structure. The indentation depth ranges from about 4 000 to 7 000 nm. Figure 10 illustrates the scatter plot relating elasticity modulus and hardness from both methods of measurements. Similar dispersions of the elasticity modulus values are shown in the graph. The final value varies statistically from 165 to 175 GPa.

Figure 11 represents the comparison of mechanical properties for selected loading forces. As can be seen in

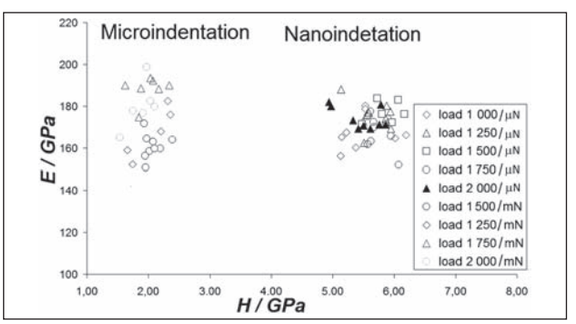


**Figure 10.** Ratio between elasticity modulus and hardness

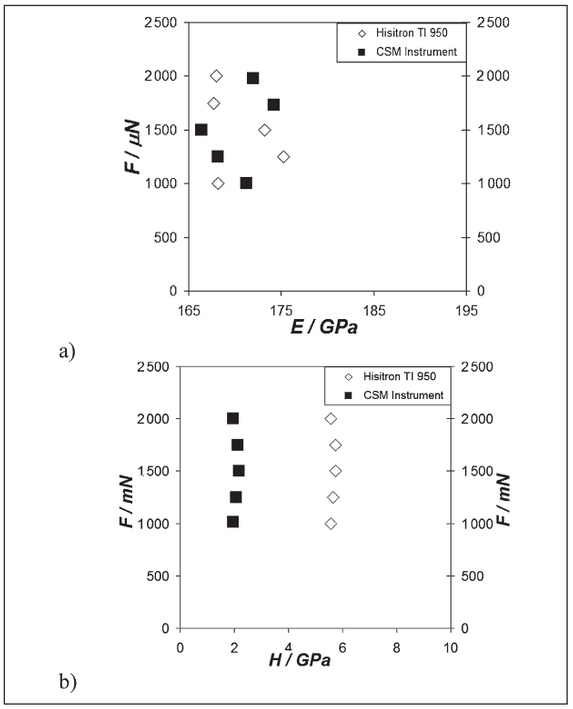


**Figure 11** Comparison of mechanical properties for selected forces a) elasticity modulus b) hardness

Table 3 **Results of mechanical properties**

| F/µN | Nano-hardness | SD | F/mN | Micro-hardness | SD |
|---|---|---|---|---|---|
| 1 000 | 5,55 | 0,13 | 1 000 | 2,10 | 0,20 |
| 1 250 | 5,65 | 0,08 | 1 250 | 2,07 | 0,07 |
| 1 500 | 5,74 | 0,24 | 1 500 | 2,17 | 0,16 |
| 1 750 | 5,73 | 0,19 | 1 750 | 2,12 | 0,16 |
| 2 000 | 5,56 | 0,16 | 2 000 | 1,95 | 028 |
| F/µN | Elasticity modulus | SD | F/mN | Elasticity modulus | SD |
| 1 000 | 168,17 | 0,27 | 1 000 | 171,26 | 0,35 |
| 1 250 | 175,25 | 0,10 | 1 250 | 168,12 | 0,24 |
| 1 500 | 173,22 | 0,22 | 1 500 | 166,36 | 0,17 |
| 1 750 | 167,73 | 0,15 | 1 750 | 173,82 | 0,37 |
| 2 000 | 167,95 | 0,31 | 2 000 | 172,18 | 0,19 |

the graphs, the value of applied loading force does not influence final values of elasticity modulus and hardness.

A very interesting fact was the presence of two ranges of the hardness value in areas of about 2 GPa and 6 GPa, respectively. Lower hardness values were obtained with the use of microindentation tests (see Figure 11 b). This result can be influenced by higher mechanical deformation in nanolayer occurring during interaction of abrasive particles with the basic plane. An indentation tip penetrates during the microindentation deeper into the surface layer witch is not influenced by mechanical load as the nanolayer. All results obtained from both measurements are summarized in Table 3.

## CONCLUSION

The paper presents results acquired during the evaluation of mechanical properties of surface layers using the AISI 304 type Chromium-Nickel alloy in the nanoindentation and microindentation tests. To eliminate heat load during sample preparation, the abrasive water jet technology was used to prepare sample. Subsequently, the sample was grinded and polished. To evaluate the properties, different forces were used as described in results. The nanonindentation measurement was accompanied by creation of elastic deformation, and microindentation measurement was accompanied by creation of plastic deformations. The results from both measurements are given in the Table 3. Comparing the elasticity modulus, good equality of both measurements was achieved. According to the Figure 11 b, the values of hardness different. The hardness in microindentation tests is more than 3x lower in comparison with nanohardness. It proves higher mechanical hardness in nanolayers. One of possible applications of these measurement methods is the evaluation of mechanical properties of steel layers during interaction with pulsed water jet. It would be possible to influence (control) the quality of mechanical properties in surface layers on the basis of known technological parameters of pulsed water jet.

## Acknowledgments

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# INCREASING OF HOT WORKABILITY OF 1.3302HIGH SPEED STEEL

Received – Prispjelo: 2011-11-18
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Preliminary Note – Prethodno priopćenje

Laboratory investigation of hot workability of 1.3302 high speed steel was carried out and its improving was achieved. Hot compression tests for the determination of optimal soaking temperature as well as for the study of hot workability in temperature range 1150-850 °C, strain rates range 0,001-6 $s^{-1}$ and applied strain up to 0,9 were performed. Microstructure of deformed specimen was analyzed. Apparent activation energies for hot working for upper and for lower temperature range were calculated. Onsets of dynamical recrystallization for applied deformation conditions on the basis of calculated strain hardening ratewere determined. Extending of hot working temperature range at its lower limit, i.e. down to 850 °C, by applying optimal soaking temperature was obtained.

*Key words:* 1.3302 HSS,hot compression, dynamic recrystallization, strain hardening rate

**Poboljšavanje svojstava brzoreznog čelika 1.3302 u vrućem stanju.** Data su laboratorijska istraživanja prerađivačkih svojstva brzoreznog čelika 1.3302 u vrućem stanju koji su doprinijeli poboljšanju tih svojstava. Izvedeni su pokusi vrućeg sabijanja za određivanje temperature zagrijavanja kao i prerađivačkih svojstva u temperaturnom rasponu 1 150-850 °C, brzinom deformacije 0,001-6 $s^{-1}$ i stupnja deformacije do 0,9. Analizirana je mikrostruktura deformiranih proba.Izračunane su prividne aktivacijske energije za vruću preradu za gornje i donje temperaturno područje. Počeci dinamičke rekristalizacije za primijenjene uvjete deformacije utvrđeni su na temelju izračuna brzine deformacijskog očvršćavanja. Primjenjujući optimalno temperaturu zagrijavanja dobiveno je povećanje vrućeg radnog temperaturnog raspona na svojoj donjoj granici, odnosno do 850 °C.

*Ključne riječi:* 1.3302 HSS, vruće sabijanje, dinamična rekristalizacija, brzina deformacijskog očvršćavanje

## INTRODUCTION

High speed steels (HSS), and also other tool steels, are in their applications subjected to high mechanical, thermal, tribological and chemical loads. HSS are highly alloyed with Cr, W, Mo, V, etc., i.e. carbide forming elements; the following types of carbides are usually present: MC, $M_2C$,$M_6C$, $M_7C_3$, and $M_{23}C_6$. During heating, soaking and hot deformation, various processes regarding the carbides take place in the steel, i.e. decomposition, dissolution, formation as well astheir growth and coarsening. The type of carbides, their quantity, morphology, shape and size depend on the chemical composition of steel and processing parameters, e.g. casting temperature, solidification rate, soaking temperature and time.Carbides in the steel improve hardness, strength and wear resistance. However, they also cause decreasing of hot workability, i.e. they narrow temperature range of safe deformation in comparison to other steels,[1-5]. The upper limit of the temperature working range is related to the occurrence of incipient melting of eutectics and phases with low melting point on grain boundaries as well as to grain growth. On the other hand,the lower limit of safe hot working range is related to precipitation of secondary carbides, characteristics of primary carbides in the matrix and/or on grain boundaries as well as to decreased recrystallization rate. Thus the microstructure of HSS consists of a martensitic matrix with ledeburitic and secondary carbides. However, to predict thebest hot working parameters and final microstructure, a detailed understanding of interactions between hot deformation behavior, softening mechanisms (recrystallization and recovery), and phase transformations is necessary, [5-9].

HSS 1.3302 is used for special tools such as tufting knives and loopers, slot cutters, blades, etc. Demands for hot rolling of profiles with small dimensions are expressed by the industry,which also leads to final hot rolling at lower temperatures as usual. In this paper, optimal soaking temperature for hot working of this HSS was investigated. Hot compression tests at various temperatures (also bellow 900 °C) and strain rates were also performed. Initial dynamic recrystallization (DRX) for selected strain rate and temperature was determined by means of strain hardening rate.

## EXPERIMENTAL PROCEDURE

Hot workability of 1.3302HSS was examined using cylindrical hot compression tests. The cylindrically shaped specimens ($\Phi$10 mm × 15 mm)taken from soft

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annealed square billet (100 × 100 mm) with chemical compositionare presented in Table 1.

Table 1 **Chemical composition of 1.3302 HSS / wt.%**

| C | Cr | Mo | V |
|---|---|---|---|
| 1,28 | 4,15 | 0,85 | 3,75 |
| W | Si | Mn | Fe |
| 12,9 | 0,045 | 0,40 | Base |

Hot compressiontests were carried outusing Gleeble 1500D thermo-mechanical simulator. Previously appropriate soaking temperature was determined using a new proposed procedure, [5].The use of this procedure can result in expanding of the safe hot working temperature range as well as in improved mechanical properties. Conditions for study of hot workability were as follows: temperature range 850–1150 °C, constant strain rates range0,001–6 $s^{-1}$ and applied strain of 0,9.Test samples were heated at 3 °C $s^{-1}$ to the soaking temperature and held there for 10 min. Afterwards they were cooled at 2 °C $s^{-1}$ to the deformation temperature and held there for another 10 min before they were compressed. In order to determine the activation energies, the peak stress values were fitted to the empirical sine-hyperbolic equation, [5,7-14].

## RESULTS AND DISCUSSION

Initial microstructure of soft annealed state, as taken from the supplied billet, consistsof ledeburitic and secondary carbides inserted in spheroidesed perlite matrix. Using the new procedure, the optimal soaking temperature was determined to be at 1180 °C. The useof this optimal soaking temperature prevents the growth of carbides during soaking which increasesthe hot workability, especially at a lower limit of the temperature range.

In this section, single hit stress-strain curves for 1.3302 are presented. Figure 1a illustrates the effect of temperature on the stress–strain curves at a constant strain rate of $\dot{\varepsilon}$ = 0,001 $s^{-1}$, where flow stress is decreasing with higher temperatures. All curves exhibit a rapid initial increase to the maximum stress, characterized by a peak, followed by a stress decrease to the steady state. This indicates that DRX acts as mainsoftening mechanism during deformation, [5-11]. Initiation of DRX can be identified from the change in the slope of a strain hardening ratecurve $\theta$, [12,13] which is obtained by derivation of the flow stress $\sigma$ and is calculated as:

$$\theta = \left( \frac{\partial \sigma}{\partial \varepsilon} \right)_{\dot{\varepsilon}}. \qquad (1)$$

Obtained results on derivation, where DRX initiates, are presented in Figure 2 foreach individual deformation condition.From both figures, it is clearly visible that with the decreaseof deformation temperature and the increase of strain rate,the initiation of DRX is shifted to higher stresses (Figure 2a), as well as to higher strains (Figure 2b). Especially at lower temperatures and lower strain rates,the initiation of DRX is shifted to slightly lower initial strains.

Another important feature that can be obtained from stress curves are peak stresses used to model deformation process. Values for the peak stresses for all deformationconditions were collected and are plotted in Figure 3. There is a clear falling trend of the peak stress values when the temperature is increased. As expected, peak stress values increase with higher strain rates at any given temperature.

The apparent activation energy for hot workingwasobtained using the following hyperbolic sine equation, [5-11,14]:

$$Z = \dot{\varepsilon} \exp\left( \frac{Q_{\text{def}}}{RT} \right) = A \sinh^{n} (\alpha \sigma) \qquad (2)$$

where $Q_{\text{def}}$ is the apparent activation energy for hot working determined from the peak stress, $A$ and $\alpha$ are the material constants, $n$ is the stress exponent $\dot{\varepsilon}$, $\dot{\varepsilon}$ is the strain rate, $\sigma$ is the flow stress, $T$ is the absolute temperature and $R$ is the gas constant. The details for calculationof all constants are given elsewhere in [11]. Acti-

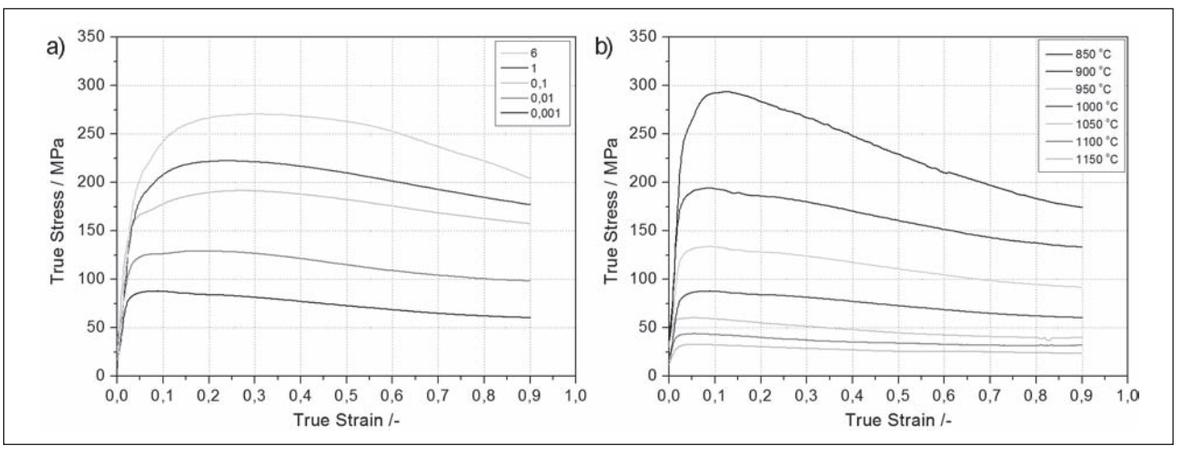


**Figure 1** Stress–strain curves a) for temperature of 1100 °C and various strain rates, and b) for strain rate of 0,001 $s^{-1}$ and various temperatures

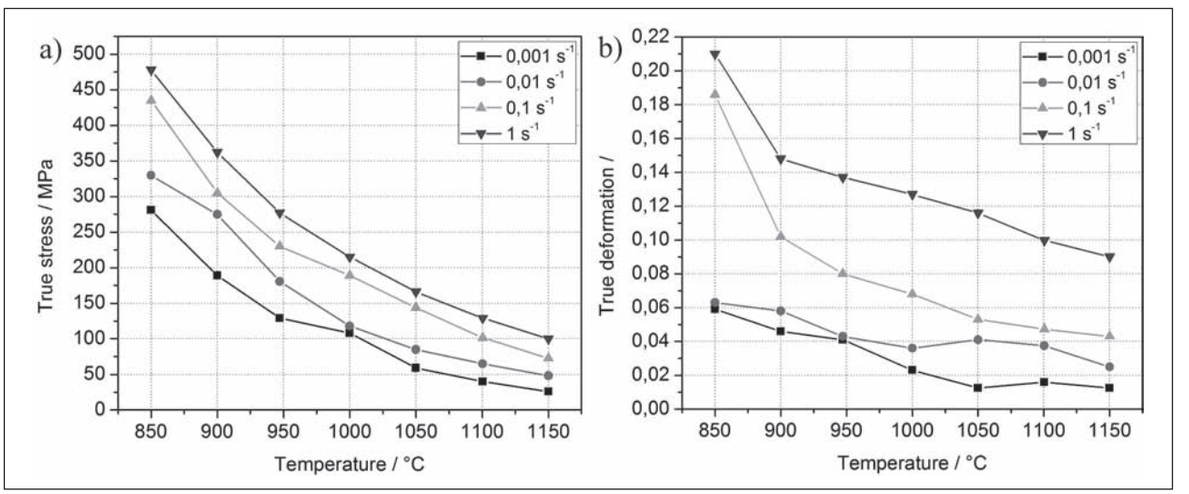


**Figure 2** Strain hardening rate a) in dependence on temperature, true stress and strain rate, b) in dependence on temperature, strain (deformation) and strain rate

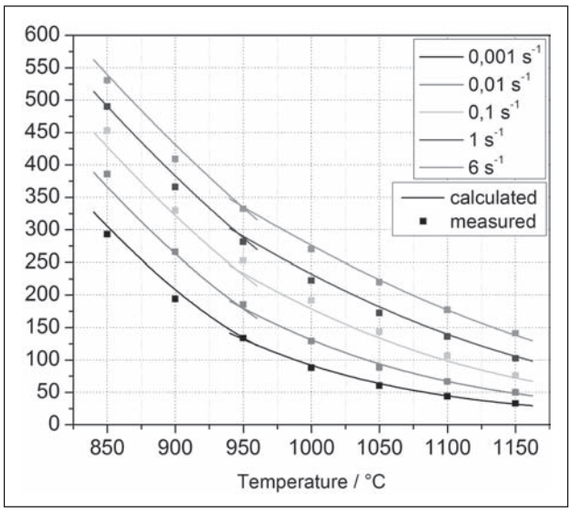


**Figure 3** Peak stress versus temperature for different strain rates

vation energies and other constants of hyperbolic sine equation were calculated for two temperature rangesdue to the precipitation of secondary carbides bellow 1000 °C, [5,7]. For the lower temperature range, i.e. 850–950 °C,the obtainedvalues are:$\alpha$ = 0,005671 MPa$^{-1}$, $n$ = 6,42, $Q_{def}$ = 870 kJmol$^{-1}$,while for the upper temperature range, i.e. 950-1150 °C, these values amount to: $\alpha$ = 0,00721 MPa$^{-1}$, $n$ = 5,37 and $Q_{def}$ = 606 kJ mol$^{-1}$.The comparisons between calculated (eq. 2) and measured peak stresses at various thermo-mechanical conditionsare given in Figure 3. Good agreement between experimental and calculated values for peak stresseswas obtained.

Figures 4a–4d show microstructures of the center of deformedsamples at various strain rates and deformation temperatures. Figures 4a and 4b depict the effect of the constantdeformation temperature at 1150 °C and strain rates at 6 s$^{-1}$ and 0,001 s$^{-1}$, respectively.

The mixture of martensitic and retain austenitic matrix microstructure with fewlarge eutectic carbides is depicted in Figure 4a. Small eutectic carbides are dispersed on the grain boundaries. The mean size of recrystallized grains amounts to approximately18 μm. Figure 4b showslath shaped martensite matrix with dispersedsecondary and irregular eutectic carbides. Figures 4c and 4d depict the effect of constant deformation temperature of 850 °C, at strain rates of 6 s$^{-1}$ and 0,001 s$^{-1}$ onthe microstructure, respectively.On bothfigures, fine lath shaped martensite matrix is observed with dispersed small spherical and irregularly shaped coarse carbides. Lower safe deformation limit for HSS steels was previously 920 °C, [5]. However with use of the optimal soaking temperature no cracks were observed on deformed specimens at 850 °C. This is attributed to the determination of optimal soaking temperature. Furthermore, the microstructures confirm that the fraction of recrystallized grains is higher when the deformation temperature is increased. Similar results are noticedwhen the strain rate is lowered, which provides more time for DRX.These results comply with the findings of other authors, cf. [3, 5, 7, 10, 14]. The start of DRX and the small amount of recrystallized material volume is visible at highest strain rate (6 s$^{-1}$), Figure 4a.

## CONCLUSION

Hot compression tests for 1.3302 HSS in wide range of deformation conditions were carried out. The optimal soaking temperature was assessed and the microstructure of deformed specimens was analyzed. The strain hardening rates were determined and the apparent activation energies for two temperature ranges were calculated.The following conclusions can be drawn:

- The optimal soaking temperature of 1180 °C extends safe hot working range, from 920 °C down to 850 °C. That supports industrial aims for hot rolling of profiles with smaller dimensions thanso far.
- When the strain rate is increased or the temperature is lowered, the apex of stress is shifted to higher strain.

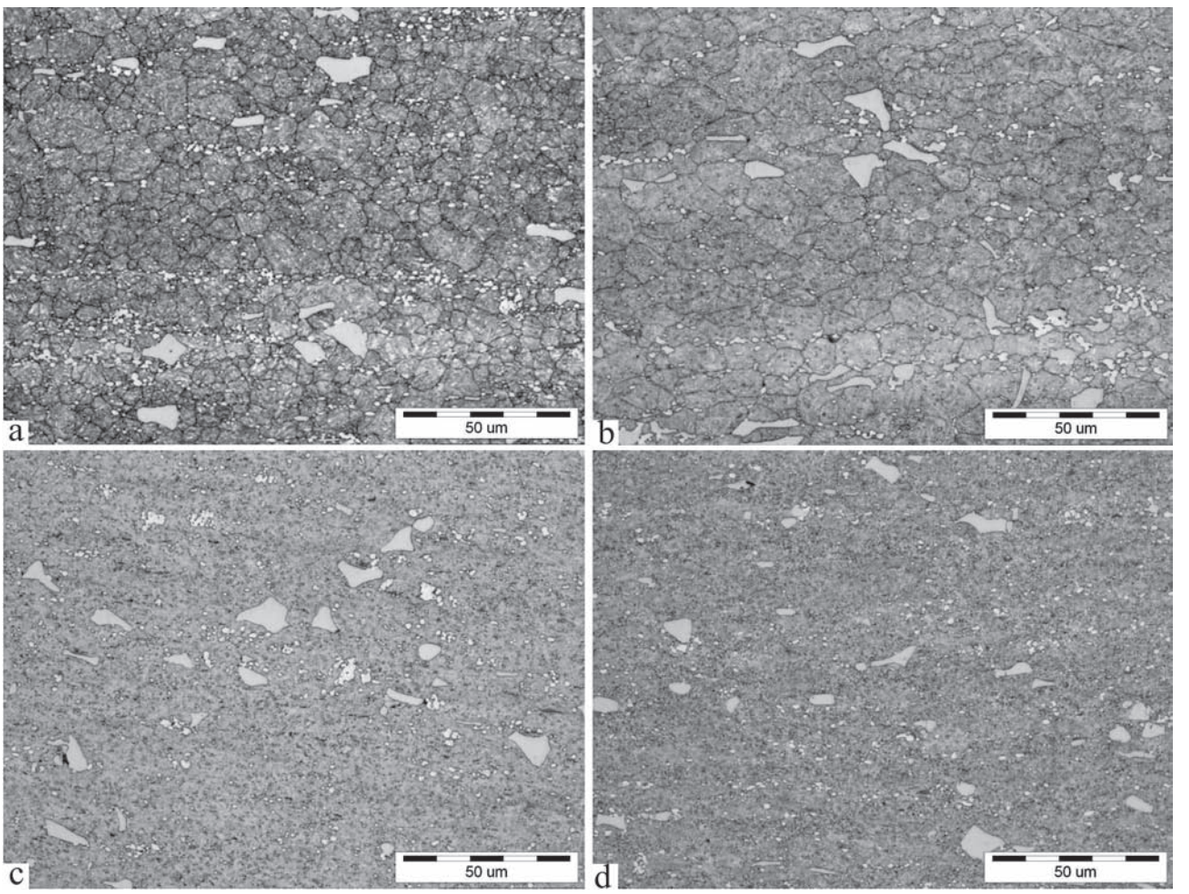


**Figure 4** Microstructure in the middle of deformed specimendependent on the temperature and strain rate: a) 1150 °C, 6 $s^{-1}$, b) 1150 °C, 0.001 $s^{-1}$, c) 850 °C, 6 $s^{-1}$, d) 850 °C, 0.001 $s^{-1}$

- The apparent activation energy for temperature range 950–1150 °C amounts to 606 kJ $mol^{-1}$, while for lower temperature range, i.e. 850–950 °C, this value amounts to 870 kJ $mol^{-1}$. Strain values for the initiation of DRX increase with increasing strain rate and decreasing temperature.

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# KINETICS OF CHROMIUM EVAPORATION FROM HEAT-RESISTING STEEL UNDER REDUCED PRESSURE

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Preliminary Note – Prethodno priopćenje

This paper describes a kinetic analysis of the process of chromium evaporation from ferrous alloys smelted under reduced pressure. The study discussed comprised determination of the liquid phase mass transfer coefficient as well as the value of the constant evaporation rate. By applying these values as well as the values of the overall mass transfer coefficient estimated based on the relevant experimental data, the fractions of resistance of the individual process stages were established.

*Key words:* chrome, steel, evaporation, pressure

**Kinetika isparavanja kroma iz toplinski otpornog čelika pod smanjenim tlakom.** Prilog opisuje kinetičku analizu procesa isparavanja kroma iz željeznih legura pod smanjenim tlakom. Studija obuhvaća utvrđivanje koeficijenta prijenosa mase tekuće faze kao i vrijednost konstantne stope isparavanja. Primjenom ovih vrijednosti i vrijednosti koeficijenta ukupnog prijenosa mase utvrđenog na temelju odgovarajućih eksperimentalnih podataka, ustanovljene su frakcije otpora pojedinih faza procesa.

*Ključne riječi:* krom, čelik, isparavanje, tlak

## INTRODUCTION

The problem of loosing components of alloy metal baths during smelting is particularly significant when even the slightest change in the content of the evaporated component alters the properties of the alloy being cast. In the case of high-chromium steel smelting, one must deal with losses of chromium, particularly in the processes conducted under reduced pressure conditions. This phenomenon was observed by numerous researchers including Bellot [1] in the process of smelting of stainless steel with the chromium content of 17 % by weight.

## ANALYTICAL PART

In order to perform a kinetic analysis of the process of chromium evaporation from liquid iron, results of the experiments discussed in the papers of Ohno [2], Bellot [1] and Blacha [3] were applied. The aforementioned authors investigated chromium evaporation from steel containing from 1 to 25 % by weight of Cr smelted under the conditions of reduced pressure in induction furnaces. The overall mass transfer coefficient values established by the said authors based on experimental data for chromium as well as the basic parameters of the experiments conducted have been collated in Table 1, whereas Figure 1 depicts the pressure impact on the overall mass transfer coefficient for the process of chromium evaporation being analysed.

Table 1 **Basic parameters assumed in the study of the process of chromium evaporation from ferrous alloys and the overall mass transfer coefficient values**

| Temp. / K | Press. / Pa | Initial chromium concentration in bath / % wt. | Overall mass transfer coefficient value k x 10-6 / $ms^{-1}$ | Ref |
|---|---|---|---|---|
| 1 873 | 1,33 | 0,98 | 2,10 | [2] |
| 1 873 | 1,33 | 1,89 | 2,00 | [2] |
| 1 873 | 0,13 | 2,83 | 2,83 | [2] |
| 1 993 | 1,33 | 17,00 | 5,56 | [1] |
| 1 993 | 4,27 | 17,00 | 5,29 | [1] |
| 1 993 | 13,3 | 17,00 | 3,21 | [1] |
| 1 993 | 26,7 | 17,00 | 2,21 | [1] |
| 1 993 | 48,0 | 17,00 | 1,15 | [1] |
| 1 993 | 66,7 | 17,00 | 0,78 | [1] |
| 1 993 | 133 | 17,00 | 0,59 | [1] |
| 1 773 | 150 | 23,56 | 0,80 | [3] |
| 1 773 | 150 | 23,56 | 0,95 | [3] |
| 1 823 | 150 | 23,47 | 1,40 | [3] |
| 1,823 | 150 | 23,50 | 1,37 | [3] |
| 1 773 | 70 | 23,84 | 1,21 | [3] |
| 1 773 | 70 | 23,71 | 1,14 | [3] |
| 1 823 | 70 | 23,37 | 1,46 | [3] |
| 1 823 | 70 | 23,11 | 1,57 | [3] |
| 1 773 | 10 | 23,36 | 2,16 | [3] |
| 1 773 | 10 | 23,07 | 2,68 | [3] |
| 1 823 | 10 | 22,21 | 2,98 | [3] |
| 1 823 | 10 | 22,43 | 3,12 | [3] |

C Kolmasiak, Czestochowa University of Technology, Department of Production Management and Logistics, Czestochowa, Poland

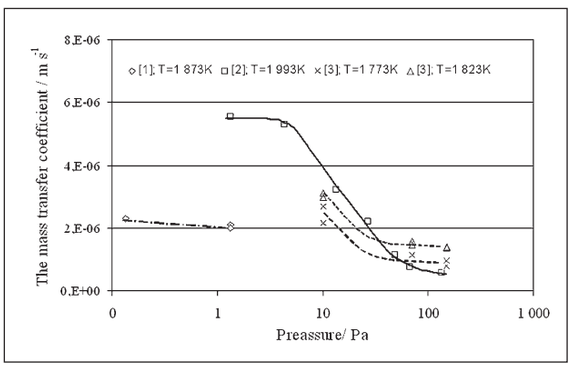


**Figure 1** Change of the mass transfer coefficient (k) depending on pressure established for the process of chromium evaporation from liquid iron based on [1-3].

## MASS TRANSFER COEFFICIENT FOR THE LIQUID METALLIC PHASE

Or the sake of a description of a mass transfer process in liquids, penetration models are most frequently recommended at present. However, in the evaporation process being analysed, their application is limited, this resulting from the fact that, in those models, in the dependencies describing the mass transfer coefficient, the parameters being used are difficult to estimate. According to Higbie's model, where transfer coefficient $k_l$ is described by the following dependence:

$$k_l = \left(\frac{D_{A-B}}{\pi \cdot t^*}\right)^{0,5} \quad (1)$$

where:

$D_{A-B}$ – interdiffusion coefficient for the liquid components,

$t^*$ – time for which the given component remains on the surface.

such a parameter is time t*. Dependence (1) can only be used to determine the value of coefficient $k_l$ in the process of the liquid bubbling with gases, including liquid metallic alloys [4, 5].

In Danckwerts's penetration model, coefficient $k_l$ is described by the following dependence

$$k_l = \left(D_{AB} \cdot s^*\right)^{0,5} \quad (2)$$

where:

$s^*$ – proportionality factor.

Factor s* determines the relation between the area restored in a unit of time and the liquid's total area. Also in the above case, this coefficient is difficult to determine. In paper [6], based on an analysis of the flow field of induction stirred liquid Fe-Cu alloy, it was found that the entire surface of metal is practically in motion at any given moment, and hence the value of parameter s* → 1.

When induction stirred mixed liquid volume occurs in the process analysed, it is recommended that for the sake of establishment of mass transfer coefficient Factor s* determines the relation between the area restored in a unit of time and the liquid's total area. Also in the above case, this coefficient is difficult to determine. In paper [6], based on an analysis of the flow field of induction stirred liquid Fe-Cu alloy, it was found that the entire surface of metal is practically in motion at any given moment, and hence the value of parameter s* → 1.

When induction stirred mixed liquid volume occurs in the process analysed, it is recommended that for the sake of establishment of mass transfer coefficient $k_l$ Machlin's model should be applied. According to this model, the coefficient is described by the following dependence:

$$k_l = \left(\frac{8D_{AB} \cdot v_m}{\pi \cdot R_m}\right) \quad (3)$$

where:

$v_m$ – near surface velocity of liquid metal,

$R_m$ – melting pot's internal radius.

Most authors investigating the evaporation rate for volatile components of metal bath assumed after Machlin that velocity $v_m$ is constant for most induction aggregates and equals 0,1 ms$^{-1}$. Also the authors of publication [2] made such an assumption. A detailed analysis of the flow field for induction stirred liquid metal implied that not only does velocity $v_m$ depend on the current frequency, but also on the melting pot's arrangement against the inductor [7, 8].

In the analysis discussed, in order to establish the value of coefficient $k_l$ with regard to the studies referred to in publications [1, 3], dependence (3) was applied. In the calculations, according to Ohno and Yamamoto [9], the value of $D_{Cr-Fe}$ for temperatures of 1 823 K and 1 873 K was assumed to equal 3,04 and 3.42 · 10$^{-9}$ m$^2$s$^{-1}$ respectively. At the same time, the near surface velocity value of $v_m$ was assumed to equal 0,1 ms$^{-1}$. Table 2 contains values of coefficient $k_l$ estimated for all the experiments discussed.

## CONSTANT VELOCITY OF THE EVAPORATION PROCESS

According to Langmuir's equation, the maximum mass flux of the component being evaporated from the surface is determined by the following dependence:

$$N_i = \frac{\alpha \cdot p_i}{\sqrt{2\pi RTM_i}} \quad (4)$$

where:

$\alpha$ – evaporation constant,

$p_i$ – balance pressure of component "i" being evaporated over the liquid solution,

$M_i$ – molar mass of component "i".

Constant evaporation velocity $k_e$ is described by the following equation:

$$\kappa_e = \frac{\alpha \cdot p_i^0 v_i M_p}{\rho_p \sqrt{2\pi RTM_i}} \quad (5)$$

where:

$p_i^0$ – equilibrium pressure of component "i" over pure bath,

$\gamma_i$ – activity coefficient for component "i",
$M_p$ – molar mass of primary metal,
$\rho_p$ – density of primary metal.

The values of constant evaporation velocity $k_e$ determined based on equation (5) have been collated in Table 2. In the calculations, the activity coefficient values for chromium in liquid metal were assumed after publication [10].

Table 2 **Values of constant evaporation velocity and mass transfer coefficient for chromium evaporation from liquid ferrous alloy**

| Temp. / K | Mass transfer coefficient for the liquid phase $k_l \cdot 10^6$ / ms$^{-1}$ | Constant evaporation velocity $k_e \cdot 10^6$ / ms$^{-1}$ |
|---|---|---|
| 1 873 | 5,90 | 3,30 |
| 1 873 | 5,00 | 3,30 |
| 1 873 | 7,40 | 3,30 |
| 1 993 | 472 | 23,6 |
| 1 993 | 472 | 23,6 |
| 1 993 | 472 | 23,6 |
| 1 993 | 472 | 23,6 |
| 1 993 | 472 | 23,6 |
| 1 993 | 472 | 23,6 |
| 1 993 | 472 | 23,6 |
| 1 773 | 176 | 2,02 |
| 1 773 | 176 | 2,02 |
| 1 823 | 176 | 2,02 |
| 1 823 | 176 | 2,02 |
| 1 773 | 176 | 2,02 |
| 1 773 | 176 | 2,02 |
| 1 823 | 185 | 3,95 |
| 1 823 | 185 | 3,95 |
| 1 773 | 185 | 3,95 |
| 1,773 | 185 | 3,95 |
| 1 823 | 185 | 3,95 |
| 1 823 | 185 | 3,95 |

## PROCESS RESISTANCE ESTIMATION

Having established the values of overall mass transfer coefficient $k$ for the chromium evaporation process being analysed, determined based on the relevant experimental data, as well as the estimated values of coefficients $k_l$ and $k_e$, one could determine the fractions of resistances of the individual stages in the total process resistance. As for the resistance due to the mass transfer in the liquid phase, its total resistance fraction did not exceed several per cent (Figure 2). An exception can be found in Ohno's studies [2], where the resistance exceeded 25 %. This discrepancy probably results from the fact that, for the sake of calculations, the said author assumed the diffusion coefficient value for chromium in liquid iron being an order of magnitude larger than those provided in other publications. Therefore, one may generally assume that within the pressure range from 1 to 150 Pa, in the range of temperatures being analysed, the mass transfer does not determine the process of chromium evaporation from iron for the alloys containing from 1 to 24 % of Cr.

Figure 3 depicts the fraction of resistance related to the reaction of the chromium evaporation occurring on the liquid metal surface in the total process resistance. It

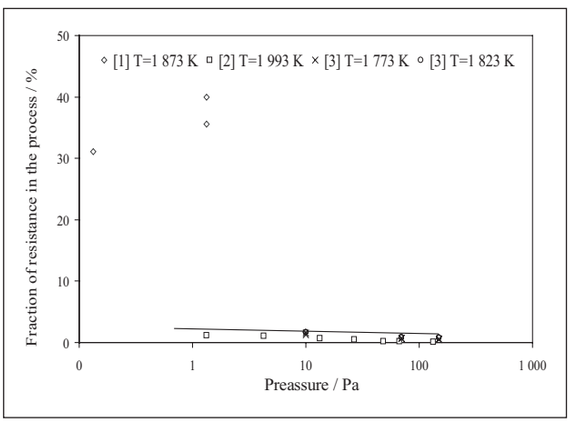


**Figure 2** Fraction of the liquid phase mass transfer resistance in the total process resistance.

is evident that this fraction increases considerably as the pressure in the system is dropping, and it decreases with the temperature increase. For temperatures below 1 860 K, this fraction reaches the values exceeding 50 % which implies that the process analysed is then determined by the rate of the surface reaction. Figure 4, on

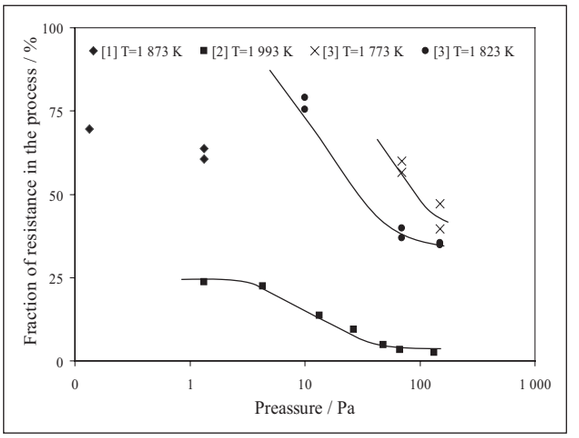


**Figura 3** Fraction of the evaporation process resistance in the total process resistance during smelting under the reduced pressure conditions.

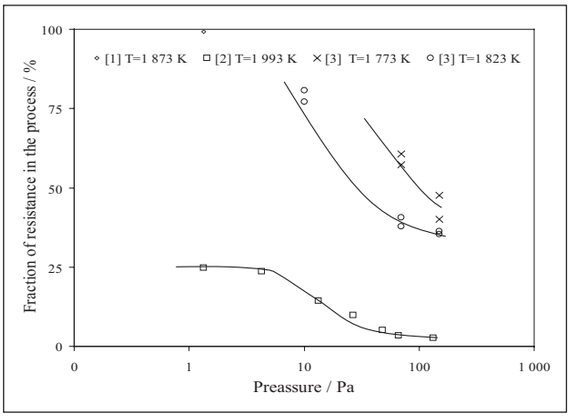


**Figure 4** Overall fraction of the liquid phase mass transfer resistance and the evaporation reaction resistance in the total process resistance.

the other hand, depicts the fraction of overall resistance due to the mass transfer in the liquid phase and the evaporation reaction in the total process resistance. It is also evident that the dependence in question is identical as compared with only the evaporation reaction. Therefore, at high temperatures, the stage actually determining the chromium evaporation process being analysed is the mass transfer in the gaseous phase, since the overall fraction of resistances of other stages does not exceed 30 %.

## CONCLUSIONS

The results obtained by the authors in the study of the chromium evaporation process during vacuum smelting of ferrous alloys have been confirmed in other publications. By indicating the stages determining the chromium removal from the ferrous alloy one may obtain relevant information on the option of reducing or even avoiding this phenomenon. The mass transfer coefficient values calculated for the liquid phase as well as the constant evaporation velocity and the values of the overall mass transfer coefficient obtained based on experimental data have enabled determination of the resistances of the individual stages as well as their fraction in the total process resistance.

The resistance fraction of the chromium evaporation stage occurring in the liquid alloy/gaseous phase interfacial surface in the total process resistance clearly implies a strong dependence on the pressure in the system as well as the temperature. For temperatures below 1 860 K, this fraction accounts for more than 50 % which may imply that the process analysed is determined by the rate of the surface evaporation itself. For the overall fraction of the resistance due to the mass transfer in the liquid phase and the evaporation reaction, an identical dependence is clearly observed as for the fraction of the evaporation reaction only. Consequently it may be claimed that, at high temperatures, the stage actually determining the chromium evaporation from ferrous alloys is the mass transfer in the gaseous phase, since the overall fraction of resistances of other stages does not exceed 30 %.

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# CRYSTALLIZATION AND STRUCTURE OF CAST A390.0 ALLOY WITH MELT OVERHEATING TEMPERATURE

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Preliminary Note – Prethodno pripćenje

The paper presents the research on the influence of melt overheating temperature on crystallization parameters and primary structure of cast AlSi17Cu5Mg (A390.0) alloy overheated to temperature: 820 °C, 880 °C, 940 °C and 1 000 °C. It was found that the degree of overheating influences the change of microstructure significantly and morphologies of primary silicon of the castings from Al-Si alloys. Research has shown that the overheating of the liquid metal bath is one of the methods of finding more applications of hypereutectic Al-Si system alloys without the addition of modifiers.

*Key words:* cast Al-Si Alloy, crystallizatio, structure, melt overheating temperature,

**Kristalizacija i struktura lijevane A 390.0 legure iz taline zagrijane na povišenim temperaturama.** Članak daje istraživanje utjecaja taline na parametre kristalizacije i primarne strukture lijevane legure AlSi17Cu5Mg (A 390.0) zagrijane na povišenim temperaturama: 820 °C, 880 °C, 940 °C i 1 000 °C. Utvrđeno je da stupanj utjecaja pregrijavanja mjenja značajnije mikrostrukturu silikata lijevanih Al-Si legura. Istraživanje ukazuje da pregrijavanje tekućeg metala je jedna od metoda pronalaženja veće primjene hipereutektičkih Al-Si legura bez dodataka modifikatora.

*Ključne riječi:* lijevane Al-Si legure, kristalizacija, struktura, pregrijana talina

## INTRODUCTION

In normal casting conditions the crystals of primary silicon in hypereutectic of Al-Si alloys show many morphological features such as: polygons, star-shaped and thick plates, “big arms”, etc. Such coarse-grained structure has a negative influence on mechanical properties (HB, Rm), tribological properties and the possibility of machining of the aluminium castings. The key aspect for the increase in the number of applications of Al-Si alloys is then the size decrease and the uniform arrangement of the primary crystals of silicon. It can be achieved by modification, refining, the use of ultrasound [1-3] and with the use of melt overheating of liquid alloy before casting [4-6]. Such action causes the melting of the heterogeneities and impurities, the increase of density and/or the appearance of new pads for heterogeneous nucleation of primary Si crystals.

The increase of melt overheating temperature causes the change of the morphological shape of the structural casting ingredients of the Al-Si alloys which is characteristic for disintegrated structure without the application of modifying additives.

The results of these studies [7-9] have proved that in the case of hypoeutectic silumins, an increase in the melt overheating degree results in a partially reversible change of their structure, while in the case of hypereutectic alloys this change is practically irreversible.

## TEST MATERIALS AND METHODS

The base alloy used in this study was hypereutectic A390.0 alloy that the results of chemical composition are compared in Table 1. The cast AlSi17Cu5Mg (A390.0) alloy was melted in a SiC crucible of Balzers VSG induction furnace, using as a charge material pure aluminium (99,99 wt.% purity) and Si (99,95 wt.% purity) remelted to obtain a homogeneous chemical composition. Before casting, the alloy was refined with ”Rafglin-3”, added in an amount of 0,3 wt.% respective of the alloy weight.

Table 1 **Chemical analysis of the examined silumin, /wt.%**

| Alloy | Si | Cu | Fe | Mn | Mg | Ni | Al |
|---|---|---|---|---|---|---|---|
| A390.0 | 16,61 | 4,85 | 0,23 | 0,03 | 0,95 | 0,03 | rest |

The tested alloy is characterised by the low coefficient of thermal expansion, very good resistance to corrosion, high hardness and resistance to material consumption. That is why it is widely applied to cast internal combustion engines, blocks and bodies of cylinder compressors and to cast pumps and braking systems.

The cast A390.0 alloy overheated to four temperatures: 820 °C, 880 °C, 940 °C and 1 000 °C, and casted to 780 °C temperature. The effect of alloy overheating on the solidification parameters was examined by ATD

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on a Crystaldigraph NT3-8K apparatus equipped with Mlab2 programme. The studies of solidification process were completed with light microscopy and scanning electron microscopy, using a Hitachi microscope with EDXS Norah attachment based on the Voyager programme. Preserving the same parameters of melting and casting, the examined silumin was poured into a standard QC 4080 Heraeus Electro-Nite probe, plotting the temperature curve (TA) and its derivative in function of time dT/dt (ATD).

## AIM AND SCOPE OF STUDIES

The aim of the studies was to determine what effect the degree of melt overheating on the solidification process and microstructure evolution of A390.0 alloy. The scope of the studies included:

- melt overheating to: 820 °C, 880 °C, 940 °C and 1 000 °C,
- holding the melt for 40 minutes in an electric chamber furnace,
- cooling the alloy "in air" at a rate of about 277/Ks$^{-1}$ to a temperature of 780 °C with subsequent pouring into an QC 4080 standard ceramic sampler,
- thermal analysis, plotting of solidification curves and determination of solidification temperatures: $T_{liq,}$ $T_{Emin.,}$ $T_{Emax.}$, $T_{EMg,}$ $T_{ECu}$ and $T_{sol.}$,
- microstructure examinations.

## THE RESULTS OF STUDIES

As an example, Figures 1 and 2 shows the thermal analysis graph plotted for cast A390.0 alloy no overheated and overheated to 940 °C.

The characteristic solidification temperatures read out for the examined alloy from the thermal analysis curves A390.0 alloy overheated to 940 °C shown in Table 2.

Figures 3 and 4 compares the values of solidification temperatures ($T_{liq,}$ $T_{Emin,}$ $T_{Emax,}$ $T_{sol.}$) and crystallisation temperatures of the complex eutectics: $T_{EMg}$, $T_{ECu}$ with

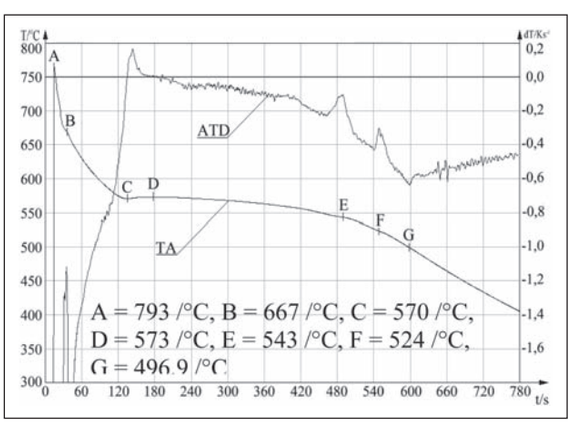


**Figure 1** Thermal analysis graph plotted or cast A390.0 alloy no overheated with characteristic temperatures

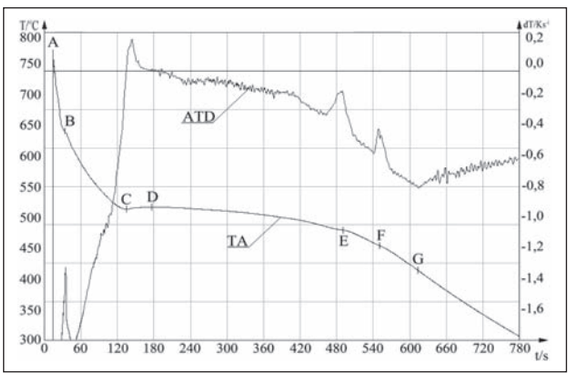


**Figure 2** Thermal analysis graph plotted for cast A390.0 alloy overheated to 940 °C

melt overheating temperature read out for the examined alloy from the ATD curves.

A complementary research to the overheating temperature on solidification process was study of microstructure. Samples were taken from the areas of temperature measurement.

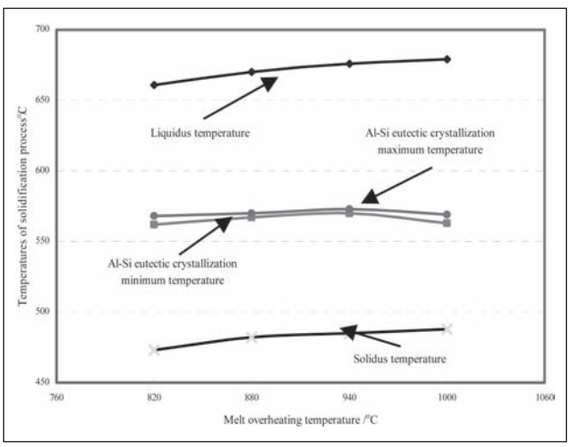


**Figure 3** Effect of melt overheating degree on solidification temperatures: $T_{liq}$, $T_{Emin.}$ $T_{Emax.}$ and $T_{sol}$

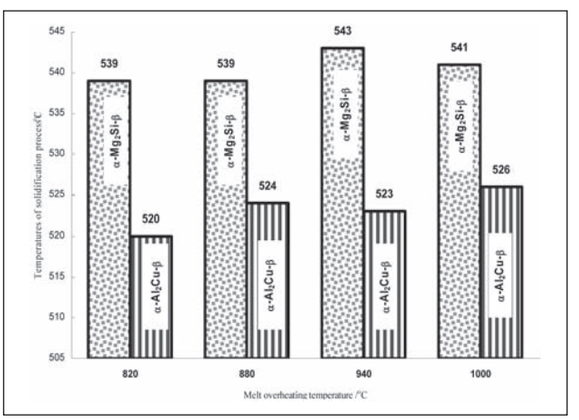


**Figure 4** Effect of melt overheating degree on solidification temperatures complex eutectic: $T_{EMg}$ α-$Mg_2Si$-β (1) and $T_{ECu}$ α-$Al_2Cu$-β (2)

Table 2 **The characteristic solidification temperatures cast A390.0 alloy overheated to 940 °C**

| Point on TA | Time /s | Temperature /°C | Temperature description |
|---|---|---|---|
| A | 15,5 | 780 | pouring temp. – $T_{por.}$ |
| B | 35,0 | 678 | liquidus temp. – $T_{liq.}$ |
| C | 134,5 | 570 | Al(α)-Si(β) eutectic crystallization minimum temperature – $T_{E\,min.}$ |
| D | 180,5 | 573 | Al(α)-Si(β) eutectic crystallization maximum temperature – $T_{E\,max.}$ |
| E | 490,5 | 543 | α -$Mg_2Si$- β eutectic crystallization temperature – $T_{E\,Mg}$ |
| F | 549,0 | 523 | α -$Al_2Cu$- β eutectic crystallization temperature – $T_{E\,Cu}$ |
| G | 623,5 | 485 | solidus temperature – $T_{sol.}$ |

## DISCUSSION OF RESULTS

Proper selection of melting and casting parameters is very important as it determines the processes of nucleation, crystal growth and shaping of the primary microstructure. Better knowledge of these phenomena can have a significant impact on further determination of the liquid alloy ability to develop certain types of crystal microstructure after the solidification process (cluster structure), which can improve the casting mechanical properties and performance. To investigate the effect of melt overheating temperature on the solidification parameters and microstructure, an cast A390.0 alloy was selected that overheated to 820 °C, 880 °C, 940 °C and 1 000 °C temperatures.

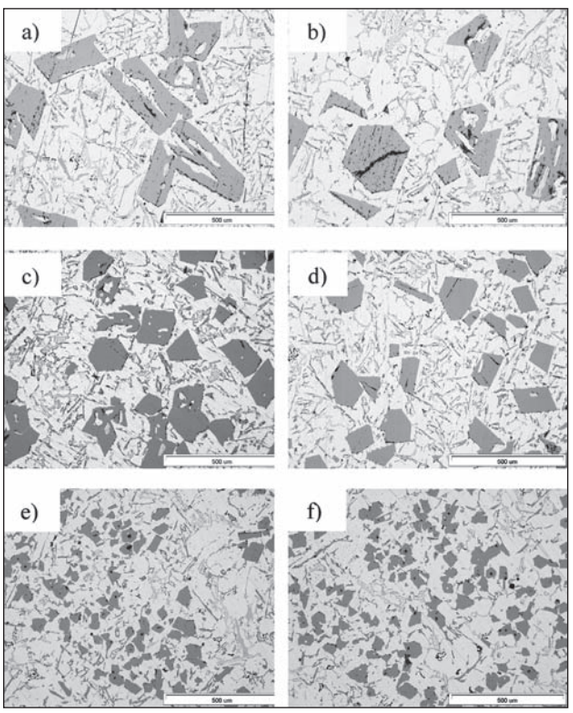


**Figure 5** Microstructure of cast A390.0 alloy a, b) without overheated and overheated to: c) 820 °C; d) 880 °C; e) 940 °C; f) 1 000 °C

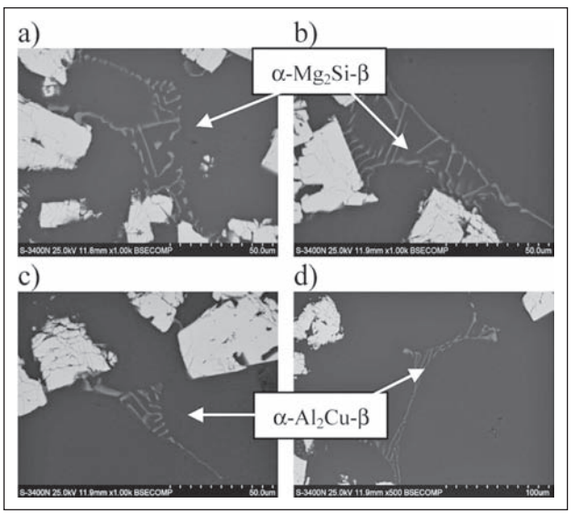


**Figure 6** Microstructure of A390.0 alloy overheated to 940 °C with com-plex eutectics: a, b) α-$Mg_2Si$-β and c, d) α-$Al_2Cu$-β

The key issue in an assessment of the time/temperature parameters of the liquid alloy overheating was maintaining the conditions of melting and casting at a similar level. This eliminated the effect of other factors, and enabled correct determination of a relationship that is believed to exist between the overheating degree and solidification parameters of the examined cast A390.0 alloy.

For this purpose, the ATD thermal analysis was applied, plotting next the solidification curve of the examined alloy, overheated to selected temperatures.

Studies have proved that overheating of A390.0 alloy to 820 °C, 880 °C, 940 °C and 1 000 °C raises quite considerably the crystal-lisation temperature of the primary silicon crystals - $T_{liq}$ ($T_{liq.}$ = 678 °C), compared to the silumin cast from 780 °C, i.e. without overheating - difference is 11 °C. The effect of copper and magnesium added to the cast A390.0 alloy is not so prominent as regards the value of the temperature $T_{liq}$. From the theory of crystallization it follows that magnesium added to silumins has no beneficial effect on the modification process. It is added mainly to facilitate the heat treatment. Examining a relationship that is said to exist between the crystallisation temperature of α+β eutectic ($T_E$) and overheating temperature of the examined alloy, one can observe that the melt overheating degree has no significant effect on changes in the value of the temperatures: $T_{Emin}$. and $T_{Emax}$. Examining the melt overheating degree on the crystallisation temperature of the ternary α-$Mg_2Si$-β and α-$Al_2Cu$-β eutectics, from Figures 4 and 6 no distinct tendency or relationship could be derived as overheating temperature and crystallisation temperature of the ternary eutectics $T_{EMg}$ and $T_{ECu}$. Examining a relationship between the solidus temperature ($T_{sol}$) and overheating temperature cast A390.0 alloy one can conclude that in melt overheating degree on the temperature of the end of crystallisation is not so prominent.

The next important issue in the explanation of the effect of overheating temperature on the solidification parameters of hypereutectic A390.0 alloy is the examination of microstructure of alloy overheating from different temperatures. Holding the alloy for 40 minutes at 780 °C (Figure 5a and 5b) did not cause any more significant changes in its microstructure. The crystals of silicon assumed a large, star-like shape, typical of unmodified alloy. However, with increasing temperature of overheating (Figure 5 c-f), high degree of structure refinement was observed. Silicon crystals reduced their size, became more compact and more evenly distributed in the matrix of α(Al)-β(Si) eutectic. Further overheating of alloy melt to a temperature of 1 000 °C did not bring any more significant changes in the morphology of silicon crystals. This can suggest that overheating of alloy is greatly responsible for the modification of AlSi17Cu5Mg (A390.0) alloy structure.

It is also worth noting that microstructure of the silumin cast from the 780 °C temperature (without overheated) includes a coarse-grained α(Al)-β(Si) eutectic, surrounded by silicon crystals and oblong precipitates of the AlFeSi phase [10-11]. Overheating the alloy reduces the size of the complex eutectics: $T_{EMg}$ α-$Mg_2Si$-β) and $T_{ECu}$ (α-$Al_2Cu$-β) - Figure 6. Hence it can be concluded that raising the temperature of the A390.0 alloy overheating not only refines the micro-structure of primary Si crystals but also dissolves the Al-Fe-Si phase-containing eutectic in α solution.

## CONCLUSIONS

Based on the conducted studies the following conclusions have been drawn:

1. Overheating of cast A390.0 alloy to 820 °C, 880 °C, 940 °C and 1 000 °C tem-peratures raises the liquidus temperature $T_{liq}$ compared to the cast alloy at 780 °C without overheated.
2. Other values of solidification temperatures: $T_{Emin.}$ $T_{Emax.}$ and $T_{sol}$ remain basically unchanged.
3. An increase in the liquid alloy overheating temperature is accompanied by refinement and more uniform distribution of the primary silicon crystals in α(Al)-β(Si) eutectic, which is typical of the alloy structure after modification.
4. Overheating of cast A390.0 alloy to a temperature above of 820 °C refines the AlFeSi precipitates, while further overheating makes them dissolve in a solution of α (Al).
5. Overheating of cast A390.0 alloy to a temperature of 940 °C will change the form of the complex eutectics: $T_{EMg}$, $T_{ECu}$ (because of the addition of Mg and Cu).

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# THE EFFECT OF HARMEFUL ELEMENTS IN PRODUCTION OF IRON IN RELATION TO INPUT AND OUTPUT MATERIAL BALANCE

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The main objectives of blast-furnace operators include maximum production of pig iron of required chemical composition at minimal cost. This can be ensured only in case of quality raw material basis and trouble-free operation of blast-furnace. Both parameters are influenced by the concentration of undesirable elements. The negative elements contained in the blast-furnace raw materials cause many technological problems in the sintering as well as in the blast-furnace process. These are mainly heavy metals and alkaline carbonates. The article deals with the analysis of material balance of zinc and selected alkaline carbonates contents in the input raw materials and output products of the blast-furnace.

*Key words*: iron, harmful elements, input raw materials, alkaline carbonates

**Utjecaj štetnih elemenata pri proizvodnji sirovog željeza u odnosu na ulaznu i izlaznu materijalnu bilancu.** Glavni cilj visokopećara uključuje maksimalnu proizvodnju sirovog željeza zahtijevanog kemijskog sastava uz minimalne troškove. To se može postići jedino na bazi kvalitetnih sirovina i besprijekornom radu visoke peći. Na obadva parametra utječe koncentracija nepoželjnih elemenata. Negativni elementi sadržani u visokopećnim sirovinama uzrokuju mnoge tehnološke probleme pri sinteriranju kao i u visokopećnom procesu. To su prvenstveno teški metali i alkalni karbonati. U radu je analizirana materijalna bilanca cinka i pojedinih alkalnih karbonata sadržanih u ulaznim sirovinama te izlaznim proizvodima visoke peći.

*Ključne riječi:* željezo, štetni elementi, ulazne sirovine, alkalni karbonati

## INTRODUCTION

Disruption of blast-furnace process is raised by a number of typical causes which most often lead to sudden changes in gas flow speed or decreased charge, and cooling or excessive heating of the furnace heart [1]. The outcomes can be changes in slag or pig iron viscosity and problems connected with their discharge from blast-furnace [2]. Most of these causes occur due to harmful substances such as alkali, zinc, lead and their compounds which can influence the course of blast-furnace process in various ways to such an extent that they can cause emergency situations. That is why it is necessary to pay extra attention to these substances and their compounds so as to prevent various serious malfunctions during the blast-furnace process.

The amount of harmful substances in blast-furnace process can therefore have significant effect on its course and technological and economic parameters [3]. Heavy metals, alkaline carbonates and silicates must be regulated and their contents in input and output raw materials must be continuously monitored.

The objective of this article is to compile the material balance of zinc, $Na_2O$ and $K_2O$ at the input and output of blast-furnace. The results of measurements in the period of one year, which were continuously performed in the monitored blast-furnace, will be used as the data.

## NEGATIVE ELEMENTS IN PRODUCTION OF IRON

Zinc belongs to heavy metals and it enters the blast-furnace process together with blast-furnace charge in the form of oxides and sulphides. With regards to its physical and chemical properties, there is a cycle in blast-furnace created between the lower parts with high temperatures which cause reduction and evaporation and the upper parts of the furnace stack with low temperatures where the vapours condensate [4]. Out of all these heavy metals, it is just zinc having the highest content in the raw materials. That is why the cycle of heavy metals can be analysed using zinc as an example. The presence of zinc in blast-furnace has a very negative effect on the lining, as it leads to build up in small pores and gaps. During the transition of zinc from gas phase to solid phase, zinc increases its volume, which may cause the distortion of the furnace lining surfaces. The main causes of blast-furnace lining damage by zinc compounds

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are: higher thermal stress, mechanical stress, oxidation and reaction with alkaline carbonates. Alkaline carbonates are supplied into blast-furnace by means of wide spectrum of components of blast-furnace charge. Great part of these components can be found in fuel.

More than one third of the total volume of alkaline carbonates entering the blast-furnace process in the form of charge can be found just in coke. It can be found mostly in the following compounds: $(K)Na_2O{\cdot}SiO_2$, $(K)Na_2O{\cdot}Al_2O_3{\cdot}xSiO_2$, $(K)Na_2O{\cdot}Fe_2O_3$, $(K)Na_2CO_3$ [5].

Alkaline carbonates have negative effect on the sintering process, quality of blast-furnace coke, quality of slag, and the lifetime of the lining. The penetration of alkaline carbonates into the lining significantly reduces the strength of refractory materials and thus the overall lifetime. That is why it is absolutely necessary to monitor the balance of harmful elements in the input raw materials and output products of the blast-furnace.

## EXPERIMENTAL PART

Content analysis of negative elements in the input raw materials and the output products were performed during a one year period in the monitored blast-furnace. Main attention was paid to the contents of Zn, $Na_2O$ and $K_2O$ in input and output materials. In case of alkaline carbonates, the feasibility limit of their quantities is expressed by sum of $Na_2O + K_2O$.

This limit depends on the blast-furnace but also on conditions of its operation, and, generally, it is 2,5-8,5 kg/t of pig iron [6]. When measuring the content of $Na_2O$ and $K_2O$, both negative substances were evaluated separately. The quantities of the individual negative elements had been determined on the basis of their measured percentage contents which were subsequently converted with regard to the weight of each raw material. Table 1 also shows the used quantities of raw materials per kilogram of produced pig iron.

Their total weight was afterwards determined on the basis of the chemical analysis results which had quantified the contents of the individual negative elements in all input raw materials. The total quantity in the input raw materials entering the blast-furnace process was determined for all the monitored elements. Table 2 shows the total percentage distribution of the content of the individual harmful elements in all input raw materials. Both sintering mixtures were unquestionably the largest sources of zinc in the blast-furnace charge within the scope of the measured values. Sinter - 2 was the source of 43,3 % of the total zinc content and sinter - 1 accounted for 36 %. Both used sintering mixtures thus contained 79,3 % of the total Zn content at the entry into the blast-furnace. The secondary sources may include pellets (6,5 %), coke (4,4 %) and a modified steel slag (3,1 %). Lump ore was the last significant source of zinc in the input raw materials; it contained 2,7 % of this metal. The content of zinc in other input raw materials can be considered as negligible due to its low levels. In case of $Na_2O$ content in the input raw materials, three main sources can be identified: Sinter - 2 (30,8 %), coke (26,8 %), Sinter - 1 (25,8 %).

Pellets represent another important source containing 9,4 % of the total volume of $Na_2O$ in charge. Other input raw materials can be considered insignificant in terms of $Na_2O$ content.

The amounts of the monitored negative elements that passed into the output raw materials undoubtedly represent a fundamental aspect here. Air losses were neglected as part of the research. The zinc oxides arising during the blast-furnace process, thanks to which there

Table 1 **Material balance - inputs into the blast-furnace process**

| | Weight | Quantity | Zn | | $Na_2O$ | | $K_2O$ | |
|---|---|---|---|---|---|---|---|---|
| | / t | / kg·kg$^{-1}$ | / % | / kg·kg$^{-1}$ | / % | / kg·kg$^{-1}$ | / % | / kg·kg$^{-1}$ |
| Sinter - 1 | 584 159 | 0,637 | 0,007 | $4{,}46{\cdot}10^{-5}$ | 0,07 | $4{,}46{\cdot}10^{-4}$ | 0,05 | $3{,}18{\cdot}10^{-4}$ |
| Sinter - 2 | 698 538 | 0,762 | 0,007 | $5{,}33{\cdot}10^{-5}$ | 0,07 | $5{,}33{\cdot}10^{-4}$ | 0,04 | $3{,}01{\cdot}10^{-4}$ |
| Slag – granulation product | 8 914 | 0,009 | 0,022 | $2{,}13{\cdot}10^{-6}$ | 0,07 | $6{,}80{\cdot}10^{-6}$ | 0,05 | $4{,}86{\cdot}10^{-6}$ |
| Beneficiated steel slag | 87 100 | 0,095 | 0,004 | $3{,}80{\cdot}10^{-6}$ | 0,05 | $4{,}75{\cdot}10^{-5}$ | 0,03 | $2{,}85{\cdot}10^{-5}$ |
| Separated material from sinter | 11 869 | 0,012 | 0,011 | $1{,}42{\cdot}10^{-6}$ | 0,14 | $1{,}81{\cdot}10^{-5}$ | 0,33 | $4{,}27{\cdot}10^{-5}$ |
| Granules | 247 301 | 0,269 | 0,003 | $8{,}09{\cdot}10^{-6}$ | 0,06 | $1{,}61{\cdot}10^{-5}$ | 0,13 | $3{,}35{\cdot}10^{-4}$ |
| Lump ore - Zaporoží | 103 900 | 0,113 | 0,003 | $3{,}40{\cdot}10^{-6}$ | 0,04 | $4{,}53{\cdot}10^{-5}$ | 0,03 | $3{,}40{\cdot}10^{-5}$ |
| Mn concentrate | 2 094 | 0,002 | 0,013 | $2{,}97{\cdot}10^{-6}$ | 0,36 | $8{,}22{\cdot}10^{-6}$ | 0,82 | $1{,}87{\cdot}10^{-5}$ |
| Limestone | 35 397 | 0,038 | 0,003 | $1{,}15{\cdot}10^{-6}$ | 0 | 0 | 0 | 0 |
| Coke | 504 334 | 0,550 | 0,001 | $5{,}50{\cdot}10^{-6}$ | 0,084 | $4{,}62{\cdot}10^{-4}$ | 0,171 | $9{,}41{\cdot}10^{-4}$ |
| Oil | 8 723 | 0,009 | 0 | 0 | 0 | 0 | 0 | 0 |
| Raw materials - Total | 2 292 329 | | | | | | | |

Table 2 **Percentage content of harmful elements in input raw materials**

| | Zn | $Na_2O$ | $K_2O$ |
|---|---|---|---|
| | / % | / % | / % |
| Sinter - 1 | 36,0 | 25,8 | 16,5 |
| Sinter - 2 | 43,3 | 30,8 | 14,9 |
| Slag – granulation product | 1,7 | 0,4 | 0,2 |
| Beneficiated steel slag | 3,1 | 2,7 | 1,4 |
| Separated material from sinter | 1,2 | 1,0 | 2,1 |
| Granules | 6,5 | 9,4 | 17,0 |
| Lump ore - Zaporoží | 2,7 | 2,6 | 1,7 |
| Mn concentrate | 0,2 | 0,5 | 0,9 |
| Limestone | 0,9 | 0 | 0 |
| Coke | 4,4 | 26,8 | 45,3 |
| Oil | 0 | 0 | 0 |

Table 3 **Material balance – outputs from the blast-furnace process**

| | Weight | Quantity | Zn | | $Na_2O$ | | $K_2O$ | |
|---|---|---|---|---|---|---|---|---|
| | / t | / kg·kg$^{-1}$ | / % | / kg·kg$^{-1}$ | / % | / kg·kg$^{-1}$ | / % | / kg·kg$^{-1}$ |
| Pig iron | 986 508 | 1 | 0,0031 | $3{,}10 \cdot 10^{-5}$ | 0 | 0 | 0 | 0 |
| Slag | 395 692 | 0,401 | 0,0019 | $7{,}62 \cdot 10^{-6}$ | 0,38 | $1{,}52 \cdot 10^{-3}$ | 0,43 | $1{,}73 \cdot 10^{-3}$ |
| BF sludge fine | 6 714 | 0,007 | 0,53 | $3{,}61 \cdot 10^{-5}$ | 0,08 | $5{,}44 \cdot 10^{-6}$ | 0,15 | $1{,}02 \cdot 10^{-5}$ |
| BF sludge rough | 9 270 | 0,009 | 0,31 | $2{,}91 \cdot 10^{-5}$ | 0,09 | $8{,}46 \cdot 10^{-6}$ | 0,13 | $1{,}22 \cdot 10^{-5}$ |
| Discharge | 21 970 | 0,022 | 0,034 | $7{,}57 \cdot 10^{-6}$ | 0,12 | $2{,}67 \cdot 10^{-5}$ | 0,15 | $3{,}34 \cdot 10^{-5}$ |

is a closed cycle of this element in the blast-furnace, are the principle important elements from the group of monitored negative elements when judged from this point of view.

During the measured period of one year, the monitored blast-furnace produced 986 508 tons of pig iron. Table 3 also shows the volumes of all other relevant products. Chemical analysis again determined the contents of Zn, $Na_2O$, $K_2O$. Percentage contents of harmful elements were determined per kilogram of produced pig iron.

Based on the determined total weight of negative elements in the output raw materials, their relative contents in each component specified in percentage value were set again. The results are shown in Table 4. According to the performed research, the highest amount of zinc on the output side of the blast-furnace process is found in fine blast-furnace sludge (32,4 %), followed by: pig iron (27,8 %), rough blast-furnace sludge (26,2 %), blast-furnace dust (6,8 %), slag (6,8 %). In case of content of $Na_2O$ in the output raw materials, the order was: slag (97,4 %), blast-furnace dust (1,8 %), rough blast-furnace sludge (0,5 %) and fine blast-furnace sludge (0,3 %).

In case of $K_2O$, the largest part goes into slag (96,8 %); the share of other contents in the output raw materials is as follows: blast-furnace dust (1,9 %), rough blast-furnace sludge (0,7 %), blast-furnace sludge (0,6 %).

Table 4 **Percentage content of harmful elements in output raw materials**

| | Zn | $Na_2O$ | $K_2O$ |
|---|---|---|---|
| | / % | / % | / % |
| Pig iron | 27,8 | 0 | 0 |
| Slag | 6,8 | 97,4 | 96,8 |
| BF sludge fine | 32,4 | 0,3 | 0,6 |
| BF sludge rough | 26,2 | 0,5 | 0,7 |
| Discharge | 6,8 | 1,8 | 1,9 |

The concentrations of all monitored harmful elements in furnace lining were determined as well. That is why samples of lining were taken along its entire height in the course of blast-furnace overhaul. Figure 1 shows the evolution of the contents of the individual monitored negative compounds according to the height of the blast-furnace. The data of concentrations were converted to percentage expression compared to the total content of harmful elements in the lining.

The highest zinc content in the blast-furnace lining was measured at a distance of 9-10 m from the top of the blast-furnace. High levels of this element were also measured at a distance of 21-25 m from the top of the blast-furnace. With regard to the compounds of $Na_2O$ and $K_2O$, the highest values in the lining were measured at a height of 16-18 meters from the top of the blast-furnace.

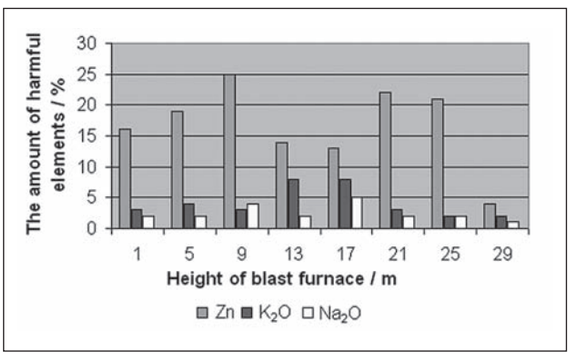


**Figure 1** Content of zinc and alkaline carbonates in the lining

## RESULTS AND DISCUSSIONS

From the monitored negative elements, particularly high contents of zinc can be found in the blast-furnace lining. Samples of lining collected during repairs of the blast-furnace have shown that zinc is mainly monitored in its metallic form. Zinc was very often found in compounds with lead. The resulting crystals containing zinc were very fragile. Zinc in the form of vapour inhales into the higher parts of the blast-furnace, which leads to formation of its deposits. These newly formed crystalline formations break off and fall back into the lower parts of the blast-furnace due to their instability. This is how a continuous cycle of zinc in the blast-furnace process runs. The most efficient method of removing zinc is during the sintering process. This is important in the face of the results of the research, as the largest proportion of zinc in the input raw materials was discovered in the sintering mixtures. The disposal of zinc within the frame of the sintering procedure requires high content of fuel, which greatly deteriorates not only the economic indicators of sintering production. If we increase the amount of fuel in the sintering mixture it leads to the formation of reducing conditions in the sintered layer and they are suitable for disposal of zinc. At the same time, however, you must be aware that the formation of reducing conditions in the sintered layer is counterproductive with regard to reduction of the amount of sulphur compounds. Zinc and alkaline car-

bonates can be effectively removed by adding chlorides. Creating reducing conditions represents another option. If chloride agents are used, there is an immediate change into gas chlorides which freely leave the process.

As demonstrated by the performed research, the main sources of alkaline carbonates are especially ores, from which they pass into the sintering mixtures. It is necessary to accurately monitor the alkalinity of sintering mixture, because the amount of alkaline carbonate is in direct relation. With increasing alkalinity of the sintering mixture there is a simultaneous increase of content of alkaline carbonates. Coke is another important source. However, during the process of coal coking, there is no fundamental change in the amount of alkaline carbonates. Most of the alkaline carbonates then merge into the blast-furnace process. The content of $K_2O$ in coke was 45,3 %. The content of this compound is naturally given by the quality blast-furnace coke. The highest contents of alkaline carbonate in the blast-furnace lining were detected in its central part, where they are melting. Alkaline carbonates entering the blast-furnace process, especially as part of ores and coke concentrate and accumulate in temperature range of 950 °C – 1 150 °C. Their presence in the blast-furnace lining can mean increased risk of destruction. The negative effect of alkaline carbonates can already be observed at low temperature zones.

## CONCLUSIONS

In order to regulate the negative effects of harmful elements on the blast-furnace process, it is necessary to continuously monitor the material balance. Variability of conditions in the blast-furnace, especially the thermal ones, can significantly contribute to elimination of harmful elements from the blast-furnace. However, it is also important to minimize the harmful elements supplied to blast-furnaces in raw materials of the charge. It is necessary to select such materials that contain minimum amount of harmful elements, despite the economic pressures. In case of removing harmful elements from the blast-furnace, it is necessary to regulate thermal and technological conditions in such a way to make it possible to remove the highest possible amount of alkaline carbonates through slag.

A large number of alkaline compounds entering the blast-furnace process are included in coke. This is unfortunately caused by the economic conditions. In recent years, there has been a significant increase in world prices of all fuels. Blast-furnace coke has become a significantly more expensive raw material and metallurgical companies are forced to buy even raw materials of lower quality. These aspects then naturally affect the amount of harmful elements entering the blast-furnace. In case of purchase of high-quality ore raw materials with low content of harmful elements, a significant reduction of harmful substances entering the blast-furnace process can be achieved. This is particularly important for the regulation of alkaline carbonates which can be reduced during the sintering process but to a very limited extent. Alkaline carbonates in blast-furnace process significantly affect mainly the viscosity of slag, which worsens the technological parameters of the process. Many studies have also proved the negative effect of alkaline carbonates and heavy metals on the properties of lining. Higher amount of harmful elements penetrating into the lining reduces the strength of refractory materials, which must naturally be prevented.

In case of zinc entry into the blast-furnace process, it is also necessary to mention its high content measured in the form of blast-furnace sludge. The utilization of these secondary raw materials obviously means economic effect which, however, brings along negative aspects as well. Using small metallurgical wastes produced during iron ore sintering causes ecological problems, in addition to technological ones. Increased proportion of dust particles in the mixture deteriorates the pelletizing ability of the sintered mixture and reduces the speed of sintering. The sintering process can significantly reduce the content of zinc entering the process in the form of sludge, which, on the other hand, means high amount of harmful elements leaking into the atmosphere. It is important at this point to use a quality system for separation of dust particles and purification of the leaking gases.

Monitoring the individual harmful elements in the manufacturing aggregates and optimizing the composition of the charge in such a way to prevent exceeding certain limit values set on the basis of operational experience remain the main measures of blast-furnace plants in terms of negative effects of harmful substances.

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**Note:** The responsible translator for English language is Petr Jaroš (English Language Tutor at the College of Tourism and Foreign Trade, Goodwill - VOŠ, Frýdek-Místek, the Czech Republic). Revised by John Vlcek (Literacy Tutor at West Suffolk College, Bury St Edmunds, England).

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# DEVELOPMENT AND EVALUATION OF THE MODEL FOR THE SURFACE PAVEMENT TEMPERATURE PREDICTION

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Preliminary Note – Prethodno priopćenje

This paper examines the existing models for predicting pavement temperatures and formulates a new one using a regression equation to predict the minimum and maximum pavement surface temperatures depending on the air temperature. Also, the paper presents a model for pavement temperature prediction according to the Superpave methodology and conducts the validation of the model for measured temperatures.

*Key words:* temperature, pavement, prediction

**Razvoj i ocjena modela za predikciju temperature površine kolničke konstrukcije.** U članku su predstavljeni postojeći modeli za predikciju temperature kolnika i formuliran je novi model pomoću regresione jednadžbe kojom se predviđaju minimalne i maksimalne temperature površine kolnika u ovisnosti od temperature zraka. Također je predstavljen i model za predikciju temperature prema Superpave metodologiji i izvedeno je vrednovanje modela za izmjerene temperature.

*Ključne riječi:* temperatura, kolnik, predikcija

## INTRODUCTION

Well-known facts and the experience prove us that, apart from traffic load, temperature and material moisture in the courses of the pavement structure and subgrade have the most significance in comparison to all external factors. Since the regime of the moisture in the pavement and in the subgrade largely depend on the heating regime, it can be concluded that temperature is a factor with a very wide and significant influence on the behaviour of the pavement structure.

Pavement structure is a multi-layered system composed of diverse materials whose behaviour is more or less dependent on the temperature.

The main task, then, is to determine physical and mechanical properties of materials in the conditions equivalent to the conditions in the real pavement structure. In this sense, with the bitumen-bound materials, it is important to determine their characteristics in the range of temperatures in the pavement structure, with the special consideration on the impact of extreme temperatures, as shown in Figure 1 [1].

The damage of the pavement structure depends on the demanded functional pavement characteristics, which are defined primarily in relation to the following: traffic volume, participation and weight of cargo vehicles, ambient conditions, valid vehicle speed, exploitation costs, and maintenance costs. Figure 2 presents a

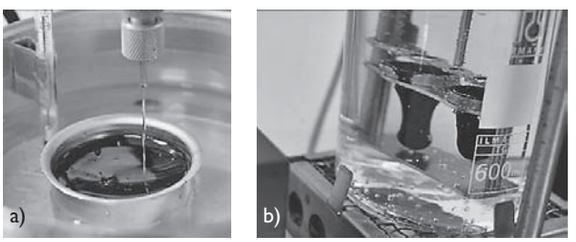


**Figure 1** Examination of physical and mechanical properties of bitumen depending on the temperature: a) penetration and b) melting point [1]

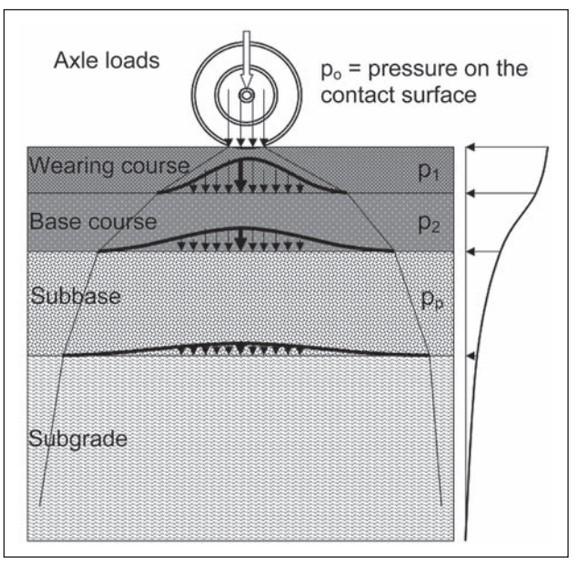


Figure 2 Flexible pavement and load distribution [2]

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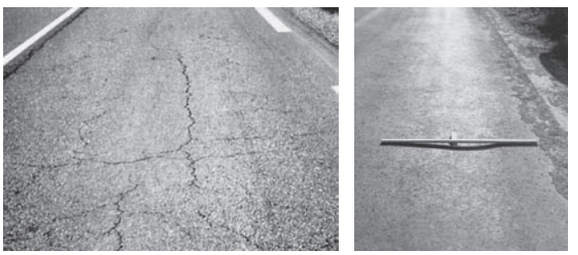

a) b)

**Figure 3** Pavement damage: a) line and grid cracks and b) rutting [1]

scheme of load transfer from the vehicle axis, through the pavement courses, subbase, and subgrade.

In the case when the selected materials do not satisfy the appropriate bearing capacity in diverse types of load and different ambient conditions (temperature and moisture), diverse damage and defects in the pavement structure can occur, and they can be manifested in all courses (longitudinal and transverse cracks) or only in upper courses (surface damage of asphalt courses).

Figure 3 provides an overview of some characteristic cases of the pavement structure damages.

## CALCULATIONS ON PAVEMENT TEMPERATURE

The occurrence of high temperatures in the warmest periods of the year can significantly increase the influence of the viscous component in the behaviour of the asphalt mixture and can lead to greater pavement deformations, especially with the action of heavily loaded wheels moving slowly or standing still (extreme example are bus stations, traffic lanes for heavy vehicles on a hill, etc.).

Due to this reason, it is extremely important to determine the danger of the appearance of deformations in the condition with extreme temperatures, and primarily to determine the height and duration of these temperatures, as well as to analyse traffic load in detail. Therefore, pavement temperature largely depends on the season and the position of the Sun, as presented in Figure 4.

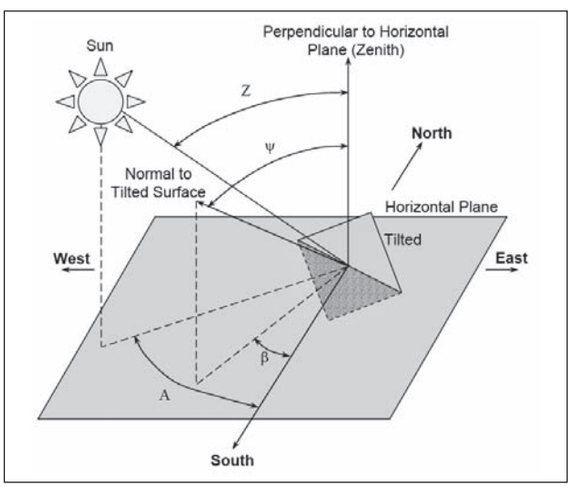


**Figure 4** Defining the position of the Sun [3]

## State of the art

One of the first researchers examining the problem of calculating maximum pavement temperatures based on the weather reports was Barber in 1957. Dempsey [4] developed a simulation model based on the theory on heat conductivity and energy balance on the pavement surface. Strategic Highway Research Program (SHRP) formed the Long-Term Pavement Performance (LTTP) programme in 1987 as a product of 20-year-long research for better defining the pavement characteristics in situ. 64 (LTTP) locations were selected as a part of the Seasonal Monitoring Program (SMP). The result of the SMP research is the SUPERPAVE (Superior Performing Asphalt Pavement) method for designing asphalt courses.

From the initial (SHRP) tests to SMP, models for defining pavement temperature were developed in order to help in the formation of adequate asphalt courses; they were provided in the conditions of PG (Performance Grade) [5].

The comparison of the selected PG and the real temperatures was investigated by Mohseny and Symons [6], Bosscher et al. [7] and Diefenderfer et al. [8]. The research of Marshal et al. [9], Denneman et al. [10] provide an empirical model that enables the user to estimate the temperature profile of the pavement structure during any part of the day.

## DETERMINATION OF PAVEMENT TEMPERATURES USING THE SUPERPAVE METHOD

After several years long research (LTTP and SMP) on the behaviour of pavement structure under traffic load and in environmental conditions, the method for designing asphalt pavements, called SUPERPAVE, has been formed.

The process of calculating pavement temperature from air temperature is as follows:

- Convert average 7-day maximum air temperature to pavement surface temperature,
- Calculate 7-day maximum pavement temperature at the design depth,
- Convert minimum air temperature to minimum pavement surface temperature,
- Calculate minimum pavement temperature at the design depth.

Environmental conditions are specified in terms of average 7-day maximum pavement design temperature and minimum pavement design temperature. The average 7-day maximum pavement design temperature is the average of the highest daily pavement temperatures for the 7 hottest consecutive days in a year. The lowest annual pavement temperature is the coldest temperature of the year. The asphalt binder specification uses the designation PG x-y, where PG = Performance Graded, x = high pavement design temperature, and y = low pavement design temperature [4].

The pavement surface temperature can be calculated using the following regression equation (Huber 1994):

$$T_{s(\max)}=T_{a(\max)} - 0{,}00618\cdot\phi^2 + 0{,}2289\cdot\phi^2 + 24{,}38 \quad (1)$$

The equation for minimum asphalt surface temperatures recommended in the Superpave is as follows:

$$T_{s(\min)}=0{,}859\cdot T_{a(\min)} +1{,}7 \quad (2)$$

## MODEL FOR PAVEMENT SURFACE TEMPERATURE PREDICTION

### Data used for model formation

The data for the model formation were collected during the period of nine consecutive years, with breaks related to technical and organizational issues. Monitoring temperature changes in the air, and pavement courses was conducted at several diferent locations.

### Methodology and anticipated results

The model developed with the objective of predicting pavement surface temperature is based on the regression data analysis. Regression equations are formed to predict maximum and minimum pavement surface temperatures, depending on the maximum (at 3:00 p.m.) and minimum (at 7:00 a.m.) air temperature.

Data analysis is performed in the programme STATISTICA. The analysed pavement structure is presented in Figure 5. The analysis was done on a half-rigid pavement structure where two bearing courses (15 and 20 cm) were stabilized by a hydraulic binder. Other courses and pavement were the same as with flexible pavements, so methodologically they can be treated as flexible pavements.

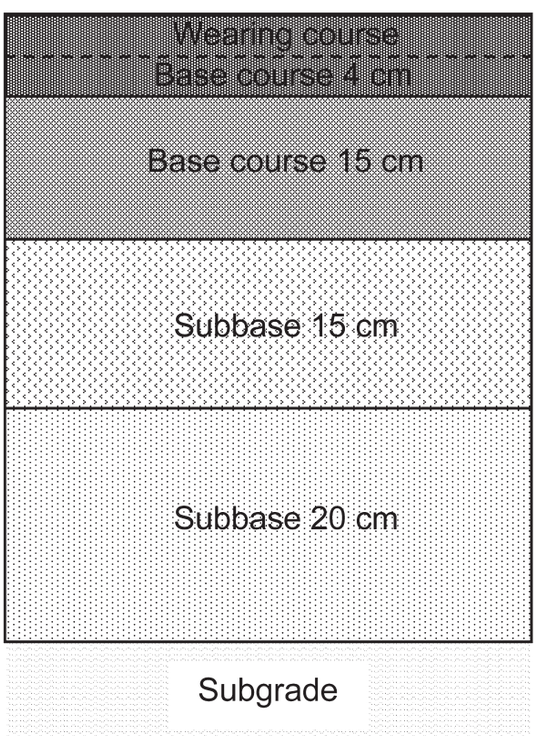


**Figure 5** Overview of the analysed pavement Structure

### Regression equations

The model predicting maximum temperatures in the pavement surface can be presented by the following equation:

$$Y_{p,\max}=0{,}065567 + 1{,}268887\cdot X_{a,\max} \quad (3)$$

Standard model deviation is 3,0016. Correlation coefficient is 0,972651.

The model predicting minimum temperatures in the pavement surface can be presented by the following equation:

$$Y_{p,\min}=0{,}318933 + 1{,}10967\cdot X_{a,\min} \quad (4)$$

Standard model deviation is 1,8569. Correlation coefficient is 0,980397.

## MODEL VALIDATION

Based on the formulated model for predicting maximum and minimum pavement surface temperatures (3, 4), the model validation has been performed by comparing measured and predicted pavement temperatures (Figure 6).

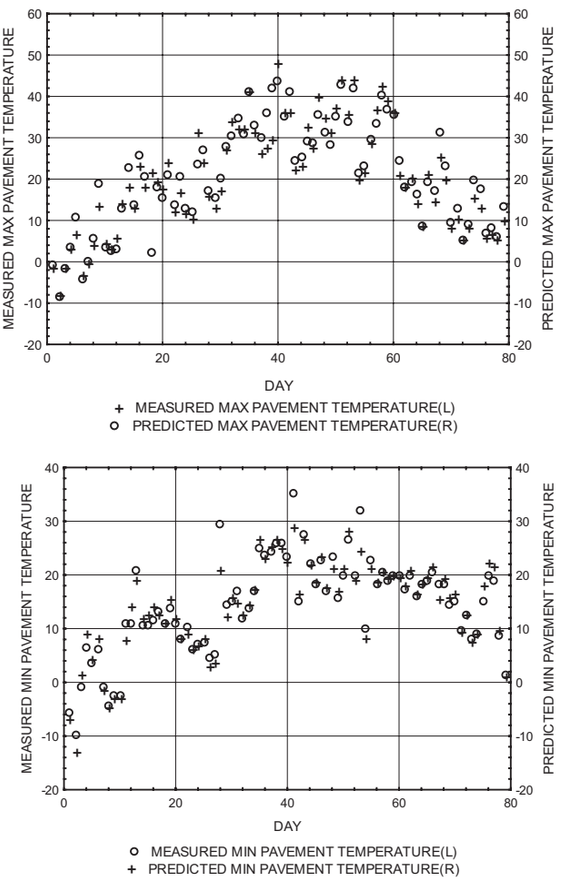


**Figure 6** Validation of the model for predicting maximum (a) and minimum (b) pavement surface temperatures

The mean absolute error (MAE) between measured and predicted maximum pavement temperatures is 2,291912 while standard deviation of error (SDE) is 5,091 and between measured and predicted minimum pavement temperatures MAE is 1,169958 and SDE is 1,816 (Figure 6). On comparing measured maximum pavement surface temperatures and temperatures according to the SUPERPAVE methodology, it has been determined that the MAE is 18,68676 and SDE is 5,194 while the MAE between measured and predicted minimum pavement temperature is 2,197991 and SDE is 2,833.

## CONCLUSION

The paper formulates new models for predicting minimum and maximum pavement surface temperatures using regression equations, in dependence on the ambient air temperature. Furthermore, model validation has been conducted. Based on the correlation coefficient, standard model deviation and the mean absolute error (MAE) and standard deviation of error (SDE) between measured and predicted pavement temperatures, it can be concluded that the models predict pavement surface temperatures well and that they can be utilized for calculations in analysing air temperature influence on a pavement structure.

On validating the model for pavement temperature prediction according to the SUPERPAVE methodology and in relation to the measured temperatures, the conclusion is that the model does not predict pavement temperature with adequate accuracy.

## Acknowledgment

The authors acknowledge the support of research projects TR 36017 and 174019, funded by the Ministry of Science and Technological Development of Serbia.

## Legend of symbols

$p_0$ pressure on the contact surface /Pa

$p_1$, $p_2$, $p_p$ pressures at the specified depth of pavement /Pa

$T_{\alpha(\max)}$ the daily maximum air temperature /°C

$T_{s(\max)}$ the daily maximum asphalt surface temperature /°C

$\Phi$ latitude of the desired location /degrees

$T_{s(\min)}$ the daily minimum surface temperature /°C

$T_{\alpha(\min)}$ the daily minimum air temperature /°C

$Y_{p,\max}$ predicted maximum daily surface pavement temperature /°C

$X_{a,\max}$ measured maximum daily air temperature /°C

$Y_{p,\min}$ predicted minimum daily surface pavement temperature /°C

$X_{a,\min}$ measured maximum daily air temperature /°C

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# NECESSITY AND EFFECTS OF DYNAMIC SYSTEMS FOR RAILWAY WHEEL DEFECT DETECTION

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Preliminary Note – Prethodno priopćenje

State of railway vehicles highly influences transport safety due to vehicle derailments and in the same time worsens the quality of freight and passenger transportation. One of important elements that influence the state of railway vehicles is the wheel state. Wheel defects are common in railway transport. Therefore, timely defect detection is very important. This paper presents ways and effects of timely detection of wheel defects.

*Key words:* railway wheel, defects, diagnostics, dynamic monitoring.

**Potreba i efekti dinamičkih sustava za detekciju defekata točkova željezničkih vozila.** Stanje željezničkih vozila bitno utječe na sigurnost prometa zbog rizika iskliznuća i istovremeno smanjuje kvalitet prevoza robe i putnika. Jedan od bitnijih čimbenika koji utječu na stanje željezničkih vozila jeste stanje točkova. Defekti točkova su česta pojava u željezničkom prometu. Iz tog razloga, veoma bitno je pravovremeno otkrivanje defekata. U ovom radu su prezentirani načini i učinci pravovremenog detektiranja defekata točkova.

*Ključne riječi:* željeznički točak, defekti, dijagnostika, dinamički monitoring

## INTRODUCTION

An extraordinary event in railway operations implies an event which impedes or makes service impossible, endangers human lives and destroys railway property and goods in transportation. Analyses show that about 60 % of extraordinary events in railways are caused by the technical malfunction and about 40 % are the consequence of human failures in operations or maintenance.

For equipment for contactless detection of overheating, flat spots, uneven loading or loading out-of-gauge the most interesting are derailments in the process of shunting. This is the biggest cause of accidents on Serbian Railways (SR) (77 % ÷ 100 % in the last two years), and a large number of operating accidents (about 17 %, but in the last two years over 20 %).

Higher degree of automation on railways is achieved through process of modernization. The current world trend is the application of modern control systems for a dynamic monitoring of vehicles [1, 2].

In addition to brake systems wheel sets are important from the point of reliability and safety of railway vehicles. Risk of derailments exists, threatened by poor technical condition of the wheels. This is why early detection of wheel defects and the implementation of systems for their detection are multiple profitable for infrastructure managers and railway operators.

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## WHEEL DEFECTS

The nature of defects can be different: mechanical wear, defects in wheel material and non-homogeneous material, defects caused by heat stresses and overheating.

All defects that may happen on the surface of the wheel rolling circle are divided into seven groups (Figure 1).

The wear of wheels and rails results from a complex dynamic relationship within the movement of rail cars at the track with wheelspin. Analysis of wear of tracks and wheels are essential for safety and economics. The most important influences on the wear rate are usually classified into several groups [3]: wheel and rail materials, geometry of the wheel-rail contact, variations in production and assembly, the conditions of exploitation,

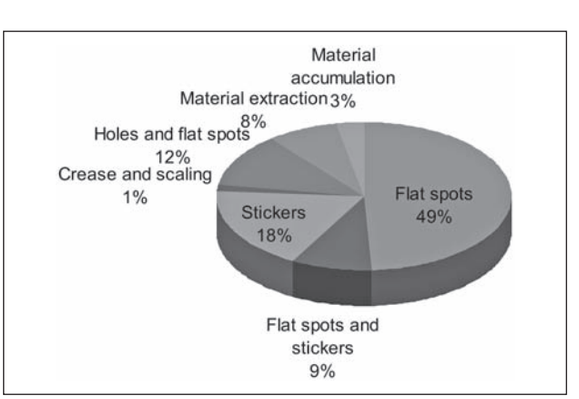


**Figure 1** Defects on the surface of the wheel rolling circle

constructional features of the vehicle that affect its dynamics and motion track geometry.

The hardness of the material point of the rails, determine the speed of their wear. Wear is less when the material is harder than the material point rails. Recommended point is that the material has a hardness of up to 10 % higher. The wheel wear process significantly affects the heat treatment process applied. On the basis of experimental tests it has been proofed that for same hardness it can be got in different wear [4]. Normal hardening annealing gives a very negative resistance, while isothermic hardening during the pearlite phase gives better results.

European standard for making of wheel steels defined as follows steels: ER6, ER7, ER8 and ER9. Hardness Brinell, to a depth of 35mm below the surface is given in Table 1.

Table 1 **Hardness on the wheel edge by Brinell**

| Steel mark | The minimum value for categories | |
|---|---|---|
| | K1 (>200 km/h) | K2 (<200 km/h) |
| ER6 | - | 225 |
| ER7 | 245 | 235 |
| ER8 | 245 | 245 |
| ER9 | - | 255 |

Studies have shown that increasing the surface hardness of the rolling wheel on thermal treatment of HB 450, and wreath on HB 600 ÷ 800, may 1,5 ÷ 3 times reduce wear of wheels and rails [4].

During braking process, the brake pad in contact with surface of rolling wheels, the vehicle kinetic energy of is converted into heat and in very high percentage transferred to the wheel. Consequently temperature rises and can reach values that cause the limit excees of elasticity of materials, plastic deformation and residual stresses after cooling. These residual stresses can be large enough to cause the initial point cracks at the edge of the wheel (broken) and even breaking point with major consequences for safety.

The main indicator of the thermal load point is the colour transition between the rim and wheel body or the traces of oxidation on the edge of the wheel. If the brake pads are outside of the wheel rolling surface, then the high thermal stresses occur, especially in the outer part of the surface which gives rise to excessive residual stresses and wheels braking. Typical examples of wheels braking are shown in Figure 2.

**Figure 2** Typical examples of wheels braking [5]

The break points may be affected by defective construction vehicles and low quality materials in manufacture.

Occurrence of defects is caused by the heating of the wheels due to braking. Heating rolling surface leads to plastic deformations, and thus to increased wear due to friction.

Another type of defects are defects of thermal-mechanical nature. These defects are characterized by creation of rings around the wheel edges, especially in the case of brakes made of composite materials. The reason of these defects are unequal working conditions on surface layers of metal wheels and brakes in the contact zone and the penetration of abrasive particles and dust on the metal surface along the edge of brake. Local resistance point ("flat spot") are caused by wheels blocking as results of plastic deformation caused by heating of the contact surface.

Thermo-mechanical defect is creation of labels and annealing sites ("white spots") on the rolling surface. Both defects are due to the combined effects of wheel heating. Above mention layers have high hardness (up to 900 HB) and features of high residual voltage due to which form micro cracks. Stickers can also be torn of the wheel which leads to straining of axel, vehicle and rail.

White spots are caused by sudden cooling of overheated to a temperature higher than the critical for structural changes in the surface layers of metal wheels. Low temperature and high humidity contribute to the appearance of white spots.

Transverse cracks on the surface of the wheel are prevalent form of defects, resulting of alternating heating during braking and cooling.

Unusual and undesirable defect is tearing of metal wheels under the influence of external and internal forces. It precedes the disorder homogeneity of the material ("pulling out of material"). This defect contributes to the martensitic structure of the surface layers of metal which is characterized by high hardness and breakability.

The main reason for the formation of flat spots is improper braking (air brake overload devices, tightened the handbrake and the wrong braking lever). In the case of brake inserts of composite materials and higher braking level starts thermal overheating, and thus the appearance of defects on the surface of the wheel rolling surface [3].

## DIAGNOSIS OF DEFECTS WHEELS

Stationary systems used for diagnostic and monitoring on open line diagnose the mechanical condition indirectly (temperature and noise measuring) and directly

(measuring the acceleration of the mechanical part in the movement).

Measuring stations provide continuous monitoring of vehicle status and parameters of superstructure loads. Measuring equipment (installed on the line) and the measurement process does not interfere with the normal conduct of transport.

Example of installation check point for railway wheel defect detection with dynamic weighing is shown on Figure 3 [6]. Check point measure all axle loads and vertical interactions between rails and wheels on vehicles in movement at a speed of 120 km/h.

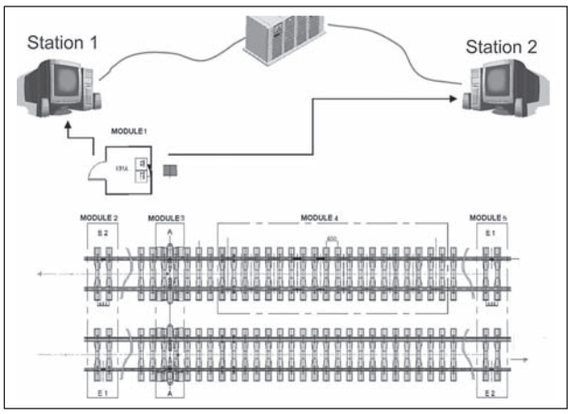


**Figure 3** Sheme of stationary installation

Generally, the trains are registered in both travelling directions; weighbridge axles' temperature is measured contact less on the left and on the right side. Simultaneously, the wheel center and brake disks temperature is also measured. Every body that has a temperature above absolute zero emits electromagnetic radiation proportionally to its temperature. The wavelength of that radiation is within the range 0,7 ÷ 1000 μm. The range of interest for technical measurements is 0,7 μm to 14 μm [6].

The most important characteristic of the device for detection of overheated axle bearing (HOA) is double checking of axle bearing' pair of wheels. Sensor device uses gauges which follow rail deflection caused by the wheel seating force. Sensors are put onto the rail, between sleepers.

A computer loads measu-rement data when the train passes through measurement point and calculates axle loads of every wheel and the size of flat places. Sensor device is mounted on the rail side, along neutral line (Figure 4). Gauges are welded onto the rail.

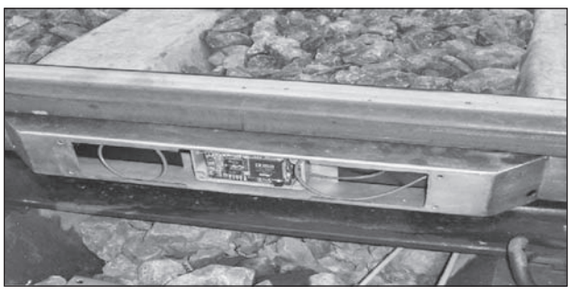

**Figure 4** Measurement module in a box

In a case of any irregularity detected on trains passing over the installation, pictogram alarms will be shown on each monitor connected to the stationary system network (Figure 5 a, b, c and d).

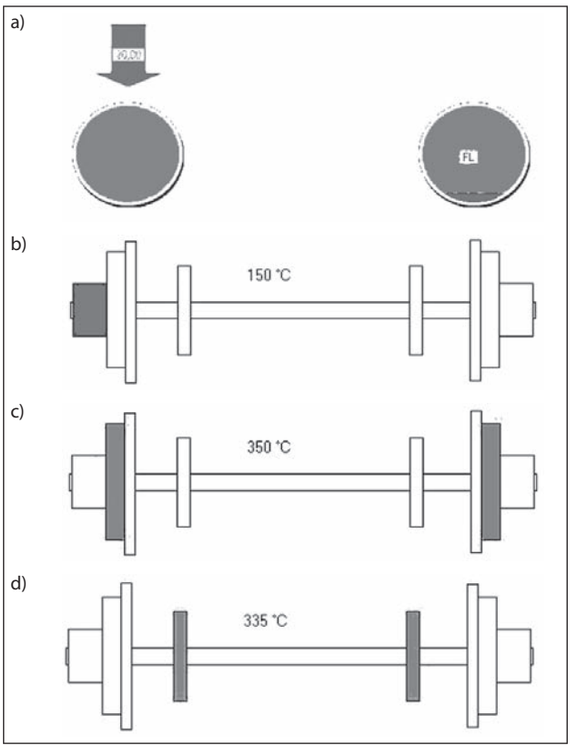


**Figure 5** Irregularity detection: a) Overloaded wheelset and wheel flat spot, b) Overheated bearing detection, c) Irregular wheel temperature d) Irregular brake disc temperature

## MODEL FOR EFFECTIVENESS EVALUATION OF EQUIPMENT INVESTMENT

The specific view in the accident data base is given by the aspect whether it is possible to recognize one fault state by some wayside monitoring system. Risk is always defined as a product of probability and severity. The European standard [7] offers the possibility to deal with different risks by using a risk matrix [8]. For operational application the qualitative descriptions of probability and severity are quantified (Table 2). The calibrated matrix covers the range of operational scope. The protection goal for wayside train monitoring at SR is set up to 500 000 € per year. Finally, the protection goal divides the matrix into two areas: one below the protection target and one above the protection target where there is a serious demand to set preventive measures to reduce risk to the infrastructure manager caused by car related fault states which may destroy the infrastructure.

The estimate of installations application is carried out after taking into consideration all costs and benefits by standard dynamic ratability methods.

Results for the investment estimate are:

- Internal rate of return (IRR) = 11,99 %,
- Net present value (NPV) = 603 719 €.

The Internal rate of return, which is inside the profitable zone, leads to the conclusion that the investment is profitable from an economic point of view. The Internal rate of return would be significantly higher if indirect costs could be taken into consideration.

The Sensitivity Analysis has been carried out after estimates of all relevant financial effects which can come about from this investment. The relationship between input parameters and the Project rate of return has been analysed. The Sensitivity Analysis has been carried out using the following assumptions – IRR:

- Basic case = 11,99 %
- Increase of investment by 20 % = 9,64 %
- Decrease of investment by 20 % = 15,32 %
- Increase of savings 20 % = 14,78 %
- Reduction of savings 20 % = 9,26 %.

Table 2 **Calibrated risk matrix in Mio.€ per year [8]**

| | | | | |
|---|---|---|---|---|
| A (Weekly) | 0,24 | 2,4 | 24,0 | 240,0 |
| B (Monthly) | 0,06 | 0,6 | 6,0 | 60,0 |
| C (Once a quarter) | 0,02 | 0,2 | 2,0 | 20,0 |
| D (Yearly) | 0,005 | 0,05 | 0,5 | 5,0 |
| E (Once in ten years) | 0,0005 | 0,005 | 0,05 | 0,5 |
| F (Once in one hundred years) | 0,00005 | 0,0005 | 0,005 | 0,05 |
| | IV (Insignificant - 5 000 €) | III (Marginal - 50 000 €) | II (Critical - 500 000 €) | I (Catastrophic - 5 000 000 €) |

## CONCLUSION

Unlike Western European and Central European railways on Serbian Railways detections of overheating, flat spots, uneven loading or loading out-of-gauge are performed only when the train stops at the station. In the world already exist more sophisticated methods that can detect defects during the movement of trains.

With the aim of failure detection it seems to be important to install a wayside network of train monitoring devices which are capable of non-contact and dynamically detection, processing and reporting of appropriate signals (at a distance and with the required accuracy) in the case of overheating, flat spots, uneven loading.

As it is clearly shown in the project sensitivity analysis, the project is highly resiliant to all variations of input parameters and also to expected divergences. The facts indicate investment return and necessity of immediate project realization which should significantly reduce costs for both infrastructure and vehicle maintenance.

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# FOUNDRY INDUSTRY – CURRENT STATE AND FUTURE DEVELOPMENT

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Review Paper – Pregledni rad

The casting production is considered as one of the main factors influencing the development of world economy. The state of art and foresight of world's casting production is discussed in the paper on the basis of the latest statistical data. The progress gained during the last few years in foundry engineering is shown as a way to further development of foundry technology. The last decade brought significant changes in the world map of the greatest casting producers. Globalization and transformation of economic systems is reflected by variations of foundry production in different countries, more over the globalization of economy is regarded not only as a chance but also as a menace for the European foundries.

*Key words:* foundry, casting, production, development.

**Ljevačka industrija – sadašnje stanje i budući razvitak.** Ljevačka proizvodnja se smatra jednom od glavnih utjecajnih faktora u svjetskom gospodarstvu. Stanje postignuća i predmnijevanje ljevačke proizvodnje na temelju posljednjih statističkih podataka daje se u ovom članku. Polučeni napredak tijekom nekoliko posljednjih godina u ljevačkoj tehnici je prikazan kao putokaz budućeg razvitka ljevačke tehnologije. Posljednja dekada donosi značajne izmjene na svjetskoj karti najvećih proizvođača odljevaka. Globalizacija i tansformacija ekonomskog sustava održavanja se raznolikošću u ljevačkoj proizvodnji različitih država, što više globalizacije gospodarstvo se motri ne samo kao šansa nego i kao ugroz europskih ljevaonica.

*Ključne riječi:* ljevarstvo, odljevak, proizvodnja, razvitak

## INTRODUCTION

The casting production is considered of the main factors influencing the development of Word economy. Actual capacity of the world's casting production, which is higher than 91 mln metric tons per year (2010), is strongly diversified. The last decade brought significant changes in the Word map of the greatest casting producers. Globalization and transformation of economic systems is reflected by variations of foundry production in different countries, moreover the globalization of economy is regarded not only as a chance but also as a menace for the European foundries [1].

## ESTIMATION OF THE CURRENT SITUATION IN THE WORLD'S CASTING PRODUCTION

A casting production in the last years has had an increasing tendency. It is shown by the fact, that the world casting production increased by 13,7 % from 2009 to 2010. However, the total casting production being 91,4 million tons in 2010, was still lower than the production in 2008 being 93,5 million tons and than the peak year 2007 when the casting production equaled 94,9 million tons.

Out of 36 countries, main casting producers in the world, in 4 countries only the casting production in 2010 was lower than in 2009 (Canada, Norway, Serbia and Slovenia). Whereas Taiwan and Brazil had the highest production increase in this period, being 42 % and 41 %, respectively.

10 countries, the largest casting producers in the world produced in 2010 approximately 88 % of casting, having the same participation in the global production as in 2009. The largest casting producers in the year 2010 were: China, India, USA, Germany, Russia, Brazil, South Korea, Italy and France (Figure 1, Table 1).

Casting production in the EU countries in 2010 is shown in Figure 2.

The leader in the casting production from many years is China, which produced 43 % of castings in 2010. The second place, however with the production 4-times smaller than China, belongs to India, which share is 10 %, due to 22 % increase in relation to 2009. A significant production increase (11 % as compared with 2009) obtained also the United States of America. The EU countries share in the casting production equaled approximately 15 % (Figure 3) [2-4].

The highest fraction constitute gray iron castings, which tonnage in 2010 was 44,1 million tons, it means above 48 %. Castings of the spheroidal cast iron constituted nearly 25 % and increased by 1% in relation to

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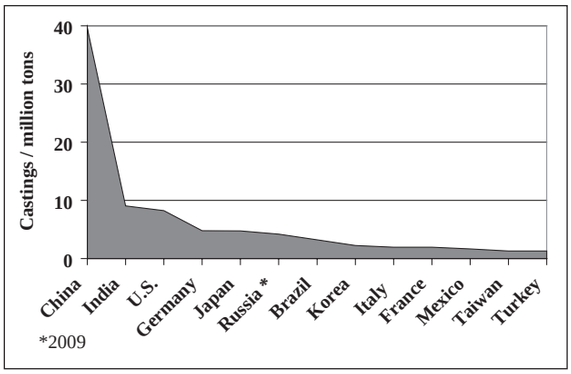


**Figure 1** Castings production in the leading world countries in 2010 [2]

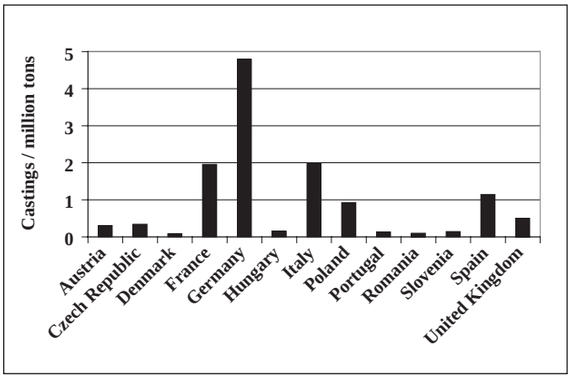


**Figure 2** Casting production in the EU countries in 2010 [2, 3]

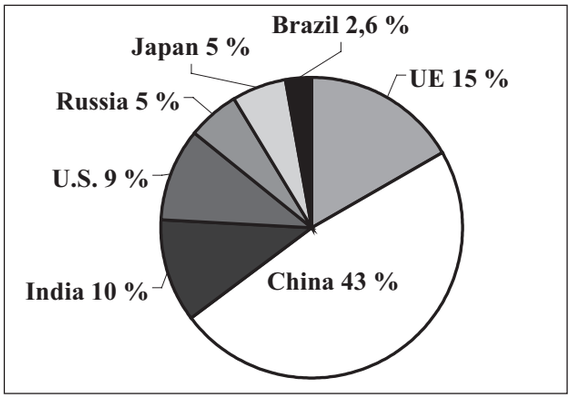


**Figure 3** Leading countries share in the world castings production [2-4]

2009. Whereas the share of steel casts equaled approximately 11 % and was slowly decreasing during the year 2010, in a similar fashion as the non-ferrous metals castings, which equaled approximately 16 % in 2010 (Figure 4). Among the non-ferrous metals castings the dominating position was taken by the aluminium alloy castings (approximately 11 % of the total world casting production). The share of magnesium, zinc, copper and other non-ferrous metals was very small.

Casting production value of 10 largest producers – with indicating the kind of material – in the year 2010 are shown in Table 1.

Tendencies in the global production of castings with indicating the kind of material (in years 2001-2010) are

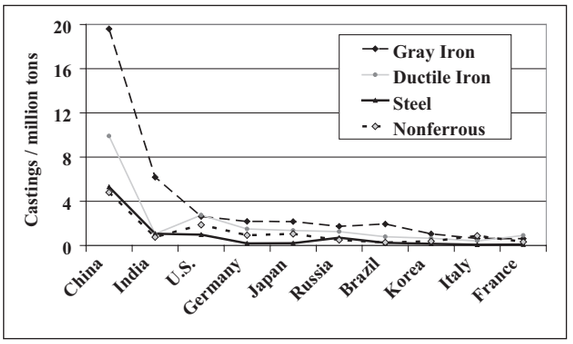


**Figure 4** Fraction of individual casting materials in the world production in the year 2010 [2]

Table 1 **Casting production in countries being the largest producers, showing fractions of various materials used [2]**

| Country | Gray Iron | Ductile Iron | Steel | Nonferrous | Σ |
|---|---|---|---|---|---|
| | Castings / thousand tons | | | | |
| China | 19 600 | 9 900 | 5 300 | 4 800 | 39 600 |
| India | 6 180 | 1 050 | 1 070 | 750 | 9 050 |
| U.S. | 2 630 | 2 750 | 980 | 1 870 | 8 230 |
| Germany | 2 180 | 1 490 | 192 | 930 | 4 792 |
| Japan | 2 160 | 1 350 | 207 | 1 040 | 4 757 |
| Russia | 1 740 | 1 260 | 700 | 500 | 4 200 |
| Brazil | 1 940 | 786 | 243 | 273 | 3 242 |
| Korea | 1 040 | 653 | 157 | 382 | 2 232 |
| Italy | 630 | 405 | 64 | 870 | 1 969 |
| France | 623 | 916 | 85 | 333 | 1 957 |

presented in Figure 5, while for the selected largest casting producers – in Figure 6 a, b. It is worth to notice that the crisis of the year 2009 influenced the China casting production very favourably, and in a certain degree also India, while the remaining countries reported the production decrease.

The total number of foundry plants in the world amounts to more than 48 000, out of which nearly 55 % are located in China. The second place in respect of the foundry plants number belongs to India, where there is more than 9 % foundry plants. The most of them are

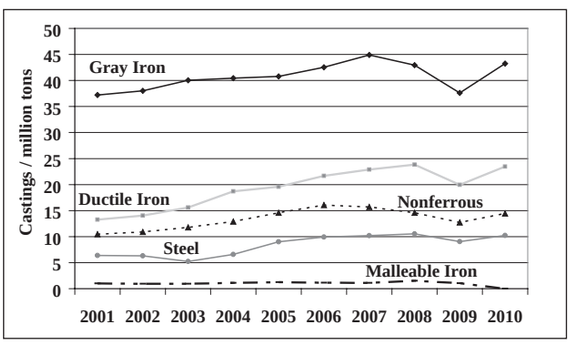


**Figure 5** Casting production in the years 2001 – 2010, showing fractions of various kinds of material used [5]. Notice: It is expected that in 2011 production of ferrous alloy castings was 78 million tons, aluminium alloy castings approxinately 13 million tons, and copper alloy castings 1,6 million tons [6].

producing iron castings (50 %). An average annual production of one foundry plant equals in China 1 500 tons, in India app. 2 000 tons, while in Japan nearly 3 000 tons, in the USA – 4 000 tons, and in Germany – the clear leader in productivity – above 7 800 tons. This indicates that the foundry industry is highly fragmented in the first two countries, which at the same time are the largest casting producers [7].

The foundry industry is predominantly still an SME industry, with 80 % of companies employing less than 250 people. The foundry production which is now undertaken results from fewer units and less employees. This can be explained by progressive up scaling and automation in the foundry units. The relationship between unit size, production and employments is well illustrated in Figure 7 (ferrous foundry) and Figure 8 (nonferrous foundry).

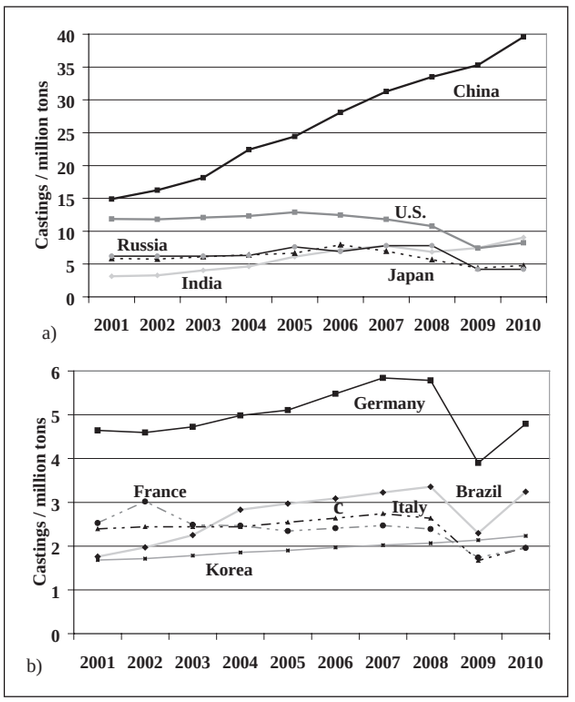


**Figure 6** Total casting production in 10 countries, being the leaders, in the period: 2001 – 2010 [5]

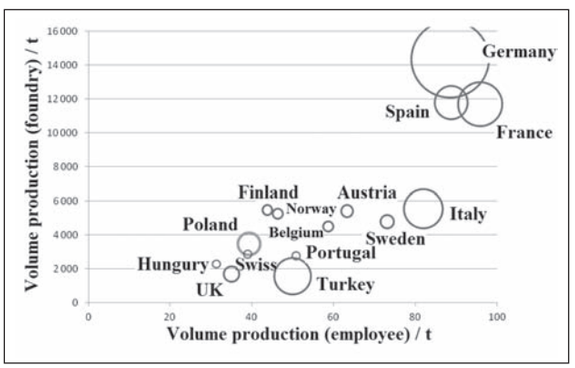


**Figure 7** Ferrous foundry productivity data for various European countries. Notice: the size of the circle represents the total production in the specified country [2-4]

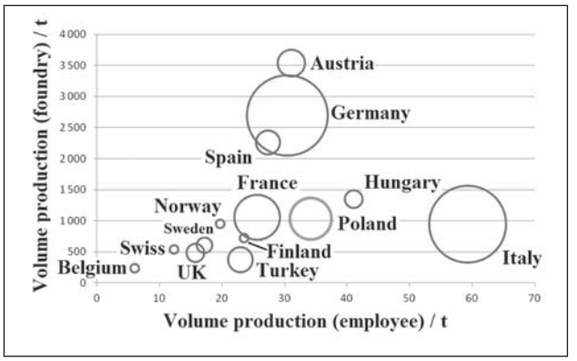


**Figure 8** Non ferrous foundry productivity data for various European countries. Notice: the size of the circle represents the total production in the specified country [2-4]

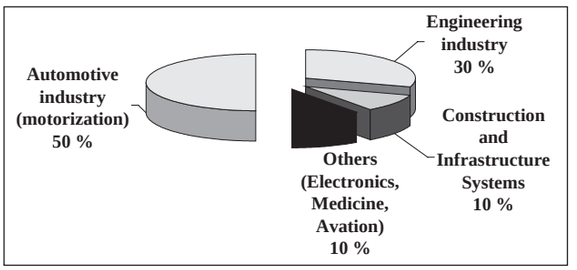


**Figure 9** Main markets server by the foundry industry

The comparison of the production effectiveness in the European countries in years 2009 and 2010 indicates an increase. Within the ferrous alloy castings the production effectiveness is the highest in Germany, France and Spain. Whereas within the domain of the non-ferrous metals castings the sequence is as follows: Austria, Germany, Spain.

The main markets server by the foundry industry are the automotive, general engineering and construction sectors (Figure 9).

## IS THE FOUNDRY INDUSTRY AS THE PRODUCTION TECHNIQUE HAVING FUTURE?

Analysis of the world economy and its development trends indicates for the constantly growing share of foundry industry as the production and treatment technology of metal products. The biggest growth of casting production takes place in the countries being the economic leaders, in which it constitutes the significant part of the global income (Figure 10).

Continuous development of technologies and means of production did not cause any elimination of casting as a production techniques, but – on the contrary – increased its importance and resulted in treating the foundry industry as a significant and constant element of economic and civilization development of nations. Direct shaping of metal products of practically every degree of complication, realized by the limited number of technological procedures, eliminating several additional operations – necessary when other production tech-

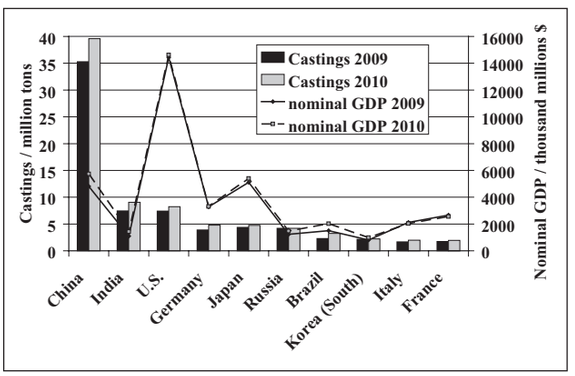


**Figure 10** Gross domestic product (GDP) and the castings production in 2009 and 2010 in countries being the leaders in the casting production

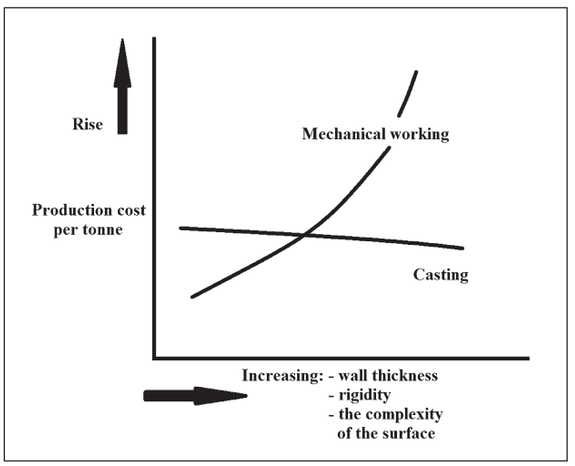


**Figure 11** Comparison of the production costs of the product obtained by means of the casting technology and mechanical treatment technology [8]

niques are employed – constitutes still the basic and advantage of this method, even when castings are in the range of the so-called "high-tech" (Figures 11, 12).

## CHANCE AND DIRECTIONS OF THE FOUNDRY INDUSTRY FURTHER DEVELOPMENT

The most important research directions leading to further development of the foundry industry:

- development of new technologies and casting alloys,
- melting and liquid metal preparation,
- manufacturing of moulds and cores,
- preparation of casting materials and composites,
- pouring, solidifying and cooling of casting,
- technological waste management,
- new production systems and quality control,
- sustainable development of foundry industry,
- energy and material efficient technologies.

## CONCLUSIONS

European metalcasting industry, just as most European and USA manufacturing, suffered greatly from the early in this decade. Moreover, substantial dynamics in the global economy, especially off-shore sourcing of cast

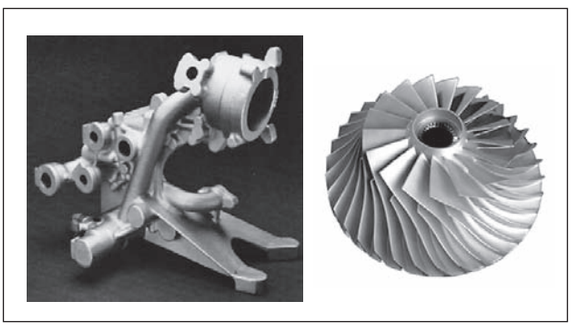

**Figure 12** Examples of castings made with the application of the most modern casting technologies

metal components as well as the off-shore manufacturing of durable goods that require castings continue to profoundly reshape European metal casting industry. The effects of the recession were magnified by the influx of low-priced castings from off-shore sources including Brazil, India and particularly China. Nowadays it is becoming clear that economic trends and technological advances are creating an inflection point in the growth rate for cast metals components. The growth in the world economy, particularly in such countries like: China, Russia, India and Brazil will fuel demand for casting related to transportation and an industrialized infrastructure.

Metalcasters need to invest in technology and in people. A meaningful improvements in casting design, modeling, prototyping and production will be of the highest importance if foundries want to achieve increasing the capabilities and lower costs.

Finally foundries need to invest in people. The knowledge and skills needed to keep pace are changing even faster than the technology. Over the next 50 years, new skills will need to be developed every three to five years. Ongoing training and education will be a must for successful foundries.

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# MATHEMATICAL MODELLING OF FLAT AND LONG HOT ROLLING BASED ON FINITE ELEMENT METHODS (FEM)

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Review Paper – Pregledni rad

The aim of this paper is to critically assess the potential of mathematical modelling which uses finite element method software for solving operation problems in the hot rolling of flat and long products. We focused on concrete issues faced by rolling plants in the Moravian-Silesian region (Czech Republic). The investigation was always combined with field or pilot measurements or laboratory experiments.

*Key words:* steel, hot rolling, finite elements method (FEM), roll pass design, friction

**Primjena metode konačnih elemenata (MKE) pri matematičkom modeliranju toplog valjanja plosnatih i šipkastih proizvoda.** Cilj članka je kritička ocjena mogućnosti matematičkog modeliranja rabljenjem softvera metode konačnih elemenata pri tekućem razrješavanju problema toplog valjanja plosnatih i šipkastih profila. U konkretnom primjeru fokusirano je na tvrtke u Moravsko-Sleskom rejonu (Češka). Istraživanja su uvijek kombinirana pilot mjerenjima ili laboratorijskim eksperimentima.

*Ključne riječi:* čelik, toplo valjanje, metoda konačnih elemenata (MKE), kalibracija valjaka, trenje

## INTRODUCTION

The main object of industrial research and development is to optimise the means of production for the manufacturing of a given product. The optimisation criteria may vary, depending on the requirements for the final product. In general, they should be based on full understanding of the manufacturing process. In forming processes, the knowledge of deformation mechanisms is crucial. Without knowing the impact of friction, material properties and tool geometry on the operation of the process, it is impossible to propose optimum shapes of tools, the configuration of machines, and to predict occurrence of defects and evolution of microstructure. Field (pilot) trials and physical modelling (laboratory rolling, forming simulators) alone cannot reveal the exact values of thermomechanical parameters and their distribution: e.g. the distributions of various parameters across the product cross-section are virtually impossible to determine. This is why process modelling using computer simulation has an increasing importance in today's metal forming processes [1-18].

## SUMMARY OF KEY OUTCOMES

Our research provided a vast amount of results, all of which have been published in the form of conference talks or in professional journals. Our work comprises the following topics which may be classified with respect to the optimisation criterion as follows (the institutions where physical experiments were conducted are listed in the parentheses):

- ■ Friction in hot rolling:
- □ Impact of friction coefficient on spreading of rolled steel products (Department of Materials Forming, VŠB-TU Ostrava (DMF), ŽDB GROUP a.s., Rolling mill, (ZDB)).

In this study, pilot rolling of 100×100 mm billet into 20 mm diameter bar in 13 passes was carried out. In each roll pass, a sample was taken and a cross-section print of the rolled bar was made. Simulations of individual roll passes were carried out for various friction values according to Tresca, ranging between 0.1-0.9. Other boundary conditions of the given roll pass remained the same. Comparison of the calculated cross-sections (see Figure 1) with the prints provided an as-

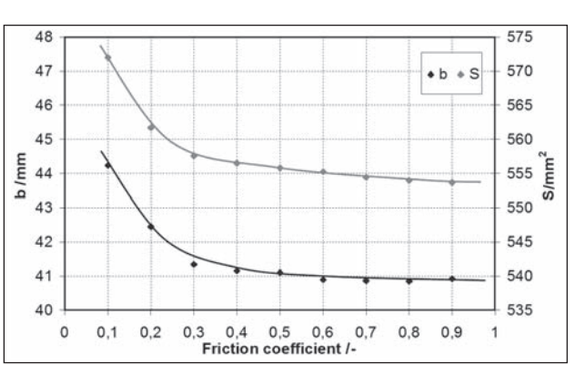


**Figure 1** Dependency of the width b and the area S of the stock on various friction values in the roll groove R 20

R. Fabík, J. Kliber, T. Kubina, VSB-TU Ostrava, FMME, Ostrava, Czech Republic, I. Mamuzic, University of Zagreb, Croatia, S.A. Aksenov, MIEM, Moscow, Russia

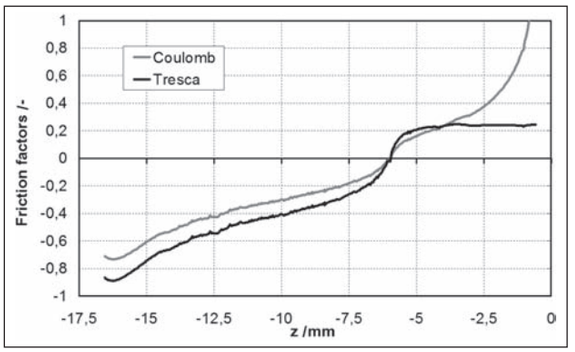


**Figure 2** Dependence of Coulomb and Tresca friction factors on the distance from the plane of exit [20]

sessment of the optimal friction coefficient value for each roll pass [19].

- ☐ Finding the friction coefficient value using inverse analysis of the rolled product shape (DMF).

The design and industrial application of a method of determining the friction coefficient and the friction factor along the arc of contact (see Figure 2) were based on the analysis of rolled product shape upon laboratory rolling. Results show that simplifying the mathematical model of rolling by using a constant value of friction may become one of the most significant sources of error [20].

- ■ Temperature field in a rolled product:
- ☐ Cooling of shaped products in HCC rolling mill (ArcelorMittal Ostrava, a.s. (AMO)).

Inverse analysis (IA) principles were used for determining the temperature field upon rolling in shaped products as input data for subsequent computer simulation of cooling. The input parameter for IA was the dependence of the rolled product's surface temperature on time.

- ☐ Definition of the temperature field in a rail upon rolling in VH rolling mill (Třinec Steelworks, a.s. (TZ)).

A method of determining temperature fields in rails and their exporting into FEM software for the purpose of heat treatment simulation was elaborated and verified

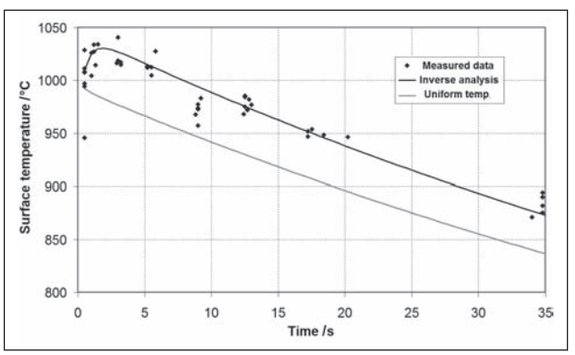


**Figure 3** Measured surface temperatures and calculated cooling curves for a uniform temperature field ($T$ = 1 000 °C) and for a temperature field computed using inverse analysis

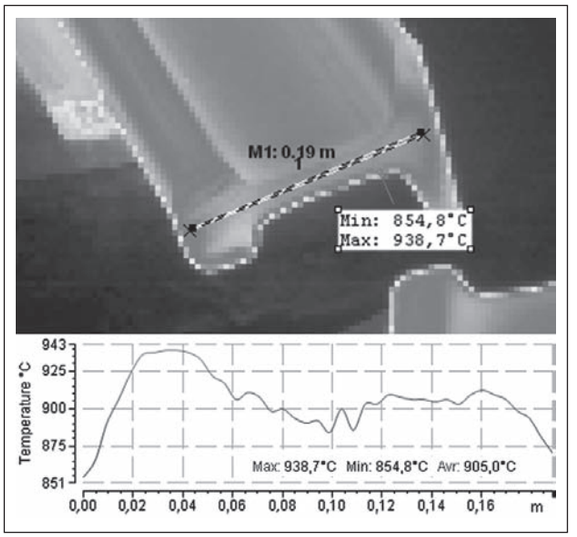


**Figure 4** Analysis of a thermal image of the rail's cross-section after cutting off the rail's front end

in production. It relies on measuring the temperature field across the cross-section of the rail after cutting off its front end (see Figure 4). It is then described using a mathematical model with temperature variables associated with selected points on the rail's surface.

This method can be used in applications where the temperature field is very difficult to estimate (non-symmetric rolled products) and in those, where the full-scale FEM simulation of the rolling process becomes costly due to the process complexity.

A method of measuring temperature fields in rolled products (rails) by drilled thermocouples for laboratory simulation of heat treatment was designed and applied.

A hypothetical cooling process of rails in production was simulated by means of both above-mentioned methods. The simulation clearly showed that even the processes with in-line heat-treatment operations can benefit from equalizing the temperature field within a rail in a soaking furnace prior to the actual cooling. This can provide both higher hardness in the rail head and a less steep hardness gradient beneath the surface.

- ■ Evolution of microstructure in a rolled product:
- ☐ Assessment of capabilities of controlled rolling in a medium section rolling mill (AMO).

Mathematical analysis of microstructure evolution in rolled 40×5 mm flat bar showed that in terms of microstructure, the current process is very close to the optimum setting. However, our analysis also revealed that in case of 40×60 mm sections, the finish rolling temperature cannot be controlled.

- ☐ Obtaining the thermomechanical parameter vs. time dependences for rolling in HSC mill to be used as input data for plastometric experiments (heat treatment, DMF).

In pilot experiments with thermomechanical rolling of steel bars in the continuous fine section mill at TZ, non-homogeneity of microstructure and significant scat-

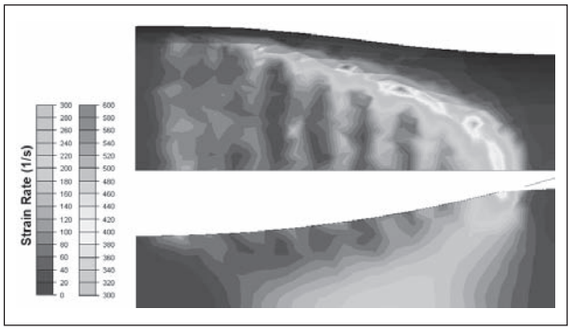


**Figure 5** Distribution of strain rate across the cross-section and on surface – prefinishing stand, ASC rolling mill at TZ

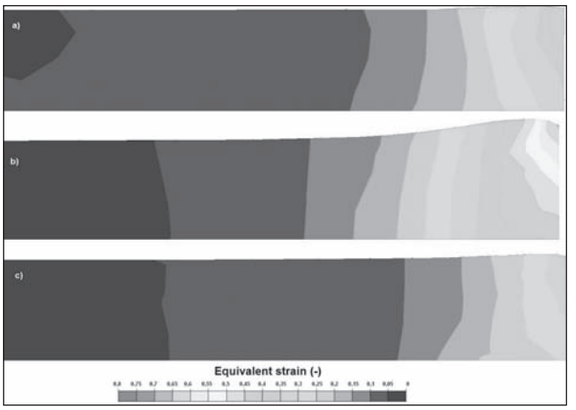


**Figure 6** Dog bone shape and equivalent strain after vertical rolling: a) slab head b) middle of slab c) slab tail [22]

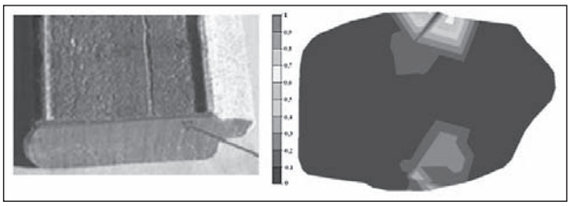

**Figure 7** Left: defect in the final rolled product. Right: FEM simulation of the probability of lap occurrence caused by the wear of the first roll pass

ter in grain size across the bar's cross-section were revealed. FEM simulation was used as an efficient tool for describing the thermal-stress-deformation fields across the rolling gap. The main attention was devoted to mapping the strain rate (see Figure 5), strain and temperature. Changes in these quantities with time were mapped for various points on the cross-section of the rolled product. The data proved the non-homogeneity of deformation parameters across the section, which is due to the applied production technology.

- □ Construction of a new model for calculating the critical strain for onset of dynamic recrystallization and its verification in a laboratory rolling process (DMF).

Strain rates in the deformation zone in rolling of flat products were analysed in depth. Due to the presence of a region of inhibited deformation, the plot of strain rate vs. time for surface layers exhibits two peaks. The absolute value of strain rate of the first peak considerably exceeds the average value obtained using conventional formulas.

Taking into account this fact and upon an analysis of continuous plastometric experiments involving sharp changes in strain rate, a new model for calculation of critical strain for the onset of DRX has been constructed. The model was tested in laboratory rolling. The agreement between results of experiments, the new and the old model was by no means satisfactory, which applies in particular to the surface region of the rolled product. We attribute this to the additional effects which were impossible to incorporate in the mathematical analysis [21].

- ■ Final shape of rolled product:
- □ Impact of parameters of horizontal-vertical (H-V) rolling of slabs on the amount of scrap after rolling (DPM).

Mathematical analysis was successfully used for designing an H-V slab rolling process which uses the short-stroke method (see Figure 6) to significantly reduce the amount of scrap resulting from undesirable shapes of the slab ends [22].

Laboratory H-V rolling was carried out to verify the mathematical model. The process was also modelled using FEM analysis. The agreement between results for the shape of the product in its crucial part (the dog bone peak) is unsatisfactory. It was revealed that the mesh density is of great importance but, at the same time, other parameters (friction, surface undercooling, flow stress of the steel) have an impact on the dog bone shape. We did not succeed in obtaining the actual shape with sufficient accuracy [23].

- □ Clarification of causes of defects in rolling of a special section (Special Section Rolling Mill, VŮHŽ, a.s.).

FEM simulation confirmed our hypothesis that the defect (see Figure 7, left) is due to greater wear of the first box pass, which, in turn, causes greater spread and a higher probability of lap occurrence (see Figure 7, right). It turned out that mathematical modelling using FEM is very suitable for this type of task [24].

## CONCLUSION

The present paper summarises the outcomes of FEM-based research into rolling processes. The combination of mathematical modelling methods with field or pilot testing or laboratory rolling is an important feature of this study. The following areas were explored: finding the friction coefficient value, modelling of temperature fields, modelling of microstructure evolution, and analysis of rolled product shape. The next part of this article will provide additional information on the assessment of formability of steels in the rolling process and development and use of a simulation program using rapid FEM algorithms.

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# APPLICATION OF LOGISTIC PRINCIPLES IN METALLURGICAL PRODUCTION

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Review Paper – Pregledni rad

Metallurgical production processes (MPP) consist of continuous and discrete types of technology operation, transport, manipulation and storing processes regards the flow of material and also the equipment and machines. Other specifics are: long production cycles, great inertia, tree structure of production processes (from roots up to the leaves), high level of investments etc. These characteristics resulted in some specifics of production logistics. This article deals with these specifics and explains it using the conditions of production processes of continuous slab casting, their heating in push furnaces at rolling temperature and rolling itself in hot wideband steel mill.

*Key words:* logistics, metallurgical production, push furnaces, rolling

**Primjena principa logike u metalurškoj proizvodnji.** Metalurški proizvodni procesi sastoje se od kontinuiranih, različitih tehnoloških procesa i sastoje se od toka materijala kao i opreme i strojeva. Specifičnosti metalurških proizvodnih preocesa su: dugački proizvodni procesi, velika inertnost procesa, struktura "stabala" u proizvodnom procesu (od korijena pa do lišća), visoka kapitalna ulaganja itd. Takva svojstva metalurških proizvodnih procesa rezultiraju nekim specifičnostima proizvodne logistike. Članak se bavi ovim specifičnostima i pojašnjava korištenje postojećih uvjeta u proizvodnom procesu kod kontinuiranog ljevanja čeličnih ploča, njihovo zagrijavanje u pećima na temperaturu valjanja i valjanje istih u čeličanama.

*Ključne riječi*: logistika, metalurška proizvodnja, potisne peći, valjanje

## INTRODUCTION

Logistics is the branch of management, where the objects of management are flows and chains with the target of their overall optimisation [1]. Logistics has a cross sectional character. The specific characteristics of the logistics of metallurgical production follow mainly from the object of management i.e. metallurgical production processes. The metallurgical production processes (MPP) of have several specific characteristics, which have to be accepted while managing them.

MPP is a chain of continuous and discrete technological, transport, manipulation and storing operations, which have to be transformed into a discrete form first when modelling these processes.

Then, there is a long production cycle and also great inertia especially for thermal processes, long delivery cycles of supplied material (even several months) and typical tree structure of the production process [1]. From these resulted the strategy of Feed Forward management [1].

Metallurgical companies are huge companies making very high investments (even billions of Euro) resulting in long recoupment period of investments and high lifetime [2]. Metallurgical products are at the beginning of the production chain. These products are materials like metals, semi-products (plates, pipes, wires) which is the reason why products with different than planned quality do not need to be scrapped (as it is e.g. in machine or electrical industry) and it can be still used for a lower quality purpose. The output of these production processes is only one product or a narrow assortment of products.

Above mentioned and other characteristics of MPP – classify these production processes into so called homogeneous production processes [1]. The costs for its automation, informatization, and logistics applications are relatively low compared with the costs for building the technology and equipments. All of these approaches bring at least 5% of cost savings. In absolute value these savings are high. That is the reason, why metallurgical companies are leaders in these applications which means also leadership in logistics as well as production logistics. [1,3].

## THE SPECIFIC CHARAKTERISTICS OF MPP LOGISTICS

The specifics characteristics from the point of logistic are:

**a)** **Great inertia** - This is influenced by a long production cycle, thermal processes (blast furnace, push furnace) and big amount of moving material flows.

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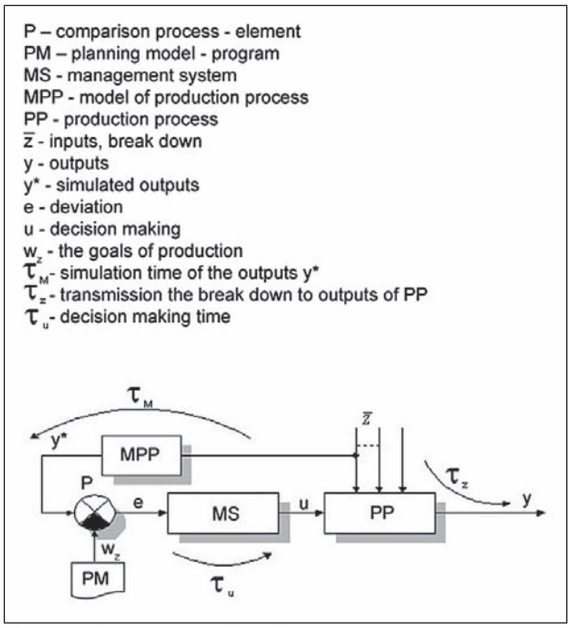


**Figure 1** The structure of feed-forward management – philosophy (FFM)

For this types of processes as the basic logistics model is the feed-forward principle of management is applied, which is based on the program – operative plan of production (PM) and monitoring of inputs $\bar{z}$ to the production processes. On the basis of the vector $\bar{z}$ and the model of production process (MPP), the forecast of outputs $y^*$ are simulated (Figure 1).

PM is usually created on heuristic principles [2].

**b)** **Big investment** and long life cycles mean long economic return. It is necessary to continuously adjust and keep the parameters of the products from the point of facility and aggregates utilization. This fact has to be taken to MMP.

**c)** **Narrow product assortment** - Narrow product assortment (metal sheets, cement, wires etc.) enables application in the production process of special purpose aggregates, facilities, and machines with high level of automation. A disadvantage here is low level of flexibility in changing the production. These characteristics have to be taken into account in the planning models (PM).

**d)** **Continuous discrete process.**

Metallurgical processes consist of continuous and discrete technology processes. If we want to create MPP, it the first step is transforming these processes into discrete types and then apply a system for modelling the discrete system, because the continuous discrete production processes are very hard to model [4]. For modelling and simulation of discrete production processes, it is easy to apply the systems such as GPSS, SimFactory, Extend, Witness etc.. The second alternative is a balance model.

Other specifics of metallurgical processes are:

**1.** Tree structure from roots to leaves.

**2.** Faulty product does not need to stay to be a faulty product, it can be sold as a product with lower quality [5].

## EXAMPLE OF THE LOGISTIC PRINCIPLE APPLICATION TO METAL STEEL PRODUCTION

Each company has its own specific structures of production processes, rules and objectives of management, is unique and also is unique from the viewpoint of logistics [6]. Logistics is a management concept, which the following principles applied:

- system approach;
- co-ordination;
- planning;
- algorithmic realization; and
- overall optimization of the chain [1, 7].

In this case slabs of required sizes and quality are cast by two equipments for continuous steel casting (CC I. and CC II.). The diagram of material flows is in Figure 2. The cast slabs are transported to the slabs reparation plant where they are repaired before rolling and from there to the cold slabs storehouse or they are directly transported to four push furnaces (PF1 to PF4). After heating up to the rolling temperature they are pushed out from the push furnaces and transported by a roller table for rolling at wide hot mill (WHM - TŠP 1700). The field store yard serves to balance the differences in production at times of regular repairs at WHM - TŠP 1700 or during operation shutdowns at CC I. or CC II.

The three main parts of the steel division, WHM - TŠP 1700, PF1 - PF4 and CC I. and CC II., have their own system of operation planning.

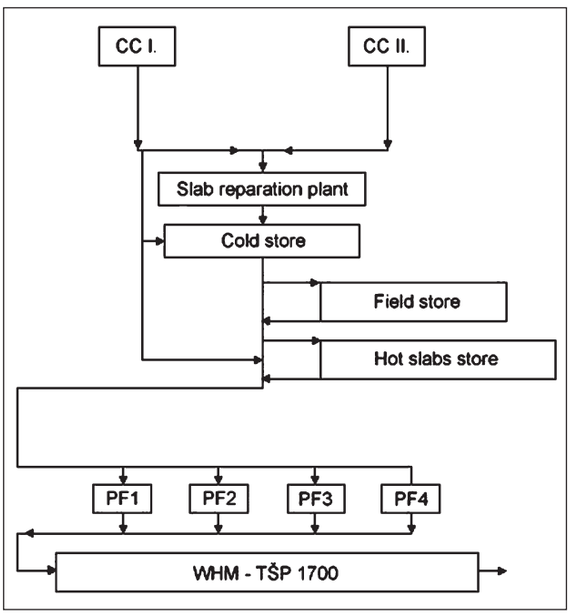


**Figure 2** Scheme of material flow in the CC – PF – WHM

Each single part is understood as unit of one system, its mutual relations create material flows, but also information relations in the way of operative plans.

One of the logistic goals of the Steel division is to coordinate production operating plans of WHM - TŠP 1700, PF1-PF4 and CC I. and CC II. in order to accomplish the maximum portion of slabs are in direct sequence (CC - FP - TŠP) thus solving the problem between the difference production capacity of Slabs reparation plant (approx. 1,5 million tons yearly) and production of CC I. and CC II. and TŠP 1700 (approx. 4 million tons yearly) but at the same time the more slabs there are in the direct sequence the less is the energy consumption for their heating up in the push furnaces (cold slabs are of outdoor temperature i.e. approximately 10 degrees Celsius, the temperature of hot slabs is from 150 to 400 degrees Celsius).

The fact that every hour material with the value of about 200 000 € flows through these aggregates requires very precise systems of scheduling. At TŠP 1700 it is so called schedule of TŠP 1700, 24 hour and 7 days plan, at FP has a schedule of charging and at CC I. an d CC II. has a schedule of casting.

Planning, system approach and processes coordination must be controlled by the overall optimization [8-10]. Individual elements of the production process have different criteria of optimization. For example, for TŠP 1700 slabs groups of the same type in the amount of 20 to 40 are best for rolling from the standpoint of rolling technology because with such amounts the best exploitation of operation and support rolls of roll stands is achieved when changing the slabs groups according to certain rules.

It is therefore an effort of operating planning of TŠP to form groups with these amounts of slabs. From the standpoint of characteristics of production processes at CC I. and CC II. it is necessary to readjust the crystallizer through which slabs are cast with every change of their size. However, the readjustment of the crystallizer means idle time of CC I. or CC II. and also creation of a reducing slab which must be adjusted before rolling (if we know how to sell it in the final product) or it becomes scrap. The goal of CC I. and CC II. is therefore to cast the greatest series of the same slabs possible. For PF the optimal batch is equal to the length of the dominant II. Zone, see Figure 3 The optimal production batch is the compromise among the technological batches for these three aggregates.

It results from the previously mentioned that local criteria of optimization must adapt to the superior overall criteria, for example maximum profit, minimum energy consumption, keeping the confirmed terms of order etc. [1, 4].

One of other characteristics of logistics is logical organization of individual operations of the production process and the algorithmic consistency of their effectuation. Algorithmic realization ensures logical order of steps, activities continuation, activities repeating, compatibility in communication and realization. Likewise with the algorithm, it can be a definite activity sequence, cycle, alternative selection- decision-making, etc.

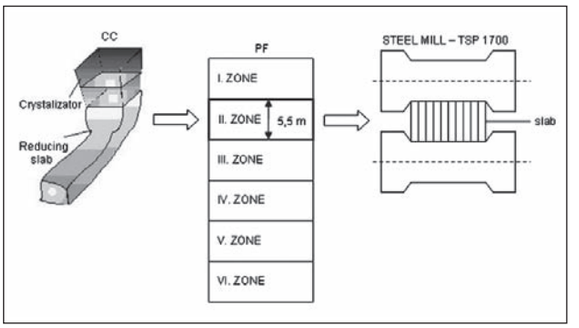


**Figure 3** Creation of the optimal production batch

## THE RELATION OF MANAGEMENT, LOGISTIC AND TECHNOLOGICAL OPERATION CONTROL IN THE CONDITIONS OF METALLURGICAL PROCESS

Inner enterprise processes of the company can be divided into three levels (Figure 4):

- economic processes;
- logistic processes (chain of the technological, transportation and cumulating operations);
- technological operations

These three groups of processes are characterized by other variables, other managing variables and managing criteria.

While technological operation control manages physical, mechanical, thermal and chemical variables like pressure, temperature, liquid level, speed of rotation, ratio among the variables etc., the management criteria are used for example to find out the optimal curve of heating with the aim define economically e.g. minimal heating costs.

When are the subjects of management of technological and transportation, cumulative processes, which are considered as the chain or network, then we speak about logistics. There are managing time, place, and capacity variables.

Management – management of economical processes of an enterprise is based on the principle of hierarchical managing i.e. the logistics have to respect the aims of the management, as the supervising level (for the whole enterprise to work optimally) and aims of the logistics are moved beyond the base level on the technological process control.

## CONCLUSION

In the 60s and 70s of previous century, automation was the basic dynamic factor of production industry. Toward the end of the 20$^{th}$ century, information systems like Steel man, SAP R/3 etc. which partly include logistics, were the dynamic factor.

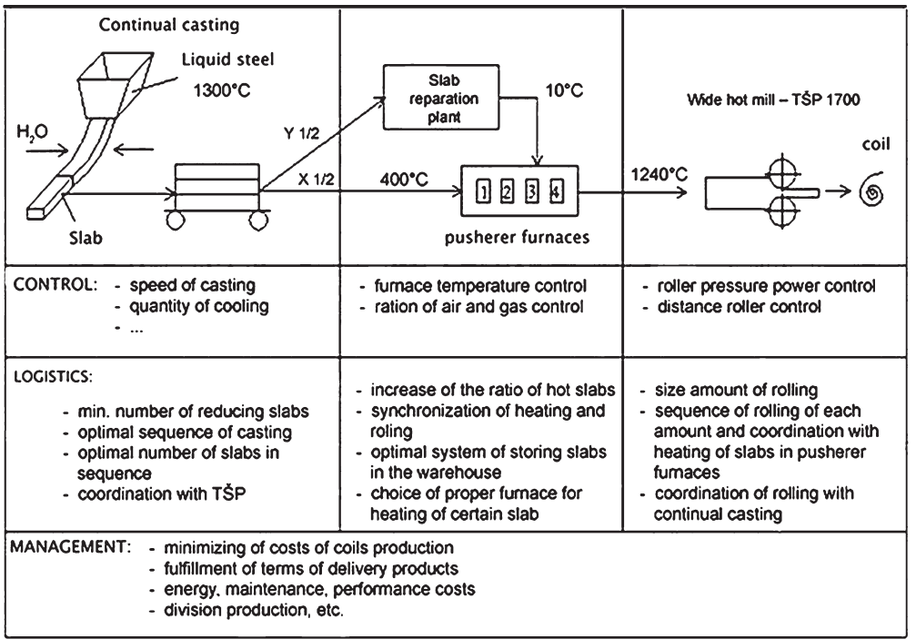


**Figure 4** An example of activities and variables for three management levels [2]

The dynamic factor of early 21st century is the logistics.

From the logistic point of view, each production process is different, each has its specifications and this is the reason why logistic systems are needed to be developed and implemented as unique, "made-to-order" systems, based on the present conditions of modelling, simulation and information technology and apply their knowledge to heuristic models and expert systems.

Metallurgical companies, especially by reason of fast return of investments, are always the leaders of implemented automation, information technologies and they are also the leading companies implementing logistics in their production.

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# TECHNO-ECONOMIC METHOD FOR EVALUATION AND SELECTION OF FLEXIBLE MANUFACTURING SYSTEMS (FMS)

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Review Paper – Pregledni rad

To find best FMS solutions, experts use numerous multicriteria methods for evaluation and ranking, methods based on artificial intelligence, and multicriteria optimization methods. Presented in this paper is a developed techno-economic method for evaluation and selection of FMS based on productivity. The method is based on group technology (GT) process planning.

*Key words:* techno-economic method, flexible manufacturing systems, productivity, group technology

**Tehnoekonomska metoda za ocjenu i izbor fleksibilnih tehnoloških sustava (FTS).** Za izbor najpovoljnijih rješenja FTS koriste se brojne multikriterijske ekspertske metode vrijednovanja i rangiranja, metode ustrojene na primjeni umjetne inteligencije, kao i metode multikriterijske optimizacije. U ovom radu prikazuje se razvijena tehnoekonomska metoda za ocjenu i izbor FTS na temelju proizvodnosti. Metoda je utemeljena na tehnološkim osnovama koje se obrazuju na principima grupne tehnologije (GT).

*Ključne riječi:* tehnoekonomska metoda, fleksibilni tehnološki sustavi, proizvodnost, grupna tehnologija

## INTRODUCTION

The complexity of cost-effective exploitation of flexible manufacturing systems (FMS) – which require high costs for production launch, on the one hand, while allowing cost-effective exploitation, on the other hand – the efforts put into comprehensive techno-economic analysis during their design and application are well justified. Clearly, the economic effects are influenced by the market, as well as the own ability to develop, improve, and adjust one's production program. Considering the high costs of FMS exploitation, all stages of their lifecycle must be analyzed, focusing on the required and possible techno-economic effects of their application [1].

Flexible manufacturing systems can be developed with various levels of automation, and autonomous functioning of particular technological systems, wich depends flexibility, mobility, accuracy and reliability, Figure 1 [2].

The design of FMS, as well as the selection of a readily available FMS for particular types of manufacturing, usually involve several variants of solutions. There are a number of multicriteria methods for evaluation and ranking of these variant solutions [3], methods which are based on artificial intelligence [4], and methods which are based on multicriteria techno-economic optimization.

Techno-economic method for evaluation and selection of FMS is based on group technology process planning. The proposed method involves analysis of parts from the production program, and application of group and type technology. This approach is based on classification of parts into technological groups, according to similarity of their design and manufacturing features. GT process plans are then designed for the parts which represent various technological groups. Thus designed, group process plans allow efficient evaluation of effects of FMS application, as well as their appropriate selection [5].

The proposed method can be successfully used for evaluation of optimal design and application solutions of flexible manufacturing cells, while other authors have applied other methods [6 - 10].

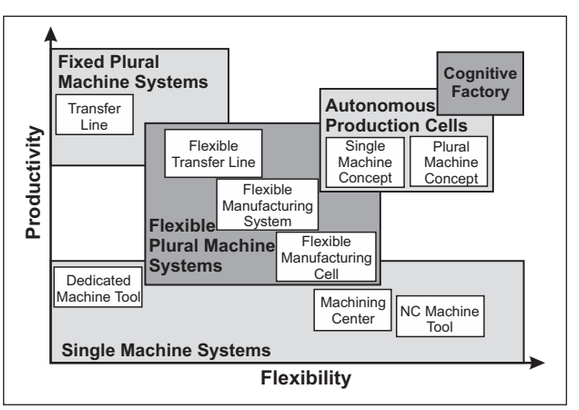


**Figure 1** Comparison of manufacturing systems according to productivity and flexibility [2]

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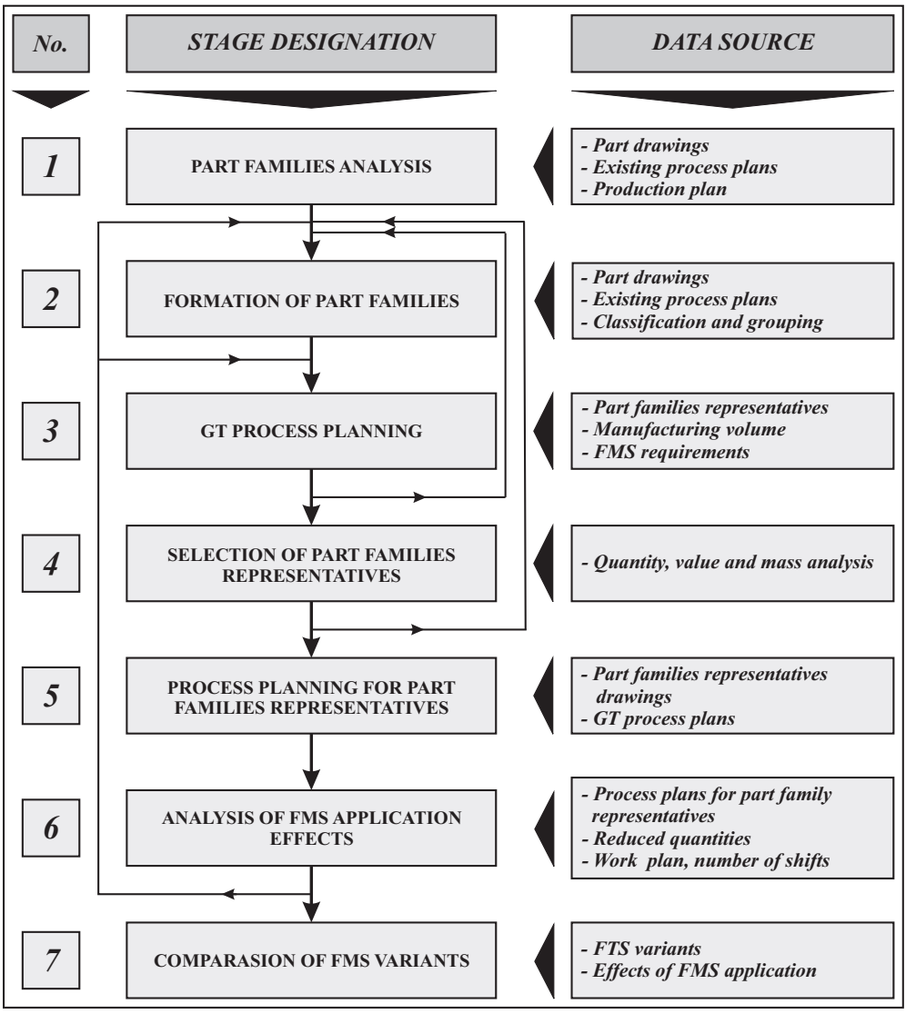


**Figure 2** Model of the techno-economic method

## OVERVIEW OF THE DEVELOPED METHOD

Although the above mentioned FMS characteristics pertain to their design, similar can be said of their application. The problem of FMS application is mostly related to process planning and optimization which, on the other hand, must be adjusted to particular FMS characteristics and limitations.

Techno-economic method whose model is shown in Figure 2, can be successfully used to solve both of the discussed problems.

Techno-economic method is based on the results of years of research autors by this paper, example [5], and applied in paper [11]. It is based on a synthesis of knowledge wich concerning the basic principles of group technology [12], and the possibilities of applying these principles [13].

### Phases of the application of developed method

The first stage in development and application of the proposed techno-economic method involves analysis of production program. Thus, for example, Figure 3 illustrates the structure of electromotor production program which, according to market demands, was modified from mass to batch production, with the appropriate level of automation and flexibility of manufacturing equipment.

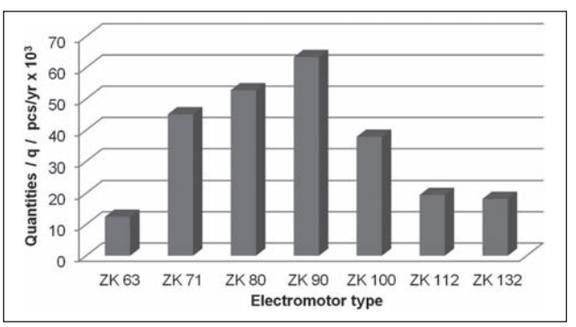


**Figure 3** The structure of production program

The second stage involves forming of part families, while the third stage pertains to group process planning for the particular part families.

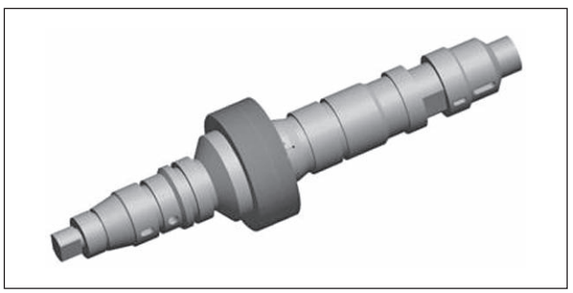

**Figure 4** Complex part of the rotor of ZK electromotor

In case of the considered ZK electromotor production program, three basic part families were formed housings, rotors and covers.

Table 1 **GT process plan for the rotor of a ZK electromotor**

| Process number | Process designation | Machine type |
|---|---|---|
| 10 | Cut-off | Metalsaw |
| 20 | Annealing | Heat Treatment |
| 30 | End machining | NC milling machine for end machining |
| 40 | Turning | Turning FMM |
| 50 | Metal sheet processing | Hydraulic press |
| 60 | Turning II | Turning FMM |
| 70 | Grinding | Grinding FMM |
| 80 | Balancing | Balancing device |
| 90 | Control | Control |

For the three part families, process plans were designed to acommodate new production environment.

GT process plans are designed based on complex parts for each part family [12]. Thus, for example, for the ZK electromotor part family the representative complex part is shown in Figure 4. Based on this complex part, group technology for manufacture of ZK electromotor was designed, Table 1.

Group process plan for particular part family defines the types of FMS required for machining processes, while the detailing of particular group machining processes allows the selection of the required level of FMS automation and flexibility [2], [8].

Group process plans and group machining processes can be designed for any part based on the data from engineering drawings, including the complex parts which represent particular part families [12]. These representatives can be selected by ABC method, given the appropriate data [13] which are shown in Table 2 for ZK electromotor part family.

Application of the ABC method for the selection of this part family (Figure 5) shows that rotors of electromotors, ZK 90 and ZK 100, have almost identical quantity, value and mass parameters within the production program. Based on additional analyses of market demands, it was established that model ZK 90 had greatest demand, which made it suitable for the representative of

Table 2 **Data required for the selection of representative part for the family of ZK electromotor rotors**

| No | Electromotor ZK designation | Quantity / q | Price / € | | Mass / m | |
|---|---|---|---|---|---|---|
| | | pcs/yr | €/pcs | €/yr | kg/pcs | kg/yr |
| 1 | ZK 63 | 12 450 | 3,07 | 38 196 | 2,61 | 32 495 |
| 2 | ZK 71 | 45 100 | 3,81 | 171 643 | 3,24 | 146 124 |
| 3 | ZK 80 | 52 800 | 6,31 | 333 204 | 5,37 | 283 536 |
| 4 | ZK 90 | 63 400 | 10,71 | 678 934 | 8,98 | 569 332 |
| 5 | ZK 100 | 37 900 | 17,98 | 681 464 | 15,31 | 580 249 |
| 6 | ZK 112 | 19 450 | 18,25 | 355 010 | 15,54 | 302 253 |
| 7 | ZK 132 | 18 200 | 31,59 | 574 979 | 26,9 | 489 580 |
| TOTAL: | | 249 300 | - | 2 833 429 | - | 2 403 569 |

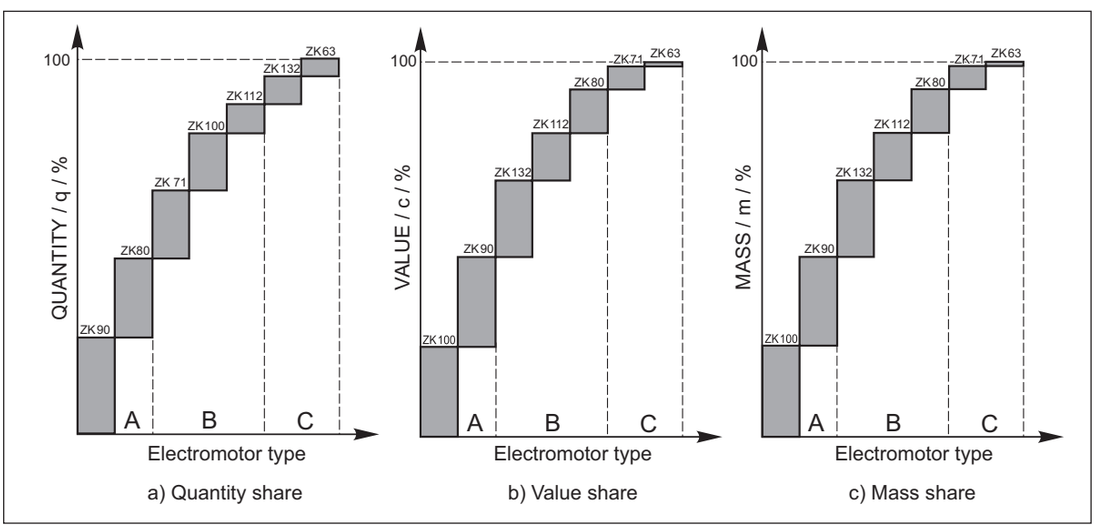


**Figure 5** Quantity, Value and Mass ABC analysis of ZK electromotor rotor

rotor part family, at the production rate of 100 batches per year.

In fact, process planning for the complex part as part family representative requires precise definition of particular group machining processes based on engineering drawings, including determination of machining times, later used for effectivity study and selection of FMS.

## EFFECTIVITY STUDY OF FMS AND ITS SELECTION

As stage six of the proposed method, the effectivity study of novel FMS solutions or application of existing FMS is founded on productivity, which can be determined based on machining process times for complex parts.

Machining time ($t_k$) for a process performed on a particular FMS can be calculated as:

$$t_k = t_g + t_a + t_p + t_{pz} + t_i \quad (1)$$

where (min/pcs):

$t_g$ – machining time,
$t_p$ – auxiliary time,
$t_a$ – tool replacement and adjustment time,
$t_{pz}$ – setup time, and
$t_i$ – idle time.

Partial and total machining times for the machining processes Turning I and Turning II performed on the complex part which represents the rotor part family of ZK 90 electromotor, are given in Table 3. Machining is performed on flexible manufacturing modul INDEX GU 800.

Table 3 **Times for turning processes on the complex part of the rotor (ZK 90)**

| Process Designation | $T_{pz}$ | $T_{pzm}$ | $t_g$ | $t_p$ | $t_k$ |
|---|---|---|---|---|---|
| | min/batch | | min/pcs | | |
| Turning I | 20 | 40 | 1,0 | 0,3 | 1,38 |
| Turning II | 20 | 40 | 1,2 | 0,3 | 1,58 |

where:

$T_{pz}$ – setup time, (min/batch)
$T_{pzm}$ – intermediate setup time, (min/batch)

## FMS productivity for machining processes

FMS productivity for a particular machining process is determined as follows:

$$Q = \frac{1}{t_k} \quad (2)$$

For the machining operations, productivity per shift is calculated in following way:

$$Q = \frac{\theta_m \cdot 60}{t_k} \quad (3)$$

For the example of turning processes performed on the complex part for rotor of ZK90 electromotor, Table 4 presents the required data and the resulting productivity per shift.

Table 4 **FMS productivity for turning processes, complex part for ZK rotor part family**

| Parameter designation | Notation | Process designation | |
|---|---|---|---|
| | | Turning I | Turning II |
| Useful time capacity | θ h/shift | 8 | 8 |
| Effective operating time | θm h/shift | 7,5 | 7,5 |
| Productivity per shift | Q pcs/shift | 326 | 285 |

By comparing FMS productivities, for both design of novel solutions and selection of existing ones, it is possible to select the most favourable solutions for the particular machining processes which is based on maximum productivity. This is the final stage in application of the proposed techno-economic method.

## CONCLUSIONS

The developed techno-economic method allows determination of most favourable FMS solutions, either during development and design, or for the selection of existing FMS solutions to be applied in manufacturing.

Evaluation of effects of FMS application - based on productivity, which uses times of machining processes for complex part representatives of particular part families - can be used in both of the cases.

The developed techno-economic method is sufficiently rational thanks to the fact that process planning as well as complex part selection are based on the principles of group technology.

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# THE ECONOMIC IMPACT OF PROHIBITING STATE AID FOR THE ROMANIAN STEEL INDUSTRY

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Review Paper – Pregledni rad

The adjustment of the Romanian steel industry restructuring programmes to the requirements of the EU and the implementation of such programmes has supported the development and growth of Romanian steel companies. The total amount of State aid allowed in Romania has been of € 1,2 billion and was mainly awarded for financial restructuring and to a smaller extent for exemption from VAT and corporation tax. The EC has constantly monitored the Romanian steel industry and the way in which State aid has been granted by the Romanian government. As a consequence of the restructuring process– whit entry into force the EU Association Agreement was enforced – several obsolescent plants have been shut down because of physical and moral wear and tear, and the total number steelworkers has decreased significantly.

*Key words:* steel industry restructuring, Romania, monitoring programme, European Commission

**Gospodarski učinak zabrane državne pomoći rumunjskoj čeličnoj industriji.** Prilagodba programa preustroja rumunjske čelične industrije zahtjevima Europske unije i provedba tih programa pripomogle su razvitku i rastu rumunjskih poduzeća djelatnih u čeličnoj industriji. Državna pomoć odobrena u Rumunjskoj ukupno je iznosila 1,2 milijarde US dolara i uglavnom se dodjeljivala za financijski preustroj, a u manjoj mjeri za izuzeće od PDV-a i poreza na dobit. EK je stalno pratila rumunjsku čeličnu industriju i način na koji je rumunjska vlada dodjeljivala državna pomoć. Kao posljedak procesa preustroja – stupanjem na snagu Sporazuma o pridruživanju EU – zatvoreno je nekoliko zastarjelih tvornica zbog istrošenosti te je broj radnika u čeličnoj industriji značajno smanjen.

*Ključne riječi:* čelična industrija, preustroj, Rumunjska, program praćenja, Europska komisija

## INTRODUCTION

Romania has had a long history of steelmaking and now the industry plays an important part in the domestic economy [1]. For instance, throughout the period of macro-economic centrally planned economy, the theoretical output of this sector amounted to 17 million tons of liquid steel [2], and the country ranked among the top 15 steel industries worldwide.

With an approximate number of 225 000 steelworkers, the maximum output during that period amounted to 15 million tons of liquid steel, a low output as compared to the levels of this indicator on the international market. The domestic market assimilated about 9-10 million tons, while exports never exceeded 3 million tons.

In the period following 1990, the domestic consumption decreased to 1,0-1,5 million tons of steel, while exports maintained a relatively constant level. The steel output in 2009 amounted to just 2,7 million tons (ranking 37 worldwide), diminishing by about 46,6 % as opposed to the 5 million tons that were produced in 2008.

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## TRENDS IN THE DEVELOPMENT OF THE ROMANIAN STEEL INDUSTRY IN THE FRAMEWORK OF EU ACCESSION NEGOTIATIONS. STATE AID CONTROL/ MONITORING

The debts of steel plants had long exceeded their economic value before the beginning of the privatisation process in 2000. The privatisation of these economic units was made in exchange for very little profit for the state, since the priority goal was the investment made by the new owners in the development of the plants. After the write-off of all the debts that had accumulated in time (about $ 1,4 billion), the intense restructuring programme agreed upon with the European Union was expected to only maintain the viable business units [2], while the production capacity of the country amounted to approximately 9 million tons of steel per year and the number of steelworkers was estimated at about 35 000 employees.

The accession negotiations for Romania's membership to the European Union were conditioned by several practical readjustment procedures to be implemented in certain industries/ sectors [3-5]. According to the negotiations, mention was made of certain transitory meas-

ures related to State aid that would enable the completion of the steel industry restructuring procedures.

The respective State aid consists in financial advantages conferred on a selective basis to undertakings by national public authorities with the aim of meeting certain public interest objectives such as environmental protection, SMEs development, development of underprivileged areas, rescuing or restructuring strategic economic agents [4].

State aid is regulated by competition policies and is mainly based on the premise that, even though the aid granted by public authorities to enterprises can be in the public interest, it disturbs the natural competitive environment. In this respect, the EU Commission has established certain rules and regulations to be observed by authorities when interfering on the market by granting state aid [5].

Thus, state aid is compatible if it observes clearly defined general economic interest objectives with general benefits on the economic development and without disturbing trade among EU member states [3-5]. The EU commission regulations provided that such financial support will be granted upon meeting certain criteria [6]:

– reinstate the viability of the recipient undertakings under normal market conditions by the end of the restructuring period;
– the amount and extent of the aid should be strictly confined to the essential measures to be taken in order to restore viability;
– the total net output reduction for finished products should amount to minimum 2 050 000 tons.

Romanian steel plants that have been subject to the above mentioned regulations accounted for over 90 % of the total Romanian gross steel output, as presented in Table 1.

Table 1 **State aid granted in the steel industry during 1993-2004 [8]**

| Company | State aid / billion lei |
|---|---|
| ISPAT SIDEX - S.A. Galati | 30 598 |
| SIDERURGICA - S.A. Hunedoara | 9 975 |
| COST - S.A. Targoviste | 2 399 |
| Wire industry - S.A. Campia Turzii | 2 234 |
| Resita - S.A. Steel Plant | 4 707 |
| Siderca - S.A. Calarasi | 72 |
| TOTAL | 49 985 |

## REFERENCE VALUES FOR THE SECTOR UNDER ANALYSIS FOLLOWING THE IMPLEMENTATION OF THE RESTRUCTURING PROGRAMME

In order to compensate for the competitive advantage that companies had gained following the receipt of State aid, several steel plants had to be wound up [7] and thus the finished goods output diminished during 1993-2008 by the above presented percentages.

The monitoring procedures conducted by the European Union [6] have revealed that Romania has complied with the provisions set by the Commission and has additionally voluntarily wound up a number of obsolescent plants, including roll mills, blooming mills, light structural mills and wire mills. We would like to stress the fact that if the EU resolution had not been favourable, the current owners of the six steel plants being monitored would have had to reimburse € 1,2 billion, which equals the amount of State aid granted by the government to the steel industry throughout the privatisation process.

This support granted for restructuring has increased the financial performance and the viability of the Romanian steel industry and, at the end of 2008, Romanian companies have recorded EBITDA (Earning before interest, tax, depreciation and amortization) scores ranging between 8,5 % and 21,6 %, while the target goal was of 10,0 %. The EBIT score (earnings before interest and taxes) ranged between 4,6 % and 19,5 %, while the target goal amounted to 1,5 % [8].

The ability of these companies to meet the viability criteria set by the European Union after the implementation of the restructuring programme is translated by the figures presented in Table 2.

Table 2 **Estimated viability criteria (post restructuring/ 2008) [8]**

| Viability according to available EU criteria | | Company | | | | | |
|---|---|---|---|---|---|---|---|
| EU standard/ value % | | ISPAT SIDEX - S.A. Galati | SIDERURGICA - S.A. Hunedoara | COST - S.A. Targoviste | Wire industry - S.A. Campia Turzii | Resita - S.A. Steel plant | Donasid-S.A. Calarasi |
| Retained earnings | EU standard value | 13,5 | 10,0 | 10,0 | 10,0 | 10,0 | 10,0 |
| | Value/ % | 15,2 | 10,7 | 12,7 | 10,1 | 10,7 | 30,17 |
| Net profit | EU standard value | 1,5 | 1,5 | 1,5 | 1,5 | 1,5 | 1,5 |
| | Value/ % | 3,1 | 2,1 | 4,1 | 1,5 | 2,1 | 26,48 |

When analysing the output and labour occupancy of the same year (2008), the number of restructured jobs in the Romanian steel industry was higher than what had been forecasted, while the annual workforce level amounted to 33 200 workers, as opposed to the estimated target of 43 308 workers. The restructuring mainly consisted in transfers, early retirement and voluntary leave schemes.

Nevertheless, the output coefficients at the end of the restructuring period (for certain beneficiaries) are well below the figures for the EU steel industry. As for cost reduction, this objective can only be reached on a long term by investing in development.

We argue that the development of viable production units during 2003-2008 (their size is presented in Table

3) has been rather constant and was specifically meant to align Romanian steel production with the international performance level.

The European Commission has concluded that all companies have reached their investment targets [6], as provided in the Individual Business Plan.

Table 3 **Total steel output at the end of the restructuring period, measured in thousand tons/year – in 2008 [8]**

| Company | Output Steel / thousand tons | Rolling capacity |
|---|---|---|
| ISPAT SIDEX - S.A. Galati | 6 000 | 6 800 |
| SIDERURGICA - S.A. Hunedoara | 950 | 3 440 |
| COST - S.A. Targoviste | 630 | 1 330 |
| Wire industry - S.A. Campia Turzii | 385 | 685 |
| Resita - S.A. Steel Plant | 450 | 1 050 |
| DONASID - S.A. Calarasi | 400 | 300 |
| GAVAZZI STEEL - S.A. Otelu Rosu | 300 | 1 520 |
| Total | 9 115 | 15 125 |

The above mentioned companies (Table 4) have invested between 150 % and 330 % of the estimated amounts, while the effects of the investment will become visible in time.

Table 4 **Total investments during the Romanian steel industry restructuring process [8], million USD**

| Company | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | Total |
|---|---|---|---|---|---|---|---|---|
| ISPAT | 35,2 | 106,1 | 100,6 | 54,8 | 47,9 | 70,0 | 30,0 | 446,6 |
| SIDERURGICA | - | | 1,0 | 1,7 | 2,1 | 2,9 | 3,4 | 11,1 |
| COST - S.A. | - | - | 2,8 | 6,9 | 7,6 | 3,3 | 0,4 | 21,1 |
| Wire ind. - S.A. | - | - | 9,5 | 7,6 | 4,7 | 2,2 | 1,2 | 25,2 |
| Resita S.A. | - | - | 0,5 | 11,5 | 8,6 | 2,6 | 3,1 | 26,3 |
| GAVAZZI STEEL | - | - | - | - | - | - | - | - |
| Donasid | - | 4,9 | 3,2 | 7,2 | 8,6 | 7,4 | 8,4 | 39,7 |
| TOTAL | 35,2 | 111,0 | 117,6 | 89,7 | 79,5 | 88,4 | 46,5 | 567,4 |

## CONCLUSIONS

With an output of about 9 million tons of liquid steel per year, Romania has completely aligned with the European steel community. There have been substantial efforts in recent years towards the development of steel production and steel rolling facilities.

The output reached by steel plants throughout the restructuring period has enabled them to face the distinctive challenges of the market demands for the following years. Most steel plants have acceptable steel manufacturing equipment, in agreement with the range of goods they produce. They have continuous steel casting furnaces – especially for continuous steel blooming. Moreover, the steelworks in question have rolling furnaces, except for COST - S.A. Targoviste and ISPAT SIDEX - S.A. Galati.

It is worthy of note that the completion of the restructuring process of the Romanian steel industry has coincided with the emergence of the international financial crisis (2007-2008). The visible decrease in the demand for steel manufactures has resulted in lower performance indicators than the estimated figures.

On the other hand, aside from the financial difficulties triggered by the world crisis, efforts must still be made for completely restoring the sustainable viability of the steel industry and to make sure it will be able to overcome any future market uncertainties. This specific objective can be reached on the long term through the constant implementation of the cost reduction strategies and through the development of sustainable and coherent strategies for the future.

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# SELECTED PROBLEMS OF DEVELOPMENT OF THE STEEL INDUSTRY IN POLAND

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The article presents the background of the general condition of the Polish steel industry the basic problems associated with the functioning of enterprises in a competitive market.

*Key words:* steel industry, Poland, restructuring processes, innovation management

**Izdvojeni problemi razvoja industrije čelika u Poljskoj.** U članku se opisuje pozadina općeg stanja poljske industrije čelika te osnovna problematika vezana za funkcioniranje poduzeća na konkurentskom tržištu.

*Ključne riječi:* čelična industrija, Poljska, procesi restrukturiranja, inovativno upravljanje

## INTRODUCTION

Today's steel market is very unstable. An increase in production and sales within the years 2005 - 2007, a subsequent drop in 2008 and 2009 and another increase in 2010 and in the first half of 2011 show evident problems faced by the steel industry. [1-4]. The apparent steel consumption has grown by almost 20 %. Demand for steel products from other sectors including automotive, metal, construction, machine - building, shipbuilding, household appliance and other industries has been growing. For example in 2010 the domestic metal industry recorded a high, 21 % increase in the sold production compared to 2009. Such direct relation indicates the need for building a strong competitive position in the steel market. Special attention should be drawn to the problem of prices. The situation is complicated because the markets of raw materials and energy are characterized by high variability of prices and the problem may become even more severe soon. Compared to 2009 the year 2010 visibly showed an economic revival (GDP grew by approx. 3,8 %). It can be proven by the fact that there was an increase in both the steel production (approx. 8 million Mg of steel and approx 7 million Mg of steel products) and the import of steel. While analyzing the conditions for development of the Polish steel industry it is necessary to make reference to production volumes of the entire domestic industry. Compared to 2009 in 2010 there was an increase in production by approx. 10,4 % and in sold production by approx. 9,8 % (industrial processing sector recorded a growth of almost 11,1 %). On the other hand, there were no major changes in the percentage-expressed structure of assortment of long hot rolled products (bars, wire rods, heavy and light sections, rails). The same applies to flat hot rolled products (thick sheet, strip metal). The conditions for development outlined here indicate the need for developing an efficient and effective system to enable implementation of innovations of any kind. Therefore, the aim of this article is to present basic problems related to the development of the Polish iron industry in view of its present state by focusing on both internal and external business conditions.

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## PRESENT PROBLEMS OF THE POLISH STEEL INDUSTRY

Generally speaking the technical level of the Polish steel industry meets international standards. Products also meet customer standards, norms and requirements. At the same time the utilization of production capacities was low and amounted to approx. 61,5 % on average. There are thus potential production reserves that can be instantly used. However, compared to 2009 Poland's share in the total steel production in the European Union did not change and amounted to approx. 5 %. At the same time a high increase in import of steel to Poland was recorded. Compared to 2009 it grew by almost 22 % and amounted to 6,7 million Mg. By comparison, export of metallurgical products was higher in 2010 by about 5 % than in 2009 and amounted to 4,2 million Mg. Better economic situation in 2010, though resulting in an increase in steel production and thus in revenues (by over 33 % compared to 2009), did not enable attaining a positive net financial result. The reason of such negative phenomenon are the growing prices of raw materials and fuels. When discussing the problem of costs, we need to take into account the problem of unemployment. At the end of 2010 the rate of employment in the steel sector was over 25 000 people, but it was lower than the rate in 2009. We do however observe a change in quality. Companies hire persons with higher

qualifications and competencies, which is necessary due to the use of modern, automatic and numerically controlled machinery, equipment and technological lines and due to the implementation of modern organizational solutions and IT systems.

In the experts' opinion the Polish steel industry is relatively modern considering the equipment, process lines and technologies used in production. This applies to both energy saving and protection of natural environment. Despite that the new decisions contained in the Climate and Energy Package and other documents show that it is necessary to conduct further and expensive adaptation works. Today's level of carbon dioxide emission ($CO_2$) by metallurgical plants is about 4 % of the domestic emission. It is not easy to lower that rate. The biggest $CO_2$ emission is generated by commercial power plants (approx. 59 %), heat and power plants and heating plants (approx. 20 %). The problem, however, remains, likewise the problem relating to the necessity of meeting environmental norms and EU directives in order to minimize negative impact of the steel industry on the natural environment [5]. The situation related to the protection of natural environment is even more difficult because the National Allocation Plan of $CO_2$ Allowances for the years 2008 – 2012 for the iron and steel industry approved by the European Commission in 2010 provides for the level of slightly above 11 million Mg of $CO_2$ while all Polish companies received a right to emit over 208 million Mg of $CO_2$ per year. We hope that the limit will be increased to reach the level close to the level demanded by the Polish government. The necessity of reducing greenhouse gases emission will result in a number of problems and needs related to investment expenditures. When discussing the ecological problems it is necessary to say that in 2010 the EU Council adopted new regulations concerning emission of gas and dust pollutants. All the actions undertaken are aimed at significant reduction of acceptable emission limits for nitric oxide, sulfur dioxide, dust emissions, etc. Although their level is approx. 1,8 % (the remaining 98,2 % is $CO_2$ emission), the steel industry faces very a big challenge to reduce that level. Other problems that need solving include: waste, sewage and water management. The problem of environmental protection becomes even more important when, besides the analysis of problems of the iron and steel industry, we take into consideration the coke industry which is closely related to the steel industry.

## ENTERPRISE MANAGEMENT WITH THE APPLICATION OF CONTEMPORARY MANAGEMENT CONCEPTS

The steel industry like any other industry must strive to implement various new solutions, new technologies and methods of organization and management. Creation, development and implementation of innovations in the conditions of global economy have become an obligation today. Collaboration between the industry and scientific and research institutions becomes essential. Changes that have taken and that are still taking place in the Polish science system are related to the fact that the science has been strongly linked to the industry. In consequence those new solutions should bring positive effects in industrial practice (easier transfer of knowledge or technologies).

In order to meet European standards, Poland has to strive to develop the knowledge and innovation based economy. Poland has to take into account the requirements of sustainable development without neglecting the requirements of competitiveness. Furthermore, actions should be strengthened to enable development of economies characterized by high employment rate, which are economically effective at the same time. All those projects require significant financial support. Such support is especially needed in the area of research and development. In that area Poland, by adopting the Lisbon Strategy, undertook to attain a 3 % share of expenditures for research and development in the Gross National Product. Considering a new attitude of scientific institutions (new system for evaluation of quality of their work and regular audits) whose basic task is to do research and developmental work for the economy's needs and transfer of technology to the industry, a new standard of collaboration between science and industry can be expected with maintained clear procedures and rules of competitiveness and effectiveness. Such collaboration will be characterized by demand and supply relations. The new system should better protect intellectual property and promote commercialization of scientific research results. Moreover, it should provide better dissemination of scientific research results and effects of scientific and developmental works. The system should enable expanding the assortment of products (and deepening the degree of their processing), facilitate the transfer of new technologies and new organizational solutions to businesses, which in turn should result in increased efficiency of its operation. By introducing modern and innovative solutions, namely product innovations, technological (process) innovations and organizational innovations (enhancement of management systems and processes) to the industrial practice, companies can significantly improve their market position.

At the turn of the century the Polish steel industry underwent deep transformations. The reason for such changes was the fact that markets had opened and it was necessary to adapt to the requirements of competition in a free market. Moreover, the steel industry, classified as a strategic industry because the majority of its products is used in almost all processing industries, had to undergo deep restructuring. Steel products do not often have their substitutes. Thus, raising the competition level of the steel industry translates into the growth of competition of other sectors. The changes implemented during the restructuring processes included: changes in the assortment of products; changes in technological processes; offer of products with a higher degree of

processing; changes in the machine park and its automation; organizational and ownership changes; changes in employment structure.

Initially the changes were of rectifying character and were often connected with the utilization of simple resources. Later on, the changes focused on development. Generally speaking all the strategic actions were concentrated on:

- adapting the products to market requirements by improving their quality and expanding their assortment, etc.
- modernization of present technological processes and on the introduction of new processes by reducing material consumption and burdensome effect on natural environment,
- introduction of modern machinery and technological lines to production by shortening production cycles, improving the organization of production, reducing the employment rate, material and energy consumption and by increasing automation of production processes,
- improvement of the employment level and structure – by reducing the number of employees, improving productivity and reducing costs of labour,
- improvement of the economic and financial situation of companies by reducing production costs, generating profits, maintaining financial liquidity and gaining permanent creditworthiness;
- enhancement of organizational solutions and on the utilization of new management concepts and methods;
- ownership changes within the sector by consolidating the steel industry (the first important step was the establishment of Polskie Huty Stali S.A. composed of independent Katowice, T. Sendzimira, Florian and Cedler steel plants), by integrating basic production activity of the consolidated steel plants and by spinning off auxiliary and service operations.

The restructuring processes and current directions for development require preparing and implementing available and relatively modern concepts, methods and techniques of management. That area of each company's operation, namely organization and management, which had been underestimated for a number of years by managers, became one of important areas that can bring measurable and immeasurable effects. Conditions for development posed by the global economy are inextricable from the requirements set. While developing and implementing their strategies companies strive to improve their competitive position, or at least to maintain it. Companies are in a constant search for areas where they can gain advantage. One of such areas, with relatively modern technologies, machines, equipment and process lines, is the efficient and modern management. Innovative processes and an ability to manage such processes play an important role not only in the literature, but in practice, too. As regards the steel industry the following should be taken into consideration:

- organization of collaboration with scientific and research institutions, universities, etc. in order to enable efficient transfer of modern technologies;
- organization of work related to the technical preparation of production,
- organization of the production process by applying modern, flexible, computer-supported production processes and systems;
- wide utilization of available methods and techniques to support management;
- implementation of new solutions in the area of logistics, etc. [6].

The implementation of the above activities should be based on the utilization of (tangible and intangible) resources to the maximum and should correspond to the chances arising from the business surroundings. In order to ensure effectiveness of the activities undertaken in the area described above it is necessary to use the tools such as:

- Project Management
- Change Management
- Knowledge Management
- Value Based Management

The observation of processes implemented in the steel sector companies, focused on constant improvement of their management systems shows that they constantly strive to raise the level of their competitiveness in strategic terms. Work is mainly focused on the implementation or enhancement and practical utilization of:

TQM – Total Quality Management; Lean Management concept; Business Process Reengineering concept; MRP (MRP I, MRP II, MRP III/ERP – Enterprise Resource Planning) class systems; Benchmarking concept; Outsourcing concept; CRM – Customer Relationship Management; Collaborative Planning Forecasting and Replenishment; Solutions that support efficient customer service (ECR – Efficient Consumer Response); EDI – Electronic Data Interchange; BSC – Balanced Scored Card; Just In Time systems; strategy for customer logistic service; other including: Single Minute Exchange of Die, Total Productive Maintenance, 5S, Six Sigma, etc.[7].

The process of searching, planning, preparing and developing innovative solutions in enterprise management is a chance, but can be a threat to a company. The strategic position attained by the company depends on many factors including its present competitive potential and innovative solutions used, which are considered as a way for turning the resources that form its strategic potential into its strategic position. Much depends on how fast the company is able to adapt to world standards in management. For the steel industry companies the activities should be aimed at gaining a good position in the supply chain. Growing globalization that affects business, deepening integration processes and development of advanced IT technologies help achieve market success only when the level of collaboration between

companies and strength of such relationships grow. Today, however, there is competition within entire supply chains, between every link of the supply chains including suppliers of raw materials, materials and components, manufacturers, logistic companies and organizational units that deliver products to the end customer. Such way of perceiving the problem indicates the need for reorganization and integration of the supply network. Interoperational processes including the ones mentioned above like ECR, CPFR or VMI (Vendor Managed Inventor) need facilitating.

## SUMMARY

The issues presented in this article emphasize the need for introducing any type of innovation to the steel industry companies and for implementing modern management tools in industrial practice. Due to the complexity of problems related to effective enterprise management, one needs to constantly support oneself with various concepts, methods and techniques of organization and management. The necessity of using such organizational innovations and ability to use them arises from development of IT technologies. The application of a number of innovative solutions, or concepts and methods derives from the fact that companies participate in the collaboration processes (supply chains) and arises from the need to compete and build a strong competitive position in global markets. It should be emphasized here that undertaking such ambitious and risky challenges by the steel sector companies is an obligation in these days, and if such actions are skillfully managed, they may guarantee a strong position in today's difficult markets.

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# EVALUATION OF RETURN ON INVESTMENT FOR PROPOSED USE OF SOLAR SYSTEMS IN POLAND

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This paper focuses on the assessment of possibilities to subsidize the purchase and installation of solar collectors in Poland by government or local government grants and special funds designed for this purpose. It analysis of costs and profits resulting from the application of solar installations in the process of heat generation for household requirements, by calculating the payback time, with taking into account prices of other energy carriers and the above mentioned subsidies. Collectors at present are manufactured solely from metals (copper, aluminium, Al-Mg alloys). The use of these materials is tied to considerable energy demand and the production technology is complex. This affects the economy of running a solar device.

*Key words:* renewable energy, solar energy, Poland, payback period, cost savings.

**Procjena povratka investicija za predloženo rabljenje solarnih sustava u Poljskoj.** Članak je usmjeren na procjenu mogućnosti novčane potpore nabavke instalacija solarnih kolektora u Poljskoj od vlade ili lokalnih pokrovitelja te posebni fondovi utemeljeni u tu svrhu. Analizirani su troškovi i dobit kao rezultat primjene solarnih instalacija u procesima zagrijavanja po zahtjevima, proračuna povratka investicije, uzimajući u obzir cijene računa ostalih, tj. više drugih usporednih energija. Sadašnji kolektori ustrojeni su od metala (bakra, aluminija, Al-Mg legure). Rabljenje ovih materijala je u svezi energetskim zahtjevima i proizvodnom tehnologijom. Utjecaji ekonomije ovisni su o solarnim uređajima.

*Ključne riječi:* obnovljiva energija, solarna energija, Poljska, termin povratka ulaganja, uštede troškova.

## INTRODUCTION

Energy plays an important role in our lives. According to several experts, without changing the way we use fuel-energy resources it is not possible to ensure sustainable development of society [1].

## Solar energy-situation abroad

The largest share of solar energy per inhabitant is currently in Cyprus, where up to 90 % of residential buildings have solar collectors installed.

In 2010 the government of Czech Republic passed the law on supporting renewable energy, in which photovoltaic will lose support in 2011. This amendment responded to continuous and uncontrolled development in the construction of solar power plants [2].

The world´s largest photovoltaic (PV) solar plant open in Southern Spain With an installed peak power of 23 MW (updated), the solar park at Jumilla, Murcia (Southeastern Spain) is the world's current highest capacity PV plant and the most efficient to-date [3].

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## Subsidies for the solar collectors in Poland

- On June 17 2010 the Board of the National Fund for Environmental Protection and Water Management signed agreements with six banks, launching a program of subsidies to bank loans for the purchase and installation of solar collectors. It means that subsidized loans will be available in 4,5 thousand banks establishments all over Poland [4].

For natural persons and housing communities, not connected to the district heating system, the National Fund for Environmental Protection and Water Management offers, through the banks, 45 % subsidies to the purchase and installation of solar collectors used for usable water heating. The subsidies include loans for the purchase and installation of solar collectors as well as equipment required for their proper functioning. The offered budget of subsidies to partial repayments of bank loans designed for the purchase and installation of solar collectors for natural persons and housing communities for a period. The table 1 shows scheduled and planned subsidy of goverment from 2010 to 2014 [5].

**Eco Fund** offers subsidies to the installation and purchase of vacuum and flat solar systems. Applications for the installation of solar collectors can be submitted by the owners of ready-to-use private houses or houses which are still under construction. The subsidized amount is 252 € for one square meter of the solar sys-

Table 1 **The total of scheduled and planned subsidy from the government [5]**

| Scheduled Payments in | Year | | | | Total [EUR] |
|---|---|---|---|---|---|
| | 2010 | 2011 | 2012 | 2013 -2014 | |
| 2010 | 1 057 | - | - | - | 1 057 |
| 2011 | 4 215 | 12 342 | - | - | 16 557 |
| 2012 | - | 5 058 | 21 211 | - | 26 269 |
| 2013 | - | - | 6 441 | 8 555 | 14 996 |
| 2014 | - | - | - | 12 581 | 12 581 |
| 2015 | - | - | - | 4 026 | 4 026 |
| Total | 5 272 | 17 400 | 27 652 | 25 162 | 75 486 |

tem, but it cannot exceed 40% of the investment. However the amount of subsidies shouldn't be lower than 12 581 €, so the sunlight absorbing surface should not be less than 50 $m^2$ . An annual limit of resources for the installation of solar collector projects amounts to 2 516 166 € (for 10 000 $m^2$ / year) in EcoFund [6].

Expenses involved in the production of solar collectors can be partially financed by the Agency for Restructuring and Modernization of Agriculture within the framework of the following measures constituting part of the Rural Area Development Program for 2007 – 2013:

- Measure 123 Adding value to agricultural and forestry products
- Measure 312 Creation and development of micro enterprises
- Measure 121 Modernization of farms.

However it should be noted that the investment will be subsidized only when the collector is used in accordance with the purpose of the supported operation. Subsidies for farmers are financed from the Agency for Restructuring and Modernization of Agriculture, which covers up to half of the total costs involved in the purchase and installation of necessary equipment. Recommended systemic instruments supporting solar power engineering are based on existing experience (for example: investment subsidies), and they comply with the legal conditions and requirements specified in the Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Furthermore these instruments correspond with the proposals of the Ministry of Economy, included in the project „Polish Energy Policy till 2030". They also refer to support systems which have been successfully applied to promote green electricity and biofuels in Poland, but never to support the „green heat" idea [7].

## CLIMATIC CONDITIONS

Meteorological conditions in Poland are characterized by an uneven distribution of solar radiation in the annual cycle. 80 % of the total annual insolation falls on six months of the spring and summer season (from the beginning of April to the end of September). Time of the solar activity in winter is shortened to 8 hours a day, and in summer this time amounts to as many as 16 hours a day.

A characteristic feature is a significant participation of diffused radiation in the total radiation. It exceed 50 % in the annual scale, and during the four winter months (November – February) it amounts to 65-73 %. The annual solar radiation density on the horizontal plane ranges from 950 to 1 250 kWh/$m^2$. Many years of analyses have proved that the highest values of the solar radiation flux occur in the Baltic area and in the eastern part of Poland. Total annual average insolation amounts to 1 600 hours [8].

## COSTS AND PROFITS

The initial investment of selected collector TS 300 is its purchase. Based on the assessment of technical-operational parameters of commercially produced and available collectors on the market can be concluded that currently manufactured collectors are solely based on a metal base, while in the construction of the absorber are mainly used metals with high thermal conductivity: copper and aluminum. The usage of metallic materials is associated with a considerable degree of energy and technology intensity production, reflecting into the price of the equipment. In terms of design solutions to manufacturers of specific products resulting from concepts, high thermal conductivity of metal elements plays an important role, which can be negatively reflected in increased rates of energy losses of body collector due to the possibility of unwanted thermal bridges existence, which is immediately reflected in the nature of heat balance of the collector and then in the economic efficiency of the whole solar equipment operation as a comprehensive energy system. The costs of metallic construction collector elements such as copper respectively aluminum absorber with the piping elements and collector metal bath, which is mostly made of Al-Mg alloys have a significant share on cost structure of individual structural elements of standard solar collector [9].

Total costs incurred for the purchase and usage of solar installations consist of investment outlays - on average 503 € to 1 007 € per one square meter of the solar collector area (in case of a four-person family the total costs amount to 2 013-4 026 €) and operation costs (costs connected with the operation of the circulating pump of about 10 €/year and periodic maintenance and refilling of the working factor - an amount of 50-76 € once every few years). Apart from the thermal parameters of the collector, the amount of the solar yield is also affected by: location, hot water demand profile, position of the collector against the directions of the world, its inclination, insulation thickness, flow of the passing heating factor, size of the heat accumulator, and assumed level of demand coverage.

In the economic assessing of the systems it is necessary to know the investment costs, operating costs and payback period of the investment. When calculating the economic profitability index values, one should take into account trends in the fuel and energy market. For

Table 2 **Economic profitability of investments in solar collectors [10]**

| Type of collector | | Flat collectors | | | | | |
|---|---|---|---|---|---|---|---|
| Solar yield [KWh/(m² year)] | | 405 | | | 435 | | |
| Investment outlays [EUR] | | 3 397 | | | 4 227 | | |
| Conventional system | | El. energy | Natural gas | coal | El. energy | Natural gas | coal |
| Price of energy carrier | | for kWh 0,11 € | for m³ 0,5 € | for t 132 € | for kWh 0,11 € | for m³ 0,5 € | for t 132 € |
| Annual savings [EUR/year] | | 2 84 | 153 | 73 | 289 | 156 | 75 |
| Return period, without taking into account [years] | price increase | 12 | 22 | 48 | 15 | 28 | 59 |
| | a 10% price increase | 8 | 12 | 18 | 10 | 14 | 20 |
| | a 10% price increase and a subsidy of 155 € | 7 | 11 | 16 | 8 | 12 | 18 |

Table 3 **Economic profitability of investments in solar collectors II [10]**

| | | | |
|---|---|---|---|
| Collector area | 7 m² | Number of persons using hot water | 4 |
| Investment outlays (629 €/m²) | 4 403 € | Tax scale | 18 % |
| Amount of effective energy from collectors | 10,08 GJ/years | Coverage of demand for hot usable water | 60 % |
| Subsidy from the National Fund for Environmental Protection and Water Management (without taxation) | 1 982 € 45 % of outlays | Effective subsidy from the National Fund for Environmental Protection and Water Management | 1 625 € 36,9 % of outlays |
| Conventional system Preparation of hot usable water | electrical energy | natural gas | coal |
| Annual savings (in the first year) | 399 € | 184 € | 98 € |
| Return period, without taking into account price increase [years] | 12 | 22 | 48 |
| Investment outlay return period | 6 years | 11 years | 17 years |

many years in the EU, and especially in Poland, one has seen a regular increase in the conventional energy prices In the years 2000-2009 average fuel and energy prices increased by about 85 %, while the highest price increase concerned the natural gas (over 160 %) and electric energy (over 90 %). Midyear fuel and energy price growth rate in the years 2000-2009 was over 7 % and it was much higher than the average inflation rate. It should also be remembered that energy prices in Poland are still lower than the prices in the EU, and the disproportions will be systematically leveled.

Economic profitability calculations can be performed with the help of available performance calculators (for example: www.inwestujwkolektory.pl) or programs for a selection of solar installations, solar yield calculation and heat demand coverage (www.kolektorek.pl). The following two Tables 2, 3 present such a comparison [10].

## CONCLUSION

To conclude, it must be pointed out that solar installations are in many cases economically viable. The payback time is shorter than the product lifetime, and the cost of energy unit generated by the collector is lower than the cost of energy generated by conventional heat sources. The cost-effectiveness depends mainly on the type of the basic heating system. The most profitable installations are those in which electricity is the main source of heating, whereas the least profitable ones are those based on coal or wood (also in case of mains heating). What also matters is the type of solar collectors, their application, applied technical solutions, quality of workmanship and installation assembly. An important element that should be taken into account while calculating the payback time is dynamics of the fossil fuel prices. It illustrates an actual return on solar collector installations, which is not as low as the skeptics say. On the other hand, profitability of the solar collectors is rarely as high as claimed by enthusiastic declarations of the majority of retail offers, even when we take into account the received financial support in the form of subsidies.

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# EVALUATION AND COMPARISON OF RETURN OF INVESTMENT FOR PROPOSED USE OF SOLAR SYSTEMS IN THE CZECH AND SLOVAK REPUBLIC

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The aim of the paper is to evaluate return of investment (ROI) and cost savings from proposed use of solar systems for residents funded by government grants. The paper deals with proposals for solar energy systems for various use, simple calculations of payback periods of solar systems financed with subsidy and without subsidy. Apart from climatic conditions, chemical composition the of the absorber and structural elements that are made of copper, respectively aluminum and Al-Mg alloy play an important role in assessing the payback period of the investment in solar panels.

*Key words:* renewable energy, solar energy, Czech and Slovak Republic, payback period, cost savings.

**Procjena i usporedba povratka ulaganja predloženog rabljenja solarnih sustava u Češkoj i Slovačkoj.** Cilj članka je procjena povratka ulaganja (PU) i ušteda troškova za predloženo rabljenje solarnih sustava stanovanja utemeljenih pod pokroviteljstvom vlade. Članak daje prijedloge za solarne energetske sisteme za različite upotrebe, jednostavni izračun termina povratka ulaganja sa i bez subvencioniranja. Dijelovi za klimatske uvjete, kemijski sastav absorbera i strukturalnih elemenata napravljeni od bakra, odnosno aluminija i Al-Mg legura igraju veliku ulogu u procjeni termina povratka investicije za solarne panele.

*Ključne riječi:* obnovljiva energija, solarna energija, Češka i Slovačka, termin povratka ulaganja, uštede troškova.

## INTRODUCTION

### Solar Energy-situation abroad

South Africa is on its way to becoming a leader in the green energy revolution with a giant solar park which, once fully built, will be the largest in the world [1].

The world´s largest photovoltaic solar plant wa s opened in Southern Spain with an installed peak power of 23 MW [2].

The largest share of solar energy per inhabitant is currently in Cyprus, where up to 90 % of residential buildings have solar collectors installed. In Israel more than 700 000 households are equipped with simple solar collectors in the price of about $ 500 [3].

### Possibilities for financing solar systems in Slovakia

Funding from the state budget is in the form of government grants under the Program of the Ministry of Economy established by Resolution No. 383/2007 on the draft Strategy for greater use of renewable energy in Slovakia.

The amount of subsidies for solar energy is:

a) € 100 per 1 $m^2$ of installed solar collectors in the range of maximally 8 $m^2$ area, including the family home,
b) € 50 per 1 $m^2$ of installed solar collectors in the range of more than 8 $m^2$ area in the family house,
c) € 100 per 1 $m^2$ of solar collectors installed in an apartment building, the maximum subsidy is not more than 3 $m^2$ for each apartment in the apartment building [4].

### Possibilities for financing solar systems in the Czech Republic

State support for domestic water heating and heating is currently very simple. This is a Program of the Ministry of the Environment which aims to implement measures that lead to energy savings and usage of renewable sources in family and residential buildings.

Determination of payback period will be calculated for single-family house with four residents, thus the area of Renewable energy sources for heating and hot water preparation will be used. If we continue to consider solar thermal heat exchanger in our discretion, then the condition for the grant is to achieve calculated annual solar gain in real use at least 350 kWh/$m^2$ area aperture collector (in the case of only for hot water preparation system)

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or 280 kWh/m$^2$ area aperture collector (in the case of domestic hot water preparation system and heating) and a total of 1 100 kWh for installation on a family house, or a total of 750 kWh per residential unit, which is connected to the system, for installation on a residential building. By installation which also serves the heating, the required calculated values of annual solar gain for the entire installation increase 1,3 times.

As shown in Table 1 the state supports domestic hot water preparation system and heating in different ways [5].

Table 1 **State aid in following sections**

| Supported aid measurements | Subsidy CZK/€* |
|---|---|
| Solar system for hot water preparation | 55 000/2200 |
| Support for project to check the correctness of the implemented measures | 5 000/200 |
| The total subsidy for domestic water heating | 60 000/2400 |

* 1 € = 25 CZK

## The proposal of solar system for a house

The following section will focus on solar system design for a natural person that is owner or co-owner of the house / 4 person household / for domestic hot water heating and heating support. We suggest to use the most often used flat solar collector TS 300 [6].

In the production of solar collectors as the most efficient method for quality control seems to be modified Failure Mode and Effect Analysis (FMEA), which is possible to eliminate defects before products are approved for production [7].

In terms of design solutions to manufacturers of specific products resulting from concepts, high thermal conductivity of metal elements plays an important role, which can be negatively reflected in increased rates of energy losses of body collector due to the possibility of unwanted thermal bridges existence, which is immediately reflected in the nature of heat balance of the collector and then in the economic efficiency of whole solar equipment operation as a comprehensive energy system.

Climatic conditions have a strong influence on the economics of solar thermal panels. Fundamental and technical parameters of the solar panel are the absorption surface: 1,76 m$^2$ and optical efficiency: 80 % that is one panel can use 700 – 930 kWh of energy per year. Other technical parameters such as weight, max. operating temperature etc. are not important for calculating the return in the assumption that they will not cause additional costs.

## Solar collectors for domestic hot water heating

When sizing the solar system for domestic hot water heating, it is necessary to comply with these rules and conditions:

- Per one habitant of house area of 1,2 to 1,5 square meters of solar collectors is needed for the preparation of 50 l of hot water a day with temperatures from 50 to 60° C a day,
- Ability to cover 58-65 % of annual energy for domestic hot water heating,
- One square meter collector area should have a reservoir (boiler) 45 to 65 liters.

For housing construction (detached houses) consumption of hot water is calculated to 0,082 m$^3$/person day. For four people it is volume V = 0,328 m3/day. We also assume that the average temperature of cold water throughout the year is 10° C. Temperature needed for common use of domestic hot water is 55° C.

While respecting these rules and conditions, we can propose the following household solar system :

$$Q_{TUV,den} = (1+z)\cdot \frac{\rho \cdot c \cdot (t_2 - t_1)}{3600} = 21{,}5kWh$$

Z - loss of heating system (assumption for domestic hot water heating by electric boiler 0,25)
ρ - water density (1 000 kg/m$^3$)
C - measurable heat capacity of water (4 186 J / Kg K)
t1 - running water temperature (55° C)
t2 - running water temperature (10° C)

By simple assumption of needed function throughout the year we get to the number of energy needed for domestic water heating:

21,5kWh· 365 days = 7,84 MWh/year

if we neglect the difference in temperature t1 during the year and amount of solar radiation. From the knowledge of annual energy consumption and intensity of solar radiation we will now define how large area and how many solar-thermal heat will be needed [8].

The intensity of solar radiation for Prague is 3 801 – 3 900 MJ / m$^2$ per year, i.e. approximately 1,07 MWh / m$^2$ per year.

The resulting absorbent surface is given by:

Sa = 7,84 MWh / year / 1,07 MWh / year per m$^2$ = 7,32 m$^2$

and the number of solar panels

7,32 m$^2$ / 1,76 m$^2$/piece = 4,15 pc.

Here it is needed to calculate with the effectiveness of the selected solar thermal heat exchanger of 80 %. This means that only 80 % of incident solar energy will be used.

Sa = 7,32 m$^2$ / (1,07 MWh/year/m$^2$· 0,8) = 7,32 / 0,856 = 8,55 m$^2$

and the resulting number of pieces

8,55 m$^2$ / 1,76 m$^2$/piece = 4,8 pc, this means 5 pcs.

If we assume the use of solar collectors to cover the hot water of 60 %, let's assume 60 % coverage of needed energy

Sa = (7,84 MWh / year · 0,6)/(1,07 MWh/year/m$^2$ · 0,8)) = 4,7 / 0,856 = 5,5 m$^2$

and consequently the number of pieces

5,5 m$^2$ / 1,76 m$^2$/piece = 3,12 pcs

We will use the same calculation for Slovakia just the incident of energy will be different according to the selected location. If you choose this energy in the size of 1 275 kWh, we analogously get to 2,6 piece of solar panel that is 3 pieces.

Empirical experience of constructors of thermal insulation is a need from 1,2 to 1,5 square meters per person. For 4 people there will probably be a need 4·1,35 $m^2$ = 5,4 $m^2$ and then the number of collectors 5,4 / 1,76 = 3,06 this means 3 pieces again.

For further calculation of return we will therefore continue using 3 pieces of solar thermal collectors.

Table 2 **Real budget proposal for domestic hot water heating systems in Slovakia [9]**

| | Price with VAT in € |
|---|---|
| Collectors (3 pcs) | 1 302,34 |
| Other material | 2 215,59 |
| Work | 558,11 |
| Technical-organizational arrangements (transport) | 119,00 |
| TOTAL PRICE | 4 195,04 |
| PRICE including a government subsidy of 200 € per $m^2$ net absorption area (1 068 €) | 3 127,04 |

The initial investment of selected collector TS 300 is its purchase. Its price in the Czech Republic is set at 1 2300 CZK. Initial investment is therefore a purchase worth of 12 300 · 3 = 36 900 CZK. We will use percentage of other materials used, transport and work related to the price of collectors from the budget table in the Slovak Republic.

Table 3 **Real budget proposal for domestic hot water heating systems in Czech republic [10]**

| | Price with VAT (CZK/€) |
|---|---|
| Collectors (3 pcs) | 36 900/1476 |
| Other material | 62 776 /2511 |
| Work | 15 813 /632,5 |
| Technical-organizational arrangements (transport) | 3 372/134,9 |
| TOTAL PRICE | 118 861/4754,5 |
| PRICE with the state subsidy (60 000 CZK/2400€) | 58 861/2354 |

The state subsidy in Czech Republic in this case is 60 000 CZK and therefore after the subsidy the total investment is 58 861 CZK.

Comparison of solar collectors use for domestic water heating in terms of cost savings and payback periods in the Slovak Republic and the Czech Republic

In our case, we calculated with a simple payback period, which is sometimes called a simple repayment period. When calculating a simple payback period it is necessary to calculate the cost of savings over conventional electric domestic hot water heating way. Input data for calculation on the basis of obtained documents are summarized in the table below, while the cost savings is calculated as:

Cost Savings = annual energy production by collectors times average price for 1 kWh of electricity.

Simple repayment period, respectively simple return is considered as a simple economic criterion. The basic calculation is:

Simple payback period = investment cost / cost savings.

With state support we can use solar energy to heat water for another approximately 17 years at low operating costs. With this subsidy, we will reduce the payback period in 4,5 year compared to the system financed without subsidy. If we consider a 2 % increase in electricity prices, the investment will be paid back in about 11,5 year, while we don´t take inflation and possible introduction of reduced value added tax (VAT) rate on the solar system into account. If we compare payback period of investments into solar technology with thermal energy from biomass from the perspective of the finances they are approximately the same (after including subsidies) but in terms of technological intensity, solar energy is more environmentally friendly [12].

Table 4 **Input data and calculated cost savings – Slovak Republic [11]**

| | DWH |
|---|---|
| Number of collectors | 3 |
| Operating costs | 13,28 € |
| Energy gain from collectors | 820 kWh |
| Annual production of energy | 2460 kWh (820kWh x 3) |
| Average price for 1 kWh of electricity in the year 2010 | 0,0957 €/kWh |
| Savings €/year | 235,42 € |

Table 5 **Simple payback period of solar domestic hot water systems – Slovak Republic [11]**

| | Without subsidy | With subsidy |
|---|---|---|
| Investment costs | 4 195,04 € | 3 127,04 € |
| Simple payback period | 17,81 year | 13,28 year |

To calculate payback periods in the Czech Republic it is important to set the price of electricity for 1 kWh. Our selected geographical location corresponds to the supplier who offers the low rate 'Komfort Kombi 16 " price for 1 kWh = 1,59 CZK with VAT.

Operation of the collector is essentially maintenance free and therefore additional annual maintenance costs will be assumed zero. Furthermore it is possible to assume gain of solar energy 820 kWh/year from one collector, the same as it was in Slovakia, therefore three collectors:

820 kWh · 3 = 2,460 kWh / year.

Annual savings in cost per kWh is therefore

2 460 · 1,59 = 3 911,4 CZK

Payback period will equal the share of investment and annual savings

Tr = 58 861 / 3911,4 = 15,04 year

Table 6 **Input data and calculated cost savings – Czech Republic [13]**

| | |
|---|---|
| Number of collectors | 3 |
| Energy gain from collectors | 820 kWh |
| Annual production of energy | 2460 kWh (820kWh x 3) |
| Average price for 1 kWh of electricity in the year 2010 * | 1,59CZK /kWh |
| Savings CZK/€ year | 3 911,4 CZK/156€ |

* "Komfort kombi 16" - price for 1 kWh = 1,59/0,0636 CZK/€ with VAT

The assumption of the energy prices increase is not considered in this comparison, but we can assume that the return will be less than 15 years and also that the lifetime of collectors will be at least 25 years. The col-

Table 7 **Simple payback period of solar domestic hot water systems – Czech Republic [13]**

| | Without subsidy | With subsidy |
|---|---|---|
| Investment costs | 118 861 CZK/4554,5€ | 58 861 CZK CZK/2354€ |
| Simple payback period | 30,3 year | 15,04 year |

lector may record revenues throughout 10 years, although its effectiveness will gradually decrease.

Table 8 **Comparison of basic indicators in the Czech Republic and Slovak Republic [13]**

| | Czech Republic | Slovak Republic |
|---|---|---|
| Investment costs | 118 861 CZK/ 4 755 € | 4 195 € |
| State subsidy | 60 000 CZK/ 2 400 € | 1 068 € |
| % of total investment subsidy | 50,5 % | 25,45 % |
| Price for 1kWh | 1,59 CZK/ 0,063 € /kWh | 0,0751 €/kWh |

The table summarizes and compares the basic parameters that affect the return on investments in solar systems for domestic hot water heating in both countries.

## CONCLUSION

Currently the most widespread and how it is possible to see from the calculations, effective way of solar systems use is domestic hot water heating. This system is a very effective method of converting sunlight into energy. While solar cells achieve efficiency to produce electricity according to the performed analysis about 10-15 %, solar collectors have efficiency from 50 to 90 % for hot water preparation. The assumption for achieving a higher degree of energy coverage needs and also a higher economic efficiency is installation of solar collectors in new buildings, the construction of low-energy house. The state can contribute to interest increase of the equipment using solar energy by providing state subsidies and tax advantages.

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# MEASUREMENTS OF THE COMMUNICATION NOISE LEVEL ON THE INTERNAL ROADS OF THE MANUFACTURING METALLURGICAL ENTERPRISE

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This publication shows the results of measurements of the noise level emitted by the motor trucks on the internal roads of the steelworks. The distribution of the metallurgical products with the use of trucks is, next to the rail transport, one of the main logistic forms of products delivery to the customer. The research was conducted on one of the busiest internal roads of metallurgical enterprise ArcelorMittal Poland in Dąbrowa Górnicza. The enterprise conducts the whole production cycle and is the biggest steel producer in Poland. On the premises of the steelworks there were five points of measurements marked where the noise level is measured and the results were compared with the acceptable noise levels defined in the norms.

*Key words*: communication noise, steelworks, car transport, distribution of products

**Mjerenje razine buke internih prometnica proizvodne metalurške tvrtke.** Članak daje rezultate mjerenja razine buke emitirane od motornih vozila internih prometnica čeličane. Distribucija metalurških proizvoda rabeći ova vozila uz željeznički transport je najvažniji način isporuke proizvoda kupcima. Istraživanja su provedena na najprometnijoj internoj prometnici metalurške tvrtke ArcelorMittal Poland u Dąbrowa Górnicza. Poduzeće sadrži sve proizvodne cikluse i najveći je proizvođač čelika u Poljskoj. Unutar prostorija čeličana odabrano je pet točaka gdje je mjerenja razina buke, a rezultati su uspoređivani sa prihvatljivim razinama buke zacrtanim u normama.

*Ključne riječi:* buka prometnica, čeličane, automobilski transport, distribucija proizvoda

## INTRODUCTION

Distribution of the metallurgical products is connected with their real delivery to the recipients. It is one of the primary tasks in the generic value chain by M.E. Porter [1]. In logistic systems of manufacturing enterprises it is the element of external logistics (outbound logistics). Logistics of distribution is present in every enterprise but not in all of them it is as important as in a metallurgical enterprise due to the size of production, the weight of transported products, their length and other parameters of technological and utility type. Distribution of metallurgical products to final customers is conducted with the use of two main forms of transport: car and rail transport. The mentioned forms of transport are a burden to the environment and are the source of dangers for the workers on the steelwork premises. One of the environmental aspects is noise.

This publication presents the results of measurements of the noise level emitted by the motor trucks loading the metallurgical products from the stockyard on the premises of metallurgical enterprise ArcelorMittal Poland JSC.

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## CAR TRANSPORT IN DISTRIBUTION OF METALLURGICAL PRODUCTS IN METALLURGICAL ENTERPRISE ARCELORMITTAL POLAND

The analysed metallurgical enterprise ArcelorMittal Poland JSC the car transport of the metallurgical products of the enterprise equals about 40 % and the rail transport is 60 % of the whole transport in the enterprise [2]. In 2010 about 4,5 million tonnes of metallurgical products manufactured by this enterprise were delivered by rail and almost 2 million tonnes by cars. To deliver such an amount 90 000 of wagons and 80 000 cars were used. If we divide the products which were transported into long and flat it occurs that 8 % more of flat products in comparison to long products are delivered to customers by cars (Figure 1) [3].

On the premises of the enterprise there are over 5 kilometres of roads measured from gate to gate in a straight line. On all of them the speed limit is 40 km/h, and on some especially dangerous sections (crossroad with rail route) the limit is 20 km/h. Some of the roads are monitored and some have photo-radars installed. The enterprise has four entry gates, three of which are supply gates for car transport, two of which with car scales. Rail transport has a separate gate. All internal

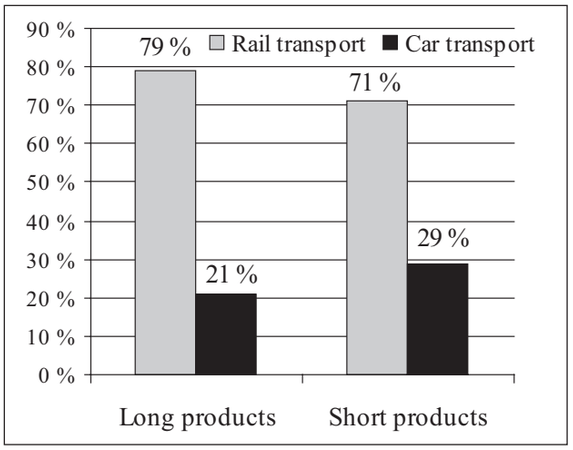


**Figure 1** Structure of product transport in ArcelorMittal Poland

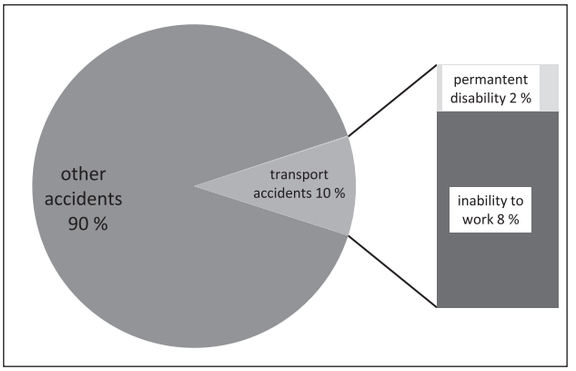


**Figure 2** Types of injuries caused by transport accidents on the premises of industrial enterprises (death accident was 0,1 % )

roads of the steelworks are equipped with road signs (warning signs, information signs) and with traffic lights. There are maps of internal roads by each of the entry gates to the enterprise.

In order to provide safety in road traffic on the premises of the steelworks ArcelorMittal Poland, the rules of traffic on the premises were constructed. The internal regulations were prepared in three languages: English, French and Polish. They are sets of orders and prohibitions and instructions which drivers of transport vehicles should respect. Besides the rules of traffic there are also rules of parking the vehicles, instructions in case of road accident(on the premises of the enterprise there is an Emergency and Fire-extinguishing Unit which should be informed) and the rules of clothing for the drivers (high-visibility vest).

The biggest traffic congestion of motor trucks in ArcelorMittal Poland in Dąbrowa Górnicza occurs on the road between the medium rolling mill and the big rolling mill, because the stockyard of the ready products is situated there. Motor trucks with loads from 7,5 to 32 tonnes move along the road. During the day the road is visited by 80 to 100 cars.

The dangers which are caused by the transport cars are: the noise, crash with another vehicle (car, forklift truck, bike, motorbike, train, emergency vehicle etc.), running down a pedestrian, running into an obstacle (road repair), running into a barrier (gate, rail barrier), sudden breakdown of a vehicle, uncontrolled skidding of a vehicle (particularly in winter), shift or slide of the transported load. Each of the dangers was indentified and assessed in the work safety card entitled: Traffic on the internal roads of ArcelorMittal Poland Dąbrowa Górnicza. In 100 % of accidents on the premises of the enterprise 10 % are road accidents (transport accidents). Figure 2 presents types of injuries caused by transport accidents on the premises of industrial enterprises [4].

One of the main dangers caused by motor truck vehicles moving round the internal roads of the steelworks is the noise which was measured within this research. Noise is defined as unwanted, unpleasant or tiresome sound for a given person in a given place and at a given time. Usually it is a sound of too high volume which means too loud sound. A human reacts to sounds with frequency from 20 Hz to 20 kHz (some sources say from 16 Hz to 16 kHz [5, 6]). Both the sounds below and above this level are inaudible for a human. In ArcelorMittal Poland JSC ¾ of occupational diseases of workers are caused by too high volume of noise. Communication noise caused by particular transport vehicles on internal roads of the steelwork is beyond measurement. Noise measurements are conducted only on work stations of individual workers. Table 1 presents the noise level of particular means of transport.

Table 1 **Level of noise created by different vehicles [7, 8]**

| Type of vehicle | Level of created noise |
|---|---|
| Single track vehicles | 79-87 dB |
| passenger car | 75-84 dB |
| transport truck | 83-93 dB |
| busses and tractors | 85-92 dB |
| road and construction machines | 75-85 dB |
| garbage trucks | 77-95 dB |

In ArcelorMittal Poland Dąbrowa Górnicza there are cards of risk assessment in relation to traffic on internal roads, the level of danger in reference to category: car vehicles were set on a moderate level (Table 2).

Table 2 **Job risk assessment on internal roads of ArcelorMittal Poland Dąbrowa Górnicza [9]**

| Category | P | S | PxS | Type of danger |
|---|---|---|---|---|
| Driving a car vehicle | 2 | 2 | 4 | moderate |
| Driving a battery-electric truck, forklift truck or pallet-lift truck | 1 | 2 | 2 | small |
| Going on foot | 1 | 3 | 3 | moderate |
| Riding a bike or motorbike | 2 | 3 | 6 | big |

Where:

P – Probability of danger occurrence (scale from 1 to 3, where 1 is low probability, 2 is average and 3 is high),

S – result which the danger can cause (assessment scale: 1 to 3, where 1 is low, 2 is average and 3 is high)

## METHODOLOGY OF RESEARCH

Tests of communication noise were conducted in an enterprise ArcelorMittal section Dąbrowa Górnicza al. Piłsudskiego 92 on internal roads (access roads to production house, storehouses, and stockyards).

The communication noise inside production house strictly connected with the manufacturing process was not tested.

The number of kilometres of internal car roads in the enterprise is 17 km (the same length as a section of the motorway A4 from junction Chorzów Batory to junction Gliwice- Sośnica). Table 3 presents data concerning the internal roads of the enterprise.

Table 3 **Characteristics of internal communication system in ArcelorMittal Poland Dąbrowa Górnicza**

| Specification | Unit of measurement | Data |
|---|---|---|
| Average daily road traffic | h | |
| Passenger cars | | |
| Transport cars | | |
| Motor trucks | | |
| Railway crossing | amount | 10 |
| Railway crossing with a barrier | amount | 2 |
| Average distance covered by vehicles | | |
| Passenger cars | km | 6 |
| Transport cars | km | 4 |
| Motor trucks | km | 4 |
| Passenger cars | % | 38 |
| Transport cars | % | 25 |
| Motor trucks | % | 37 |

Measurements were conducted according to an ordinance of the Ministry of Environment in reference to the requirements connected with conduction of measurements of substances or energy in the environment by the manager of the road, rail line, tram line, airport or port [10]. Due to the fact that the norm requires the proper meteorological conditions before and during the measurement the speed of the wind and the air temperature were measured. During measurement the wind speed did not exceed 5 m/s and the air temperature was higher than (-5 °C).

In order to define the noise levels the method of direct measurements of noise were use with the application of sampling, because according to the above mentioned regulation for roads which have traffic congestion higher than 300 vehicles per hour such method is advised.

The regulation requires giving the equivalent level. The equivalent level is one of the most common indicators of noise level assessment which has different intensity in time. The idea of this indicator is about defining the average level of acoustic pressure (in analysed time). The equivalent level is marked according to Formula 1.

$$L_{eq} = 10lg\frac{1}{T}\int_0^T \frac{p^2(t)}{p_0^2}dt \qquad (1)$$

where:
p(t) - moment value of acoustic pressure / Pa;
$p_0$ - acoustic pressure of reference / Pa;
T - time for which the equivalent level is marked /s [10].

In real situations the above mathematical definition is hard to apply. That is why a more practical formula number 2 is used to mark the equivalent level.

$$L_{eq} = lg\frac{1}{T}\sum_{i=1}^{n} t_i \cdot 10L_{ai} \qquad (2)$$

where:
$L_{ai}$- noise level at the time of $t_i$ /dB(A),
$T_i$- time of noise presence with the level of $L_{ai}$ / s,
where:

$T = \sum_{i=1}^{n} t_i$ – time of observation [10]

## RESULTS

Measurements of noise level were conducted in five points on the premises of the steelworks. The visual graph of the momentary noise volume in measurement point 1 is presented in Figure 3.

The detailed results of the noise level measurements are presented together in Table 4.

Table 4 **Noise levels in measurement points**

| | Measurement point 1 | Measurement point 2 | Measurement point 3 | Measurement point 4 | Measurement point 5 |
|---|---|---|---|---|---|
| $L_{eaq\ 8h\ [db(A)]}$ | 62 | 63 | 63 | 65 | 66 |
| Range | 31,8 | 30,8 | 33,9 | 30,8 | 32,3 |
| $L_{aeq\ min}$ | 55,4 | 58,1 | 52,8 | 53,7 | 58,9 |
| $L_{aeq\ max}$ | 87,2 | 88,9 | 86,7 | 84,5 | 91,2 |

The measurements show that the highest volume of noise was noted down in points 4 and 5 which are the supply gates for motor trucks with car scales (gate 5 for direction: Ukraine, Slovakia, Cracow and Zawiercie) and gate 7 (direction: Slowakia, Czech Republik, Germany, Dabrowa Górnicza, Bielsko-Biała, Warszawa). In those points the noise level during measurement was

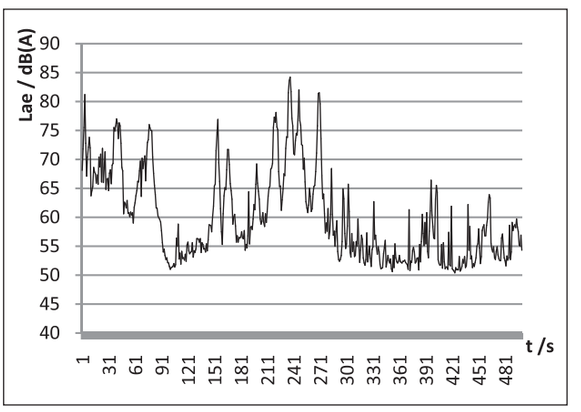


**Figure 3** Volume of noise level in measurement point 1

from 65 to 66 dB(A). In measurement point 3, not far from the stockyard of ready products the noise was on the level of 63 dB(A). In this point the range noise level (Table 4) was the highest and equalled 33,9. In the remaining points (1 and 2) the noise level was from 62 to 63 dB(A). In all measurement points the levels of noise did not exceed the levels in norms of accepted noise volume.

## CONCLUSIONS OF RESEARCH

- Due to the high level of background noise by the side of the road, that is 58 dB(A). caused by the production process in particular production houses the car traffic has a small influence on the overall level of noise. Noise level in measurement points did not exceed 66 dB(A).
- It is necessary to conduct noise measurement from the means of rail transport to present the communication noise in the enterprise in a complete way (currently the enterprise does not agree to such measurements).
- Although the level of acceptable noise level was not exceeded on the internal roads of the steelworks by the motor trucks transporting metallurgical products, it has to be pointed out that the noise in the steelworks is one of the main health hazard for the workers and due to that another noise category, even within the legally accepted norms may cause the workers' occupational diseases (accumulation of the noise levels) and, what is more, noise can be causing stress among the employees of the enterprise.

Safety and work hygiene in ArcelorMittal Poland is a priority and strategic aim and that is why there are certain steps taken in the enterprise to prevent the occupational diseases such as personal protection measures, training, preventive medical tests. Standards of safety worked out in the enterprise are available on the website wwwmyarcelormittal.com.

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# SPECIFICS OF METALLURGICAL INDUSTRY FOR IMPLEMENTATION OF LEAN PRINCIPLES

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The ideal balance between innovating and effective financing is provided by the Lean principles. The basic principle of Lean is to eliminate the wastes and to increase the efficiency of production processes. The objective of this article is to define the basic specifics of metallurgical production, to analyze the classical sources of wastes (Ohno's seven wastes) from the point of view of the identified specifics and to propose the priorities for their elimination in metallurgical production.

*Key words*: continuous improvement, Lean, Ohno's seven wastes, metallurgy

**Posebnosti metalurške industrije za implementaciju Lean principa.** Idealnu ravnotežu između inovacije i djelotvornog financiranja osigurava se Lean principima. Osnovni princip Lean-a je kako smanjiti gubitke i kako povećati učinkovitost proizvodnih procesa. Cilj ovog članka je definirati osnovne specifičnosti metalurške proizvodnje kako bi analizirali klasične izvore gubitaka (Ohnovih sedam gubitaka) i to s točke gledišta identificiranih specifičnosti i predložiti prioritete za otklanjanje gubitaka u metalurškoj proizvodnji.

*Ključne riječi:* kontinuirano poboljšanje, Lean, Ohnovih sedam gubitaka, metalurgija

## INTRODUCTION

Today, organizations in all sectors must focus on speed, performance and value for a customer in order to remain competitive. The principles of continuous improvement, which represent an important tool for achieving these goals, include setting a long-term vision, working with the challenges, continuous innovation and searching for sources of problems or tasks being solved [1]. Lean is the philosophy driving the concept of continuous improvement. The Lean principles have enabled many organizations to achieve significant economic benefits through increased quality, better cost management and improved product cycle [2]. The basic principle of Lean is to identify and eliminate wastes. This procedure increases the quality while reducing the production time and costs.

Taiichi Ohno, a former significant manager of Toyota Company and the father of the Toyota Production System has defined the seven classical types of wastes in a production company [3]:

W1: **Inventory** – all parts, products in process and finished goods that are not being processed at the moment.

W2: **Transportation** – the movements of products that are not actually required during their processing.

W3: **Motion** – people or equipment moving more than it is necessary for processing of products.

W4: **Waiting** – waiting for the next production step.

W5: **Overproduction** – production in excess of customer requirements.

W6: **Over processing** – caused by unsuitable tools or product design.

W7: **Defect** – efforts invested into controlling and elimination of defects.

Later, Womack et al. have defined the eighth source of losses such as manufactured goods or provided services which are not demanded or which do not entirely meet the expectations of customers. Many other authors also added losses caused by failure to use human talent [4]. There are many case studies on the implementation of Lean, but only minimum on its implementation in metallurgical production [5] or there are studies focusing on efficiency increase only in selected parts of metallurgical plant logistic chain [6]. However, it is just metallurgical industry that shows a number of specifics which must be taken into account when trying to apply Lean. The objective of this article is to define the basic specifics of metallurgical production, to analyze the classical sources of wastes (based on assembly types of mass production) from the point of view of the identified specifics, and to suggest the priorities for their elimination in metallurgical production.

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## EXPERIMENTAL WORK

In order to meet the desired goal, the authors conducted a survey among the experts involved in management of metallurgical companies. The Delphi method has been selected as a methodological basis used for the realization of this survey. There were two main reasons for this choice:

- The assigned topic, due to its complexity, requires the opinion of people who understand both the technical and the managerial side of affairs.
- The Delphi method does not require the experts to meet in person. It supports creative responses that might have otherwise been hampered because of the presence of others.

A team of twelve experts has been chosen. Seven experts represented the management of metallurgical companies of all levels; three experts represented research university workers, with long-term experience in management of metallurgical companies. The remaining two experts were representatives of consulting firms for increasing the efficiency of metallurgical companies. The experts had received a questionnaire from the facilitator in which they were to formulate the specifics of the metallurgical industry in relation to the seven sources of wastes described above.

The Delphi method was realized in three stages. This was done using Schmidt [7] methodology. From preparing and distributing the questionnaires to the evaluation of the third stage, the survey had taken 5 months.

## RESULTS AND DISCUSSION – ANALYSIS

Four specifics of metallurgical industry (S1 - S4) have been identified on the basis of the processed outcomes acquired by the Delphi method. The impact of each specific feature on the classical sources of wastes was analysed (Ohno's seven wastes).

**S1: Technological and technical basis of metallurgical processes**

Metallurgical industry is, above all, represented by blast-furnace and steel rolling production processes, the technological basis of which consists of physical and chemical processes taking place in technically and technologically sophisticated apparatus equipment. In case of the rolling processes, there are also mechanical and forming processes. In addition, they work with hot or liquid metal which is very difficult to store and any cooling and subsequent heating represent considerable losses of perceivable heat. Metallurgical products are not composed of components; they are made of treated material of certain shape, size, and structure, physical, chemical and other properties that make their added value. The products are manufactured on the basis of technological prescripts. While the metallurgical products are apparently simple, their quantity is enormous. The combinations of grades, shapes, sizes, heat treatments and surface treatments create up to tens of thousands of items of rolled products.

***Impact on the individual sources of wastes:***

As a result of physical and chemical nature of metallurgical production, the individual processes and their production stages are closely technologically linked. The links are mainly caused by the fact that the processes of technological transformation run, in most cases, continuously at high and entirely specific temperatures. If there are any failures in the production cycle, they can go hand in hand with wastes resulting from material degradation which will significantly outweigh the waste of under-capacity exploitation of equipment (waiting). This fact greatly reduces the possibility of inventory creation in certain stages of production (work with liquid metal does not allow storage). The production technology, however, requires keeping inventory, which has a technological function. Inventory in the ore stockyard serves as a typical example (necessary for homogenization of ores). Thanks to the nature of metallurgical products (the number of finished products is much higher than the number of input materials and raw materials), it is necessary to look for potential elimination of unnecessary transportations and handling operations, especially at the end of the material flow (in assembly types of production it is reversed).

Because metallurgical production takes place in apparatus devices, the workers do not perform manufacturing operations directly, but they have controlling and regulating function. That is why inefficient motions of people or equipment or over processing due to the use of inadequate tools do not pose a threat of direct waste of manufacturing process efficiency. From this perspective, the physical movement of workers is not of fundamental importance, unlike their qualification and experience. A large amount of waiting (defined as waiting for the next production stage) is of technological nature. Cooling of rolled products on cooling beds can serve as an example here. The waiting is also caused by service and maintenance of technically sophisticated production devices. Eventual equipment failures and accidents have very serious character and they can cause very long waiting. Over processing may occur in case the technological prescript is not observed (or it is inefficiently designed).

**S2: Material and energy demandingness**

Metallurgy is highly demanding sector of industrial production as far as the material and energy consumptions are concerned. The structure of the operating costs is dominated by the costs of raw materials, fuel and energy (up to 80% of total costs), the quality, price and utilization of which are the primary factors of metallurgical production efficiency.

Taking into account the absence of domestic raw material base, many European metallurgical companies depend on the purchase of basic input raw materials from a small number of suppliers located in relatively

remote destinations (Asia, South America, Australia). The delivery time of raw materials can vary up to many months.

***Impact on the individual sources of wastes:***

The metallurgical companies keep relatively high amounts of raw materials, materials, intermediate products and finished products in stock. Apart from technological stock at the ore stockyard, the level of inventories of raw materials is significantly influenced by weather. The winter period is particularly critical as there are delays in deliveries of raw materials and they freeze. Metallurgical companies solve this problem by stocking up in advance, which leads to increased amount of capital being frozen in inventory and increasing cost of maintaining them. Stocks of semi-finished products have negative impact on the company economics as well. In addition to the cost of their maintenance, they are also associated with high costs of consumption of heat energy needed for continuous heating of stored (unnecessarily cooled) semi-finished product.

Due to the large volume of raw materials and long distance transport, the transportation can be a source of waste of metallurgical companies as well. The examples include transportation of iron ore with low iron content, which increases the number of transported trains of wagons.

The area of defects is specific as well. Given that the defects are reversible materials which are used for new production, the wastes due to defects are reduced to energy losses. That is why it is necessary to identify defects early at the beginning of the material flow so as to discontinue production from poor quality material by using additional energy.

**S3: Large production batches and volume processed in a single cycle**

Metallurgical production has the character of mass and batch production. Mass production can be represented by blast-furnace and sintering manufacturing processes, batch production takes place in the subsequent processes. Batch production is characterized by gathering orders in large batches, which allows maximizing the capacity exploitation of the capital-intensive production facilities.

The production equipment of metallurgical companies is often designed to process relatively large quantities of products within one cycle. However, even if the devices are designed for smaller quantities, constantly increasing diversity of product range and a decreasing number of production orders can lead to problems with their exploitation.

***Impact on the individual sources of wastes:***

Gathering production orders into batches is naturally associated with higher stock of semi-finished products. In addition to that, the production batches of various processes are created on the basis of different criteria of optimality. A typical example is the discrepancy between the optimal production batch of the steel manufacturing process and the rolling processes. In the steel works, the production orders are accumulated into sequences of continuous casting according to steel grades, but rolling mills gather production orders into a rolling campaign according to the profiles (shapes and dimensions). This conflict is usually solved by creating an inventory of castings between both production processes. On the other hand, reductions of production batches lead to a decline in stock of semi-finished products, but it causes a significant increase of conversion and setup times of equipment (the length in case of metallurgical equipment varies by hours).

Large amount of material processed in one cycle can cause over-production or, on the contrary, low exploitation of equipment. Steel smelting is an example of over-production, when it is not fully covered by production orders, but it is expected to pose no problems to sell the remaining part of steel. A heat treatment furnace not used to its maximum capacity can serve as an example of low exploitation.

From the perspective of defects, large amount of material processed in one cycle is reflected in the risk of a large number of defective products.

**S4: High demandingness for organization and operational planning and control**

In a single chain, there are processes with different character of the technological process (continuous processes are combined with discrete ones), different duration of production cycles and the amount processed in one cycle. The metallurgical production processes are also influenced by a large number of factors, characterized by considerable variability, stochastic character and close mutual cohesion.

Production is characterized by its complexity and by the existence of variability of its production ways. There are often more technological methods of production of steel, more steel customers (equipment for continuous casting, forging, and foundries), various secondary metallurgic operations, and various treatment operations. Bottlenecks occurring in metallurgical production have the nature of floating capacity bottlenecks [8].

Metallurgical companies are characterized by their large extent given by their great space requirements for each technology and storage of raw materials, semi-finished and finished products. Changes in layout of production equipment, or eventually creation of some storage space would require such extensive investments that they are only very difficult to realize. In addition to that, in many companies the layout of production equipment is irrational, because it was created by gradual additions and modernizations taking place over several decades.

***Impact on the individual sources of losses:***

The occurrence of stochastic effects (fluctuations in supplies of materials and consumption of semi-finished products, variability in production and handling times,

the risk of unplanned events leading to discontinuation of the production cycle), the continuous nature of production processes and long transport distances lead to the creation of buffer stock in front of the key manufacturing devices (if allowed by the technological procedures).

The variability of production routes, the vast character of metallurgical companies and irrational deployment of production equipment lead to unnecessary or excessively long handling operations. Demandingness of organizing and operational planning and control causes organizational waiting (for example because of missing material or unavailable handling equipment), over processing because of failure to keep the technological prescript or due to defects.

## RESULTS

The synthesis of results of the analysis of classical sources of wastes in terms of the identified specifics of metallurgical production is presented in Table 1. The significance of the individual sources of wastes is indicated by crosses in the table (three crosses = very important, without cross = completely insignificant). Based on the synthesis of the achieved results, it is possible to determine the priorities for elimination of the classical sources of wastes in metallurgical companies. Priority should be given to inventory, transportation, and waiting. Defects, over processing and overproduction have a lower priority.

Table 1 **Importance of classical sources of wastes for metallurgical companies**

| S/W | W1 | W2 | W3 | W4 | W5 | W6 | W7 |
|---|---|---|---|---|---|---|---|
| S1 | xxx | xx | | xxx | | x | x |
| S2 | xxx | xxx | | | | | x |
| S3 | xx | | | xx | x | | x |
| S4 | x | x | | x | | x | x |

## CONCLUSION

The obtained results confirm the considerable potential for increasing the efficiency of metallurgical companies. However, metallurgical production is so specific that the elimination of these losses can use the familiar tools of Lean only in limited extent, or not at all. 5S technique, kanban, manufacturing cells or SMED can be used as examples. Furthermore, some sources of wastes are given by the current state of technological development of metallurgical processes and equipment [9], and their elimination is not currently possible or would require high investments. The technological inventory and waiting or long conversion and setup times can serve as examples of that.

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# S H M D ´2012.

MATERIALS AND METALLURGY
MATERIJALI I METALURGIJA

# SUMMARIES OF LECTURE
# SAŽECI PREDAVANJA

Šibenik, CROATIA, June 17 – 21, 2012.
ŠIBENIK, HRVATSKA, 17. – 21. lipnja 2012.
HOTELSKO NASELJE *SOLARIS HOLIDAY RESORT*

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10th International Symposium of Croatian Metallurgical Society «Material and Metallurgy» was held as a part of:

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| | |
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**1. M. Holtzer, R. Dańko, S. Żymankowska-Kumon;** *AGH - University of Science and Technology, Krakow, Poland*

**Foundry industry – corrent state and future development.** The casting production is considered as one of the main factors influencing the development of world economy. The state of art and foresight of world's casting production is discussed in the paper on the basis of the latest statistical data. The progress gained during the last few years in foundry engineering is shown as a way to further development of foundry technology. The last decade brought significant changes in the world map of the greatest casting producers. Globalization and transformation of economic systems is reflected by variations of foundry production in different countries, more over the globalization of economy is regarded not only as a chance but also as a menace for the European foundries.

**2. F. Vodopivec, M. Jenko, M. Godec;** *Institute of Metals and Technology, Ljubljana, Slovenia (Review)*

**Progress of use of of advanced research equipment IMT, Ljubljana, Slovenia.** In area of former Yugoslavia, a line scanning of segregation in steel was first presented in 1958 at the first International Colloquium on Residuals in Iron and Steel organized jointly by institutes from France, Germany and Yugoslavia. Scientist for Yugoslavian area started to use EPMA line scanning in 1962 and image scanning in 1967. The first EPMA started to work in 1969 in Metallurgical Institute Ljubljana (MIL), the predecessor of IMT. Relatively rapidly results significant for development of industrial technology and science were achieved and in 1975 a survey of past work was published. Some years later the level of sensitivity of 10 ppm was achieved by quantitative analysis. Already in 1969 EPMA expanded in industrial companies and research institution in whole Yugoslavia and results useful for improving steels, aluminum and copper alloys, as well in base research in metallurgy, solid phase chemistry and physics, geology and even dentistry were obtained. F.i. based on EPMA the evolution of composition of nonmetallic inclusions in steel was explained and better mastered, homogenization time for several aluminum and copper alloys shortened by half, binary equilibrium diagrams for carbides TIC and NbC and transition metals as well as some ceramic compounds determined, by analyses of some glasses larger electron beam diameter was used to obtain reliable quantitative composition. In a few years after MIL, EPMA was acquired also by research institutions and universities in Zenica, Sisak and Belgrade as well as in Institute J. Stefan in Ljubljana.

The use of TEM and replica methods became insufficient in project related at micrometers size and lower to microstructure of alloys and fracturing micromorphology and in 1978 a scanning electron microscope (SEM) equipped EPMA and image analysis was acquired in MIL. Also the use of SEM expanded rapidly and in Yugoslavian area several SEM+EPMA were in operation after few years. Very significant achievement significant for explanation of fracturing events, properties and change of properties with operation time in parts of thermal power works were obtained.

Answers to questions related of change of properties and microstructure related with grain boundary and surface segregations were not supported reliably with analyses on available analytical devices as the depth of generation of signal on EPMA was much greater that the thickness of segregation, thus results of Auger electron spectrometry (AES) became necessary. The first AES started to work at the Institute for electronics and vacuum technique (IEVT)at Ljubljana in 1986, while, at IMT an improved Field Emission AES equipped by x-ray photoelectron spectrometer (XPS) was installed in 1997. New analytical results and images were used in projects of basic and applied results, such us effect of alloy composition, temperature and time on sulfur, phosphorous, antimony, tin, copper and selenium surface and grain boundary segregation on recrystallisation of grains and texture of soft magnetic sheets. The effect of phosphorus grain boundary segregation on fracture toughness and properties of heat treated steels used in steam and nuclear power plants as well as high strength steels used in automotive industry for vehicle components-springs. The use of integrated electron spectroscopy techniques AES, XPS, TEM-EDS and EDS/WDS enabled to study in details multilayer (26 layers of thickness 50 nm) deposed on tool steels.

In 2006 approved Center of excellence of advanced metallic materials enabled to acquire a high resolution transmission electron microscope (200 keV) equipped with STEM, EDS DF and BF. IMT has acquired all advanced techniques for analysis on macro, micro, nano and atomic scale level as well as free surfaces and grains and phase boundaries phenomena.

The reliability of answers related to the effect of microstructure and heat treatment of metals was sometimes questionable because of accuracy of reliable determination of space orientation of single grains and phases in microstructure. For this reason, in IMT the new acquired STEM+EPMA was equipped with a EBSD device for determination of lattice space orientation of single grains and phases in microstructure, of related lattice parameters and the deduction of elastic stresses related to lattice parameters. Significant new information on relations between lattice space orientation of constituents of microstructure were obtained.

**3. R. Fabík, J. Kliber, I. Mamuzić*, T. Kubina, S.A. Aksenov**;** *VSB-TU Ostrava, Ostrava, Czech Republic; * University of Zagreb, Zagreb, Croatia, **MIEM, Moscow, Russia*

**Mathematical modelling of flat and shape hot rolling based on finite element methods.** The aim of this paper is to critically assess the potential of mathematical modelling which uses finite element method software for solving operation problems in the hot rolling of flat and long products. We focused on concrete issues faced by rolling plants in the Moravian-Silesian region (Czech Republic). The investigation was always combined with field or pilot measurements or laboratory experiments.

**4. J. Raab, J. Mannheim;** *Czech Steel Federation, Prag, Třinecké železárny, Trinec, Czech Republic*

**Dynamics in the Development of Global Steel Production & Consumption.** According to the statistical data issued by the World Steel Association (worldsteel) and other institutes, the production of steel hit the record value exceeding 1,5 billion tons in 2011. The prognoses refer to further growth for the upcoming years. The portfolio of the steel using branches is changing as well. The article is also dealing with the interesting developments in the China and in other developing countries, such as rest of Asia and BRIC. All these changes are influencing the current and future situation within the EU countries, namely respecting the environmental legislation, image of steel and steel industry, as well as the interest of the new generation in this industry.

**5. P. Tardy;** *Association of the Hungarian Steel Industry, Budapest, Hungary*

**Clean technologies in the steel industry.** In the lecture present the latest results of developments and eveluated the recent situation of environmental protection in the steel industry in the world. Some of the most interesting topics are: – Circulation of materials and efficiency of recycling in the steel industry; – The new BREF document on the production of iron and steel; – Specific and factory-wide solutions; – The trend to increase waste utilization; – Recyclability of steel; – Methodology of life cycle assessment in steel indutry; – CO2 emission of traditional steel technologies has been strongly decreased but possibilities are limited; – In developed countries R&D actitvity is going on to eleborate new breakthrough technologies for further decerasing CO2 emission in ironmaking.

**6. M. Ikonić;** *University of Rijeka, Croatia*

**Case study in metallurgy plants strategy formulation.** Scientists use the case study research method across a variety of disciplines. Case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships. Strategy and other complex issues research results, through case study become concrete solutions, extend experience and knowledge, and add strength to hypothesis already known through previous research. In this article we give the overview of the case study scientific method and the importance of its use in the metallurgy enterprises strategy formulation process.

**7. S. V. Dobatkin, I. Mamuzic*;** *A.A. Baikov Institute of Metallurgy and Materials Science, Moscow, Russia; *University of Zagreb, Zagreb, Croatia*

**Structure and properties of ultrafine-grained aluminium alloys and possibilities of their application.** Structure and properties of ultrafine-grained aluminium alloys, obtained by severe plastic deformation (SPD) and possibilities of their application have been considered. Two schemes of SPD as the

most developed have been considered: high pressure torsion and equal channel angular pressing. SPD of aluminum alloys leads to grain refining down to nano-size. The structure has been characterized with high dislocation density, non-equilibrium grain boundaries and changed phase composition. The possibility of raising fatigue properties and demonstration of low-temperature and high strain rate superplasticity in extra strong ultrafine-grained aluminium alloys has been shown. Usage of SPD ultrafine-grained aluminium alloys is the most prospective as semi-finished product for follow formation in condition of superplasticity.

**8. D. Malindžák**; *BERG Faculty, Technical University of Košice, Košice, Slovakia*
**Application of logistic principles in metallurgical production.** Metallurgical production processes (MPP) consist of continuous and discrete types of technology operation, transport, manipulation and storing processes regards the flow of material and also the equipment and machines. Other specifics are: long production cycles, great inertia, tree structure of production processes (from roots up to the leaves), high level of investments etc. These characteristics resulted in some specifics of production logistics. This article deals with these specifics and explains it using the conditions of production processes of continuous slab casting, their heating in push furnaces at rolling temperature and rolling itself in hot wideband steel mill.

**9. R. Kawalla, M. Schmidtchen, M. Graf**; *Institute of Metal Forming at TU Bergakademie Freiberg, Germany*
**Simulation of Plastic Deformation Processes.** This paper aimed to develop such valid and efficient models, but the accuracy must be not always 100 %. To increase the simulation several difficulties were considered, for example the deformation process with strong inhomogeneities in the material and also the local extreme deformation degrees during the process, as well as the oxidation processes on the steel surface. The necessary coefficients and models for the description of the materials and there behaviour during deformation but also the oxidation process will be discussed in the following article.

**1. I. Samardžić, B. Mateša, I. Kladarić;** *University of Osijek, Slavonski Brod, Croatia*

**The influence of heat treatment on properties of three-metal explosion joint: AlMg-Al-Steel.** The procedure of welding by explosion is as technical optimal solution of ship-shell parts joining frequently used in shipbuilding industry at transition three-metal joint: AlMg4.5-Al-St.52-3 working out. The investigations of mechanical and metallographic properties of joints, exposed on heat treatment at different temperatures levels, are performed. The results of mechanical and metallographic examinations of transition joints at elevated temperatures, direct on its use below 300 °C. The additional melting welding working out is in closeness of explosion- welded joint allowed.

**2. S. Stojadinović, J. Pekez, N. Bajić*;** *University Novi Sad; *IHIS Research and Development Center, Belgrade, Serbia*

**Micro alloyed steel weldability and sensibility testing on the lamellar cracks appearance.** In this work are given the testing results of mechanical properties welded joints and microstructure of micro alloyed steel as well as its sensitivity to lamellar cracks appearance. The obtained results show that steel has good resistance to lamellar cracks appearance and with an appropriate wire choice for welding, a good combination of mechanical properties could be obtained at room (ambience) temperatures as well as at low temperatures.

**3. J. Winczek, A. Kulawik***; Czestochowa University of Technology, Poland*

**Dilatometric and hardness analysis of C45 steel tempering with different heating-up rates.** In work have been presented results of dilatometric research of hardened C45 steel subjected to tempering. The analysis of the influence of heating rate at the kinetic determined from dilatometric curves has been made. The analysis of tempering time influence on the hardness of tempered steel has been made. Functions associating hardness with tempering time (rate of heating-up) in technological processes based on short-timed action of a heat source (eg. laser treatment) have been suggested.

**4. M. Janjić, M. Vukčević, N. Šibalić, V. Mandić*, D. Pavletić**;** *University of Montenegro, Podgorica; *University of Kragujevac, Serbia; **Univesity of Rijeka, Croatia*

**Microstructural evolution during friction stir welding oF AlSi1MgMn alloy.** This paper provides the research of the influence of geometric and kinematic parameters on the microstructure and mechanical properties of welded joint of aluminum alloy AlSi1MgMn (6082-T6) obtained through the Friction Stir Welding (FSW) process. The experiment parameters were welding speed, rotation speed, angle of pin slope, pin diameter and shoulder diameter. On the obtained welded workpieces the dynamic testing on the impact toughness, and determination of microstructural zones were carried out.

**5. P. Kovač, L. Sidjanin, D. Rajnović, B. Savković, J. Wanasin*;** *University of Novi Sad, Serbia; *Prince of Songkla University, Thailand*

**The microstructure influence on the chip formation process of Al-Cu alloy cast conventionally and in semi solid state.** For many metal alloys, the process of metal cutting is accompanied by extensive plastic deformation and fracture. To study this process, quick stop sectional samples of hypoeutectic Al-Cu alloy chip formation, either as conventionally cast alloy or as "semi solid metal" are used. The type of chip formation is classified according to crack formation mechanism and propagation. During cutting, in all specimens used, quasi-continuous chips with built-up edge (BUE) are obtained. The formation of BUE is undesirable since it is a highly deformed body with a semi stable top which periodically breaks away giving rise to poor workpiece surface quality.

**6. J. Micheľ, M. Buršák, I. Mamuzić*;** *Technical University of Košice, Slovakia; *CMS, Zagreb, Croatia*

**Degradation of mechanical properties of CrMo creep resistant steel operating under conditions of creep.** Mechanical properties of a steam tube made of CrMo creep resistant steel are analysed in this contribution after up to $2{,}6 \cdot 10^5$ hours service life in creep conditions at temperature 530 °C and calculated stress level in the tube wall 46,5 MPa. Nevertheless the strength and deformation properties of the steel ($R_e$, $R_m$, $A_5$, Z), and the resistance to brittle fracture and the creep strength limit, were near to unchanged after $2{,}1 \cdot 10^5$ hours in service. The steam tube is now in service more than $2{,}6 \cdot 10^5$ h.

**7. B. Škorić, D. Kakaš, M. Gostimirović, A. Miletić, D. Ješić*;** *University of Novi Sad, Serbia; *University of Banja Luka, BIH*

**Characterization of duplex hard coatings with additional ion implantation.** In this paper, we present the results of a study of TiN thin films which are deposited by a Physical Vapour Deposition (PVD) and Ion Beam Assisted Deposition (IBAD). In the present investigation the subsequent ion implantation was provided with $N^{2+}$ ions. The evolution of the microstructure from porous and columnar grains to densel packed grains is accompanied by changes in mechanical and physical properties. A variety of analytic techniques were used for characterization, such as scratch test, calo test, Scanning electron microscopy (SEM), Atomic Force Microscope (AFM), X-ray diffraction (XRD) and Energy Dispersive X-ray analysis (EDAX).

**8. S. Kores, M. Vončina, B. Kosec, J. Medved***; University of Ljubljana, Slovenia*

**Formation of AlFeSi phase in AlSi12 alloy with Ce addition.** The influence of cerium addition on the solidification sequence and microstructure constituents of the Al-Si alloys with 12,6 mass % Si was examined. The solidification was analyzed by a simple thermal analysis. The microstructures were examined with conventional light and scanning electron microscopy. Ternary AlSiCe phase was formed in the Al-Si alloys with added cerium during the solidification process. AlSiCe and β-AlFeSi phases solidified together in the region that solidified the last. Cerium addition influenced on the morphology of the α-AlFeSi phase solidification.

**9. W. Walke, J. Przondziono*;** *FThe Silesian University of Technology, Gliwice and Katowice, Poland*

**A comparative study of the corrosion of wire used in urological treatment under sterilisation.** The purpose of the tests was to determine whether and how sterilisation process of samples made of AISI 316L stainless steel with different strain impacts their corrosion resistance. The tests were made in alternative solution simulating human urine. Recorded anodic polarisation curves created the ground for determination of typical parameters describing pitting corrosion resistance, that enabled to evaluate steel wire corrosion behaviour under sterilisation conditions.

**10. M. Jovanović, L. Kosec, B. Zorc*;** *University of Ljubljana, Slovenia; *Welding Institute, Ljubljana, Slovenia*

**Examination of weld defects by computed tomography.** Defects in metal arc gas (MAG) welds made in S235JR low carbon steel of 6 mm thickness were examined. A sample containing lack of fusion (LOF) and pores was examined by computed tomography – CT. The computed tomography examination was performed in order to define LOF size and position as well as dimensions and distribution of accompanying pores in the weld metal.

**11. R. Rudolf, M. Anžel, E. Marković*, D. Stamenković*, M. Čolić**;** *University of Maribor, Slovenia; *University of Belgrade, Serbia; **University of Niš, Serbia*

**Gold in the past, today and future.** This paper deals with gold, which is described as a chemical element. Special attention is paid to its physical-chemical properties and, furthermore, where or in what form it can be found in nature. We discuss the role it has played through history and we inform how gold has been developed to the level it has reached today's value. Still more, when gold is broken into nanoparticles, this form could be highly useful for a wide range of processes, including general nanotechnology, electronics manufacturing and the synthesizing of different functional materials. It is important that we know that gold is also used in industry in many engineering applications (contacts in micro-electronics) and medicine (dental alloys, implants).

**12. T. Bončina, F. Zupanič, B. Markoli*;** *University of Maribor; *University of Ljubljana, Slovenia*

**Effect of cooling rate on the microstructure of an $Al_{94}Mn_2Be_2Cu_2$ alloy.** In this study the effect of the cooling rate on the microstructure of $Al_{94}Mn_2Be_2Cu_2$ alloy was investigated. The vacuum induction melted and cast alloy was exposed to different cooling rates. The slowest cooling rate was achieved by the DSC (10 $K \cdot min^{-1}$), the moderate cooling rate succeeded by casting in the copper mould (≈1 000 $K \cdot s^{-1}$) and the rapid solidification was performed by melt spinning (up to $10^6$ $K \cdot s^{-1}$). Particles of i-phase and θ-$Al_2Cu$ were much smaller and more uniformly distributed in melt-spun ribbons.

**13. J. Brezinová, A. Guzanová**; *Technical University of Košice, Slovakia*
**Possibilities of utilization high velocity oxygen fuel (HVOF) coatings in conditions of thermal cyclic loading.** The item deals with the possibilities of utilization HVOF coatings in thermal cyclic loading conditions. There were evaluated three types of coatings based on WC-Co, WC-Co-Cr and $Cr_3C_2$-25NiCr. The quality of coatings was evaluated in terms of their adhesion as sprayed and also during the cyclic thermal loading, EDX analysis and evaluation of microhardness. Construction and structure of coatings were studied using optical and electron microscopy. There was also evaluated resistance of the coatings against erosive wear.

**14. D. Jevremovic, T. Puskar, B. Kosec*, Đ. Vukelic, I. Budak**, S. Aleksandrović***, D. Egbeer***, R. Williams*****; *University Business Academy, Serbia; University of Novi Sad, Serbia; *University of Ljubljana, Ljubljana, Slovenia; **University of Novi Sad, Serbia; **University of Kragujevac, Serbia; ***University of Wales Institute, Cardiff, United Kingdom*
**The analysis of the mechanical properties of F75 Co-Cr alloy for use in selective laser melting (SLM) manufacturing of removable partial dentures (RPD).** The presented work discusses the applicability of the selective laser melting technique (SLM) in manufacture of removable partial denture (RPD) frameworks with the emphasis on material properties. The paper presents initial results of a conducted test of the mechanical properties of the F75 Co-Cr dental alloy used with selective laser melting.

**15. T. Karkoszka, M. Soković***; *Silesian Technical University, Gliwice, Poland; *University of Ljubljana, Slovenia*
**Integrated risk estimation of metal inert gas (MIG) and metal active gas (mag) welding processes.** The paper presents the results of risk analysis, using an integrated risk indicator implemented into operation of the MIG and MAG welding processes in the practice. In the welding risk management one can decide about reduce the risk by avoiding the risky ventures, or as a result of the proper preventive actions' application.

**16. B. Mateša, I. Samardžić, M. Dunđer**; *University of Osijek, Slavonski Brod, Croatia*
**The influence of the heat treatment on delta ferrite transformation in austenitic stainless steel welds.** *Shielded metal arc (SMAW) welded specimens using austenitic consumable materials with diffeerent amount of delta-ferrite are annealed in range 650-750 °C through 2-10 hours. Factorial plan $3^3$* with influenced factors regression analyse of measured delta-ferrite values is used. The transformation i.e. decomposition of delta ferrite during annealing was analysed regarding on weld cracking resistance using metallographic examination and WRC-1992 diagram.

**17. J. Piątkowski, B. Gajdzik, T. Matula**; *Silesian University of Technology, Katowice, Poland*
**Crystallization and structure of cast A390.0 alloy with melt overheating temperature.** The paper presents the research on the influence of melt overheating temperature on crystallization parameters and primary structure of cast AlSi17Cu5Mg (A390.0) alloy overheated to temperature: 820 °C, 880 °C, 940 °C and 1 000 °C. It was found that the degree of overheating influences the change of microstructure significantly and morphologies of primary silicon of the castings from Al-Si alloys. Research has shown that the overheating of the liquid metal bath is one of the methods of finding more applications of hypereutectic Al-Si system alloys without the addition of modifiers.

**18. J. Tušek, D. Klobčar, M. Pleterski**; *University of Ljubljana, A. Lešnjak, Techna, Ljubljana, Slovenia*
**The weld-pool solidification mode of ferritic stainless steels.** The paper presents the analysis of solidification mode at gas tungsten arc welding (GTAW) of AISI 430 ferritic stainless steel. Two solidification modes (epitaxial and equiaxial) were discovered, which have a major influence on a weld tensile strength. The optimal welding parameters for ferritic stainless steels were found in a narrow range. They should be selected according to mechanical strength of the welded joints and not only according to their visual appearance.

**19. T. Węgrzyn, R. Wieszała**; *Silesian University of Technology, Faculty of Transport, Katowice, Poland*
**Main alloy elements in covered electrodes in terms of the amount of oxygen in weld metal deposits (WMD).** There were investigated properties of WMD, especially metallographic structure, toughness and fatigue strength of welds with various oxygen amount. The connection between the properties of welds with the content of oxygen in WMD were carried out. The research results indicate that it should be limited oxygen content in steel welds. Subsequent researchers could find more precisely the most beneficial oxygen amount in the welds in terms of the amount of acicular ferrite in welds.

**20. F. Grešković, J. Varga, Ľ. Dulebová**; *Technical University of Košice, Slovak Republic*
**The utilize of gamma radiation on the examination of mechanical properties of polymeric materials.** The article deals about the application area of radiation crosslinking of plastics, which follows after the injection moulding. The main objective of the presented article is the research of influence irradiation dosage on mechanical properties of materials: PP filled by 15 % of mineral filler – talc. Mechanical properties - tensile strength and impact strength by Charpy were examined in dependen ce on absorbed dose of the gamma rays on various conditions and were compared with non-irradiated samples.

**21. S. Vesković, Ž. Đorđević, G. Stojić*, J. Tepić*, I. Tanackov***; *University of Belgrade; *University of Novi Sad, Serbia*
**Necessity and effects of dynamic systems for railway wheel defect detection.** State of railway vehicles highly influences transport safety due to vehicle derailments and in the same time worsens the quality of freight and passenger transportation. One of important elements that influence the state of railway vehicles is the wheel state. Wheel defects are common in railway transport. Therefore, timely defect detection is very important. This paper presents ways and effects of timely detection of wheel defects.

**22. M. Zeleňák, J. Valíček, P. Hlaváček, S. Hloch*, D. Kozak**, I. Samardžić**, M. Harničárová, J. Klich, R. Cincio*****; *VŠB -Technical University of Ostrava, Czech Republic; *University of Košice, Slovak Republic; **University of Osijek, Croatia; ***Koszalin University of Techology, Poland*
**Comparison of mechanical properties of surface layers with use of nanoindentation and microindentation tests.** The objective of the paper is a mutual comparison of different methods for evaluation of mechanical properties of surface layers. Mechanical properties were tested with the use of nanoindentation and microindentation tests. Different loads and constant deformation speed were used in both cases. Knowledge of relations and differences between nano and micromechanical properties is necessary for understanding of mechanical processes continuously occurring in surface layers during cutting processes.

**23. D. Klobčar, J. Tušek, M. Pleterski, M. Muhič***; *University of Ljubljana, Slovenia, *TKC d.o.o., Ljubljana, Slovenia*
**Thermo-mechanical cracking of a new and laser repair welded die casting die.** The paper presents the analysis of thermo-mechanical fatigue cracking of die casting die during industrial use. An innovative, production friendly approach to monitor the surface crack dimensions was introduced, which is based on measuring defect-fin on the casting part. A new four moulds die casting die was monitored 40 000 cycles in order to complete the production series. The defect-fin heights were measured every 1 000 cycles on the castings before and after repair welding of die surface cracks. The in-service die life can be prolonged with laser repair welding for several times, even thought that in-service die life for a particular repair varies.

**24. T. Vuherer, P. Maruschak*, I. Samardžić****; *University of Maribor, Slovenia; *Ternopil University, Ukraine; **University of Osijek, Croatia*
**Behaviour of coarse grain heat affected zone (HAZ) during cycle loading.** This paper presents results of a study on martensitic coarse grain heat affected zone that can appear in welded joints. Mechanical properties of martensitic coarse grain heat affected zone and its microstructure were investigated. Special attention was given to its behaviour during the cycle loading under stress concentration. Stress concentration was similar to the one in real welds. The S-N curve and the fatigue limit were determined. The Paris curve and the threshold for crack propagating were also determined.

**25. M. Mihaliková, M. Német**; *Technical University of Košice, Slovakia*
**Increments of plastic strain and hardness hv10 of automotive steel sheets.** The present paper deals with measurements of the increments of strain and hardness HV10 on automotive steel sheets. The car body manufacture trends are focused, in particular, on high energy absorption capability. The measurements were made on DP steel, micro-alloyed steel, and IF steel. The specimens were scanned using a video-extensometer technique with a CCD

camera. The result was strain increment maps, constructed using the Matlab software. The hardness HV10 was measured on the failed specimens around the notches. 3D hardness distribution maps were made from the measured values of HV10.

**26. J. Krešák, S. Kropuch, P. Peterka**; *Technical University of Košice, Slovak Republic*
**The anchors of steel wire ropes, testing methods and their results.** The present paper introduces an application of the acoustic and thermographic method in the defectoscopic testing of immobile steel wire ropes at the most critical point, the anchor. First measurements and their results by these new defectoscopic methods are shown. In defectoscopic tests at the anchor, the widely used magnetic method gives unreliable results, and therefore presents a problem for steel wire defectoscopy. Application of the two new methods in the steel wire defectoscopy at the anchor point will enable increased safety measures at the anchor of steel wire ropes in bridge, roof, tower and aerial cable lift constructions.

**27. N. M. Buketova, N. A. Dolgov*, V. M. Krasnen'kiy;** *Kherson State Maritime Academy, Kherson; *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Mechanical Properties of Epoxy Functionally Graded Coatings Bonded to Steel Substrate Evaluated by Bending.** Optimal technological conditions for formation of gradient coatings obtained. Maximum mechanical properties characterized the graded coatings formed on the basis of epoxy resin and dispersed particles of brown slurry, titanium dioxide and silicon carbide. The results show that improved strength properties had functionally gradient coating thickness of 1,0 mm, which had the highest levels of adhesion strength (63,8 MPa) and bending strength (59.4 MPa).

**28. G.V. Tsyban'ov and A.I. Novikov**; *G. S. Pisarenko Institute for Problems of Strength, Kyiv, Ukraine*
**Hypersurface equation for high-cycle fatigue.** The equation of surface is defined as the modified Ramberg-Osgood diagram using the function accounting for the specific kinetics of damage and fatigue of material. The obtained equation is used for assessing the specific residual lifetime of materials under variable loading conditions.

**29. G.V. Tsyban'ov, A. I. Novikov, I. Mamuzić***; *G. S. Pisarenko Institute for Problems of Strength, Kyiv, Ukraine; *CMS, Croatia*
**Determination of the kinetics of the stress-strain state of elements under cyclic bending.** To determine the kinetics of the stress-strain state (SSS), a numerical-analytical method has been developed, which is based on the equilibrium equation and proposed hypersurface equation for high-cycle fatigue as well as the model for the exhaustion of plasticity. This method makes it possible to determine the SSS under conditions of continuous variation of physical and mechanical properties with depth.

**30. A. V. Buketov, Yu. A. Karpenko, O. O. Sapronov, V. O. Skirdenko;** *Kherson State Maritime Academy, Kherson, Ukraine*
**Effect of Pulsed Magnetic Field on Properties of Epoxy Nanocomposites.** Influence of nanosized fillers and pulsed magnetic field treatment on the properties of epoxy composites. Treatment of composition with nanodisperse particles before the curing agent was added by a pulsed magnetic field allowed to increase physico-mechanical properties of coatings up to 15…18%.

**31. A. V. Buketov, N. A. Dolgov*, A. P. Pirog;** *Kherson State Maritime Academy, Kherson, Ukraine; *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Prediction of the Epoxy Composites Properties by Mathematical Simulation.** Mathematical simulation for heterogeneous systems on the basis of experimental studies of physical-mechanical and thermal properties of epoxy composites was developed. The relationship between the composites properties and the concentration of dispersed filler in the epoxy matrix was studied.

**32. A. V. Ivanchenko, N. A. Dolgov*, I. Vitez**;** *Kiev National University of Technology and Design; *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine; **CMS, Croatia*
**Method of Measuring Strain by Resistive Gauge with Automation Calculation of Transverse Sensitivity Correction.** New method of measuring strain at tensile test offered. According to the results of calculations the measurement results can be automatically changed adjusted for systematic component of measurement error, which caused the transverse sensitivity of resistive gauge. In accordance with the proposed method the accuracy of automated measuring systems can be improved on this value.

**33. N. A. Zubretskaya, A. S. Goncharov, S. S. Fedin, A. V. Besov*;** *Kiev National University of Technology and Design; *I. N. Frantsevich Institute for Problems of Materials, Kiev, Ukraine*
**Neural Network Forecasting of Bonded Joints Quality.** To increase efficiency of the multiple process control of welds production and forecasting their physical and mechanical characteristics, the neural network modeling is suggested according to the combination of varying technological processes. The suggested neural network approach is universal and can be applied for multiple relations of process and design parameters of bonded joints.

**34. N. K. Kycher, M. V. Borodii, E. L. Danil'chuk and M. P. Adamchuk;** *G. S. Pisarenko Institute for Problems of Strength, Kyiv, Ukraine*
**The Experimental Study of the Effect of Cyclic Creep Under the Asymmetric Proportional Loading.** To examine the behavior of material under asymmetric cyclic loading experimental studies were performed on static and cyclic strength of carbon steel 20 at room temperature. The curves of deformation under cyclic loading for tension-compression, alternating torsion and proportional loading were retrieved. There were also defined ratcheting deformation curves.

**35. E. I. Uskov, I. Mamuzić*;** *G. S. Pisarenko Institute for Problems of Strength, Kyiv, Ukraine; *CMS, Croatia*
**On Interrelation Between Short-term and Long-term Strength Characteristics of Materials.** It is shown that for predicting the long-term strength of structural materials it is required to account for not only such known characteristics as ultimate strength $\sigma_u$, yield strength $\sigma_{0,2}$, relative elongation $\varepsilon$ and reduction $\psi$, but also other non-conventional characteristics that can be obtained from the tensile stress-strain diagram. In particular, it is necessary to determine and consider strain $\varepsilon'$, at which ultimate strength of the material is attained.

**36. E. I. Uskov;** *G. S. Pisarenko Institute for Problems of Strength, Kyiv, Ukraine*
**On Features of Crack Growth Resistance for Structural Refractory Alloys at High Temperatures in Vacuum.** The results of study of the crack growth resistance for different structural refractory alloys of tungsten, molybdenum, chromium as well as of composite materials based on them are presented over the wide temperature range from room temperature to 2000ºC in vacuum. The procedures of preliminary thermomechanical treatment for materials to enhance their crack growth resistance have been proposed.

**37. V. G. Grechanyuk, I. Mamuzić*;** *Kiev National University of Engineering and Architecture Ukraine, Kiev, Ukraine; *CMS, Croatia*
**Features of Structure Formation in Composite Materials Based on Copper, Produced by Electron-beam Method.** Composite materials Cu-Mo, Cu-W were obtained from two crucibles by electron-beam evaporation and subsequent condensation in vacuum at a fixed substrate of Article 3 at 900 ± 30 ° C with a gradient of concentration of molybdenum and tungsten up to 50%. It is shown that composite materials characterized by a layered structure, whose formation depends on the concentration of components. Noted increase in corrosion resistance with increasing concentration of tungsten in the condensates Cu-W and its decline with increasing concentration of molybdenum in the systems Cu-Mo.

**38. I. V. Orinyak, E. S. Yakovleva, Ya. R. Dubik;** *G. S. Pisarenko Institute for problems of Strength, Kiev, Ukraine*
**Estimation of Crack Opening Area and Leak Rates Through Cracks in Pipes.** In this paper, using the combining method of the weight function, the approximate expression is proposed for the fundamental displacement field under polynomial load on the crack faces in the shell. This paper proposes the model on the basis of the differential equation for one-dimensional homogeneous two-phase flow, which is used in determining the leak rate unlike the approaches with simplifying methods for describing two-phase flow, for instance the Henry-Fauske model.

**39. V. P. Shvets, N.R. Muzyka, A. N. Maslo***; G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Damage Assessment of the Metal Subjected to Recrystallization under Subsequent Deformation.** The paper is devoted to the study on the damage of prestrained metallic materials after recrystallization annealing under their subsequent plastic deformation by the LM-hardness test method. With an increase in the strain level intensive damage accumulation is observed in the metal with lower values of loading as compared to the values before annealing.

**40. V. V. Khvorostyany***; G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Fracture Resistance of Ceramics and Glass with Local Damage to the Edge of the Specimen Produced by Indentation with a Rockwell Indenter.** The study of the mechanical behavior of ceramics and glass was performed by the scratch testing of the specimen surface up to its edge flaking with a Rockwell indenter (the S+EF test method). The method of determining the material sensitivity to the scratch-induced stress concentration is presented by comparing the test results obtained by the S+EF and EF methods.

**41. B. A. Griaznov, A. D. Pogrebniak*, A. S. Tugarinov**;** *G. S. Pisarenko Institute for Problems of Strength; *S. P. Timoshenko Institute of Mechanics; **National Aviation University, Kiev, Ukraine*
**Influence of the Nutal Samples Surface Mechenical Treatment on their Fatugue Strength.** Influence of surface mechanical treatment on cyclic strength of samples chromium-nickel alloy foundry EP539LM has been studied. It is shown that the endurance of the samples is greatly affected by residual stresses induced on the surface of the samples as they are processed.

**42. B. A. Griaznov, Y. S. Nalimov;** *G. S. Pisarenko Institute for Probletms of Strength, Kiev, Ukraine*
**Increase the Endurance Limit and the Removal of Unacceptable Crankshaft Deflection of Piston Engines by Piecemeal Changes of Cold Straightening.** A technique for the study of the cyclic strength of ductile iron shafts subjected to different processing techniques, resulting in shaft deflection was eliminated. For this special equipment is manufactured, where the correction is performed in static bending.

**43. B. A. Gryaznov, V. A. Kakuevitsky*, A. M. Redzyuk*, I. P. Trubachev**, Y. S. Nalimov;** *G. S. Pisarenko Institute for Probletms of Strength; *Gosavtotrans, Scientific-Industrial Assosiation; **National Technical University of Ukraine "KPI", Kiev, Ukraine*
**A Method for Increasing the Fatigue Limit for Structural Elements of Engines.** We investigated the cyclic strength of ductile iron shaft having deflection due to a failure of lubrication system. It is shown that the use of cold piecemeal changes virtually eliminates deflection shaft piston engines.

**44. K. A. Yushchenko, B. A. Gryaznov*, V. S. Savchenko, Y. S. Nalimov*, L. V. Chervyakova, A. P. Gopkalo*, A. V. Zvyagintsev;** *E. O. Paton Electric Welding Institute; *G. S. Pisarenko Institute for Probletms of Strength, Kiev, Ukraine*
**Repair of Weld Fusion Blades GTE Nickel Alloy EP539LM.** In the operation of the fatigue fracture occur blades turbines. A careful calibration of the rotor blades of cast nickel alloy EP539LM showed that these blades in a major part of the feather can be repaired by weld fusion.

**45. V. T. Troshchenko, K. A. Yushchenko*, B. A. Gryaznov, V. S. Savchenko*, Y. S. Nalimov, L. V. Chervyakova*, O. V. Kononuchenko;** *G. S. Pisarenko Institute for Probletms of Strength; *E. O. Paton Electric Welding Institute, Kiev, Ukraine*
**Experimental and computational evaluation of stress concentration in the guide blades of axial compressor unit GTK-25I.** By detailed calibration of guide blades of axial compressor unit GTK-25I was explained the reason for destruction of these blades, and offered procedures to reduce the stress referred to them.

**46. V. P. Shvets, O. A. Katok***; G.S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**The Control of Heterogeneity 10GN2MFA Steel Structure on the Results of the Hardness Characteristics and its Scatter.** The results of the studies assessed the degree of heterogeneity in the coefficient of homogeneity are the Weibull and identified the characteristics of its strength. The fields of heterogeneity, established area with a greater degree of structural heterogeneity of the material are presented.

**47. V. K Kharchenko, V. V. Bukhanovsky;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**High-temperature Strength of Tungsten, Tantalum, Alloys and Composite Materials Based on them.** The paper presents a review and generalization of the results of investigation on mechanical characteristics of tungsten, tantalum, alloys and composite materials based on them, which are used in spase rocket engineering under short-term, long-term static and low-cycle loading within short time duration in the temperature range of 290-3020 K.

**48. V. K. Kharchenko, V. V. Bukhanovsky, I. Mamuzich*;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine; * CMS, Croatia*
**Methods and Experimental Techniques of Investigation into the Physical and Mechanical Characteristics of Metallic Materials at High Temperatures.** The paper presents a rview of the methods and experimental techniques of of investigation into the physical and mechanical characteristics of metallic materials at high temperatures**.** Main regularities and existing criteria for for evaluating the load-carrying capability of refractory metals, alloyes and metallic composite materials under high-temperature mechanical loading are developed.

**49. A. G. Makaev, V. V. Kharchenko, V. V. Bukhanovsky, A. V. Bogomolov;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Evaluation of Strength Characteristics by Small Punch Test.** Indirect evaluation of strength characteristics for steels 45, 15Kh2MNFA, copper and nickel alloys by small punch test (SP) is investigated. Based on the investigation results, the analysis of SP-diagrams is performed, and the data obtained are compared with the mechanical characteristics of the investigated materials in tension.

**50. N. I. Grechanyuk, R. V. Minakova, I. N. Grechanyuk*, V. V. Bukhanovsky**, N. P. Rudnitsky**, V. V. Kharchenko**;** *I. N. Frantcevich, Kiev; *ELTECHMASH, Vinnitsa; **Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Production Technology, Structure and Properties of Condensed Cu-Cr, Cu-Mo, Cu-W and Cu-C composite Materials for Electrical Contacts.** A technology for obtaining microlayer composite materials for electrical contacts of the copper-molybdenum, copper-chromium, copper-tungsten and copper-carbon systems by means of high-speed electron-beam evaporation-condensation is developed. New morphological peculiarities of the condensed materials that cause changes in the material properties are found.

**51. N. I. Grechanyuk, R. V. Minakova, I. N. Grechanyuk*;** *I. N. Frantcevich Institute for Problems of Materials Science, Kiev; *ELTECHMASH Research and Production Company, Vinnitsa, Ukraine*
**Modern Station and Promises of Application of Technology Electron-beam Evaporation-condensation Metals non Metals in Vacuum for Resaving of Materials Electrical Contacts and Electrodes.** Priciple shemes of equipment and technological process of condensatte composite materials in systems Cu-Y-Zr-(W, Mo, Cr) making were given. It was established that besides of mentioned in spesial literature atom-molecular mechanism of mass transfer the drop mechanism is evident. Examples of practical application of condensed from the vapor phase composite materials of Cu-Mo, Cu-W, Cu-Cr, Cu-C, Cu-$Al_2O_3$ for the manufacture of electrical contacts and electrodes were reduced.

**52. A. V. Bogomolov, A. N. Mishkin;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Analysis of the Results of Investigation on Mechanical Characteristics of the Three-layer Aluminum Panels under Bending.** A comparative evaluation of mechanical properties of the three-layer panels is proposed to be carried on regarding bending stiffness. The bending tests are conducted on the three-layer aluminum beam specimens with polyethylene filler of three standard sizes, and the elastic characteristics of the outer layers and filler are determined. While test results are being processed, a good agreement (3-7%) between the experimentally obtained and calculated bending stiffness values is shown.

**53. L. S. Globa, R. L. Novogrudskaya, I. Mamuzich*;** *National Technical University of Ukraine, Kiev, Ukraine ; *CMS, Croatia*
**Computational resources of Internet portal "Strength of materials".** The paper presents the approach to the specialized internet-portal in the field of strength of materials construction is described. It is proposed to solve problems described above in the next steps: to create metadescriptions for each portal functioning elements, to make models of business processes occurred on the portal at the time of its functioning, to describe elements connections with set theory.

**54. E. Soroka, S. Klimenko*, M. Kopieikina*;** *G. S. Pisarenko Institute for Problems of Strength; *V. Bakul Institute for Superhard Materials, Kiev, Ukraine*
**Concept for Stress Strain State of PVD discontinues coatings control.** The approach to the design of PVD discontinues coatings, based on the determination of coatings' parameters subject to the sign and the level of residual stresses is devised. Obtained results are the original basis for the choice of optimal geometric parameters of coatings resistant to cohesive and adhesive failure of coated working surfaces under operating loading.

**55. E. Soroka, B. Lyashenko, J. Šipalo Žuljević*;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine; *CMS, Croatia*
**Stress Strain State of Duplex Coatings (Nitriding and PVD).** The advantages of duplex technology are demonstrated. It is shown that the composition "nitrided steel substrate − PVD-coating " is characterized by an optimal stress-strain state in comparison with the composition "steel substrate − PVD-coating. Numerical analysis (FEM) has shown that nitriding reduces by 15% shear stresses on the interface substrate-coating under contact loading.

**56. A. Selin, A. Shabetya, E. Soroka*;** *National Technical University of Ukraine "KPI"; *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**Composition "Substrate-coating" from the Position of System Analysis.** Composition "substrate-coating" is studied in terms of system analysis as a complex system with increasing uncertainty under operating conditions. Really, it was shown that in some cases, contrary to expectations, the performance of the coated surface, is lower than the characteristics of uncoated surface. This is due to premature adhesive and (or) cohesive failure of the working surface as a result of residual stresses or operating conditions.

**57. N. K. Kucher, V. N. Kucher, D. Tkalčić;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine; *CMS, Croatia*
**A Version of the Filonenko-Borodich Criterion of Strength for Materials with Different Response in Tension and Compression.** A version of the Filonenko-Borodich criterion of strength for materials with different response in tension and compression is presented. We propose new interpolation formulas that approximate the value of the limit surface based on the correlations between the intensity of the stresses and hydrostatic pressure for the two types of angles of the stress deviator.

**58. N. K. Kucher, V. N. Kucher;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*
**The Model of Elastoplastic Deformation and Associated Damage to Describe the Mechanical Behavior of Materials with Different Reaction.** The model of elastoplastic deformation and associated damage to describe the mechanical behavior of materials with different reaction in tension and compression is presented. We propose a load surface with anisotropic hardening, which involved the intensity of stress on the hydrostatic pressure and the angle form of the stress deviator. Effectiveness of the approach demonstrated in the description of deformation of concrete for different trajectories of complex loading.

**59. V. V. Usov, N. M. Shkatulyak, E. N. Tkachuk, M. Jurković*;** *South Ukrainian National Pedagogical University of K.D. Ushinskii, Odessa, Ukraine; *CMS, Croatia*
**Texture and Anisotropy of Corrosion Resistance of Low-alloyed Steel.** The textures of round bar from low-alloyed steel (Fe-0,25 % C-1,75 % Mn, 0,95 % Si) of specimen cut perpendicularly of round bar axis (the radial specimen), and of specimen cut parallel of round bar axis (the axial specimen) were researched.

**60. N. M. Shkatulyak, N. P. Pravednaja, S. V. Smirnova;** *South Ukrainian National Pedagogical University of K.D. Ushinskii, Odessa, Ukraine*
**Influence of Natural Aging on a Crystallographic Texture of Duralumin 1160.** Texture development in duralumin was researched before and after natural aging. Initial sheets were annealed at temperature 5000C within 1 hour and quenched in water. Then sheets rolled with small reductions at indoor temperature to 92 and 96 % reduction. Intensity of unusual above-mentioned orientations in a texture of sheets after rolling of 96 % more than after rolling of 92 %.

**61. L. M. Lobanov, M. D. Rabkina, A. A. Nekhotyashchiy, V. A. Perepichay;** *E. O. Paton Electric Welding Institute, Kiev, Ukraine*
**Investigation and Simulation of Damage Level of Oxygen Cylinder Shells.** A correlation was established between the coercive force and cylinder wall thickness; metallographic and crystallographic features were studied, which confirm the dependence of the coercive force on structure-texture parameters of steel; a geometrical model was constructed and a software package was tried out which implements the procedure of determination of the stress-strain state based on finite element method.

**62. V. V. Mutas, M. A. Netrebskii, M. D. Rabkina;** *E. O. Paton Electric Welding, Kiev, Ukraine*
**Assessment of the Strength of Pipelines and Pressure Vessels with Local Wall Surface Defects of Erosion-corrosion Origin.** Empirical relationships have been developed for determination of admissible values of inner pressure, depending on the depth and length of surface defects. It was proved that design (calculated) strength of pipelines and pressure vessels can be ensured at a certain ratio of these parameters. A substantiation of this effect is proposed based on the change of the pattern of stress-strain state in the wall thinning zone.

**63. A. A. Bondar, V. A. Kulichenko, I. Mamuzić*;** *National University of Construction and Architecture of Ukraine, Kiev; *CMS, Croatia*
**Use of Waste a Paper-cardboard of Manufacture in Composite Materials.** The new composite material on the basis of plaster-cement-cindery of a withdrawal knitting with the contents a paper-cardboard of manufacture (SKOP) is created. Durability and coefficient of heat conductivity of materials with the contents SKOP different factories are certain.

**64. I. N. Grechanjuk*, V. G. Grechanjuk, V. J. Apanasenko, I. F. Rudenko;** *National University of Construction and Architecture of Ukraine, Kiev, *SPC «Eltechmach», Ukraine, Vinnitsa*
**Corrosion Resistance in Excited Environments of Composite Materials on the Basis of Copper and Molybdenum.** In work composite materials which received in the form of plates a method of electron beam evaporation and the subsequent condensation in vacuum have been investigated. Elektron-microscopic researches of samples are carried out before and after corrosion tests. Influence of environment on corrosion resistance of condensates of various compositions is shown.

**65. A. M. Marchenko, M. Jurković*;** *Plazma Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Effect of Annealing on the Working Capacity of the Heat-affected Zone of Weds of Titanium Alloy.** The effect of annealing temperatures on the resistance to delayed fracture and cyclic endurance of various regions of the heat-affected zone of alloy OT4-1 is studied. The highest operating capacity under cyclic and long-term static loads is determined in the regions exposed to heating above 1270 K.

**66. L. N. Bogomolets, J. A. Shor, M. Jurković;** *Plazma Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Welding Practices of Arc Welding of Titanium Alloys.** This paper reviews the process characteristics for arc welding titanium alloys and compares these characteristics with electron beam welding and laser welding. The characteristics of active flux tungsten inert gas welding and keyhole mode gas tungsten arc welding, two recent developments to gas tungsten arc welding, are considered, as is keyhole mode plasma arc welding. Notably, conduction mode gas tungsten arc welding are shown to have comparable mechanical properties with electron beam welding in relation to both cast and wrought base metals.

**67. F. L. Goncharenko, I. K. Chuzov;** *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Structure and Service Properties of Welded Joints of Corrosion-Resistant Steel and Titanium Alloy.** The structure of welds of steel 08Kh18N10T and titanium alloy VT-6 formed by diffusion welding is studied by methods of metallographic and x-ray spectrum microanalysis. Images of microstructure obtained in the mode of reflected electrons and maps of distribution of the main elements over a cross section of a weld are analyzed.

**68. L. K. Troyan, A. F. Zaytsev, R. Križanić*;** *Modern Welding and Brazing Science and Technology Company, Ternopil, Ukraine; *CMS, Croatia*
**Evaluation of Cyclic Strength of Welded Joints with Technological Defects.** New original methodology of evaluation of cyclic strength of welded joints with technological defects is worked out. A calculation-experimental analysis of conditions for their evolution is performed. Criteria of presence of defects in welds on fixed ice-proof drilling rigs, differentiated with respect to categories of importance of structural elements and safe from the point of view of fracture mechanics and fatigue strength, are established.

**69. L. I. Kozakova, M. F. Khivrich, A. V. Chukhleb;** *Adamant Science and Production Company, Izyum, Ukraine*
**Peculiarities of Structures, Compositions and Hardness of Wear-Proof Coatings on Basis of Tungsten Carbides.** Influence of grading structure of powder wire from alloy VK9 on structure and composition of wear-proof coverings is investigated at argon-arc cladding and by gas-flame methods are examined. Adjusting powder wire with granularity up to 80; 150-280; 280-850 microns was used.

**70. Yu. P. Kopersak, S. T. Getmanchuk, R. Križanić*;** *Svarka Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Corrosion Behaviour of the Fusion Zone of welds of Al–Mg Alloy.** The corrosion behaviour of the fusion zone of gas tungsten arc welds of AMg6 Al–Mg alloy was studied. Dynamic polarisation and impedance testing were used to determine the pitting and general corrosion resistance of the fusion zone respectively. Optical and scanning electron microscopy studies were carried out to find the mechanism of corrosion.

**71. A. L. Skulsky, I. Mamuzić*;** *Svarka Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Effect of Heat Input on Residual Stress Distributions for Weld Joints on to X18N9T Steel.** The Article present bulk residual stress distributions, as measured by neutron diffraction, for the configuration of a single pass gas tungsten arc weld bead deposited on to a 10 mm thick X18N9T steel substrate. The resulting microstructures and residual stress distributions are discussed in terms of the differing thermal excursions across each weld. In regions that are austenitised during welding, the transformation strain on cooling is shown to compensate in part for thermal contraction strains.

**72. E. M. Marchenko, K. A. Zakharchuk;** *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Surface Morphology of Plasma Nitrided Layer of Stainless Steel.** Surface morphology changes of the layer on austenitic stainless steel plasma nitrided for different times at low temperature (400–450°C) were studied by *in situ* SEM observation. The results show that nitriding does not modify the annealed twin, grain size and shape.

**73. N. A. Vitrenko, P. I. Yatsenko, B. J. Brovman;** *Kharkiv National Technical University, Ukraine*
**Modern Superalloys in Heat-and-Power Engineering.** In this paper, the requirements for materials with improved high temperature performance will be considered in the context of three types of power generation system being developed to operate with greatly reduced emissions and with high levels of efficiency. The limitations of existing materials will be outlined and the need for materials with higher temperature capabilities and good fabricability will be discussed.

**74. A. V. Molybozhenko, M. Jurković*;** *State Aviation University, Kharkiv, Ukraine; *CMS, Croatia*
**High-temperature Creep of an Mg-2AL Alloy.** Creep behavior of an advanced magnesium alloy MA2-1 (4 wt.% Al, Mg balanced) was analyzed over a wide temperature range from350 to 670 K at stresses from 20 to 180 MPa in order to investigate the mechanisms governing the creep of this alloy. The stress dependences for description of creep behavior of the alloy for different conditions of temperature-power loading were proposed.

**75. O. A. Tysyachenko, V. M. Krushelnitsky;** *State Pipe Institute, Dnepropetrovsk, Ukraine*
**Residual Welding Stresses in Low-carbon Steels.** We review here the metallurgical issues that arise in low-carbon steel welds, relate these to the difficulties in calculating residual stresses, and highlight some stimulating areas for future research.

**76. G. A. Chinguraev, V. P. Zatsarinniy, F. H. Sibgatullin;** *Ko-Welding Science and Technology Company, Zaporizzya, Ukraine*
**Transient Liquid Phase Bonding of Dissimilar Nickel Base Superalloys-Wettability, Microstructure and Mechanical Properties.** The present paper investigates the wettability-microstructure-mechanical property relationships in wide gap transient liquid phase bonds between the single crystal nickel base superalloy EP747 and two polycrystalline superalloys, EI868 and EI652, using wide gap style composite in comparison with conventional BNi-4 brazing foils.

**77. M. N. Kachanovsky, F. I. Grachev, L. M. Kafarov;** *G.V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Considerable Magnetic Field Induced Strain in Ferromagnetic Shape Memory Alloys and its Condition.** In the present paper, the martensitic transformation behaviour and the magnetic field induced strain have been examined for these three alloys. In addition, considering the results obtained, the condition for realising the large magnetic field induced strain will be derived and its propriety will be confirmed quantitatively.

**78. S. M. Mitchenko, F. O. Shlapak, R. Križanić*;** *Plazma Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Creep of Sn–45Pb–2Sb Solder Alloy.** The power law creep behaviour of the Sn–45Pb–2Sb peritectic solder alloy was investigated using an impression test apparatus. The tests were carried out under constant stress in the range 15 to 40 MPa and at temperatures in the range 290 to 360 K. Assuming a power law relationship between the impression velocity and stress, power law stress exponents in the range 1–3 were determined.

**79. K. U. Chernenko, F. I. Chushko, R. Križanić*;** *Kurdumov Institute for Physics of Metals, Kyiv, Ukraine; *CMS, Croatia*
**Microstructure and Strength Modelling of Al-Cu-Mg Alloys.** During Non-isothermal Treatments: A model is developed to predict the precipitation kinetics and strengthening in Al-Cu-Mg alloys during non-isothermal treatments consisting of controlled heating and cooling. The microstructural development and strength predictions of the model are generally in close agreement with the experimental data.

**80. M. N. Kachanovsky, F. I. Shpak;** *Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Size Effects on Martensitic Phase Transformations in Nanocrystalline NiTi Shape Memory Alloys.** Results of a systematic study are presented to review various effects of crystal size on the martensitic phase transformations in nanocrystalline NiTi shape memory alloys. The experimental results are explained by a size dependent transformation barrier that accounts for the suppression of the martensitic transformation, its thermal stability and unique morphology in the nanograins.

**81. V. O. Volkov, S. M. Morozova;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Effect of Carbon Content and Carbide Morphology on Stress Strain Curve in Vcinity of Yield Point of Carbon Steels.** Experimental analysis was carried out to examine the influence of carbon content on the stress–strain curve in the vicinity of yield point. Numerical analysis was then carried out to investigate the mechanism in the microstructure through which the influence occurred. The TEM images show a concentration of dislocations in the ferrite existing between adjacent carbides lying parallel with the macroscopic loading direction.

**82. P. I. Yatsenko, and Ya. A. Bernshtayn;** *Khmelnitsky State Technical University, Ukraine*
**Influence of Carbon and Phosphorus Addition on Sintered Density and Effect of Carbon Removal on Mechanical Properties of High Density Sintered Steel.** This paper provides data on the effect of carbon and phosphorus levels on the density of liquid phase sintered steel and the impact of subsequent carbon removal on the mechanical properties. Apparent diffusion coefficients for carbon were also estimated.

**83. M. P. Grushko, S. F. Ovchinnikov, K. M. Polyachenko;** *Ko-Welding Science and Technology Company, Zaporizzya, Ukraine*
**Effects of Reaction Products on the Bond Strength of the Transition Joint Formed Between Titanium and Stainless Steel.** The study shows the presence of different reaction layers in the diffusion zone and their chemical compositions were determined by energy dispersive spectroscopy. A maximum bond strength 75 % of that of titanium was obtained for the diffusion couple processed at 800 ° C owing to finer size intermetallic compounds and the increment in joining temperature, which results in growth of brittle intermetallics leading to a sharp fall in the strength of the transition joints.

**84. A. F. Myshlaevsky, M. P. Miklun, I. Mamuzić*;** *Kirovograd National Technical University, Kirovograd, Ukraine; *CMS, Croatia*
**Effect of Plastic Strain on Grain Size of Ferrite Transformed From Deformed Austenite in Si-Mn Steel..** The effect of plastic strain on the grain size of ferrite transformed from deformed and unrecrystallised austenite has been investigated for a low carbon Si-Mn steel. The interrelation between the equivalent plastic strain epsiloneq, numerically obtained in the range 0,1<epsiloneq<4,2, and the experimental grain size of 3-8 m was analysed. The change in ferrite grain size caused by epsiloneq in the unrecrystallised austenite region has been discussed.

**85. A. P. Mamontenko, P. B. Roitman, Yu. L. Tatarchenko;** *Slavic State Teacher's Ttraining College, Slavyansk, Ukraine*
**Influence of Homogenisation Treatment on Segregation of Silicon in Ferritic Ductile Irons: a Colour Metallographic Study.** The present investigation was undertaken to explore the use of colour metallography for revealing the severity of segregation both qualitatively and quantitatively during the homogenisation treatment. The modification of the morphology of segregation of silicon during homogenisation treatment for different times was revealed clearly by colour metallographic techniques. The proportion of interdendritic areas to the total matrix area was quantified.

**86. M. H. Artsibashev, F. K. Gergel, D. Ćurćija*;** *State Economic-Technological University of Transport, Kyiv, Ukraine; *CMS, Croatia*
**Characterisation of Steel Composites Reinforced by TiC.** Carbide reinforced steel composites are useful in extensive wear resistance applications. Tensile strength measurements showed that the ultimate tensile strengths varied between 800 and 850 MPa for composites containing 0,3–0,7 wt.% Ti. Some composites show better wear resistance properties in comparison with low alloy steels.

**87. M. P. Baranivsky, A. I. Katsman, N. Devčić;** *State Aviation University, Kharkiv, Ukraine; *CMS, Croatia*
**Precipitation Hardening in Metals.** The theoretical treatments of precipitation hardening are briefly considered. The equations for strengthening by 'hard' indeformable particles and by 'soft' deformable particles are presented, and the implications are discussed. An important contribution to these increments in strength is shown to derive from variations in the volume fraction of precipitated particles that can be employed in the various systems.

**88. L. A. Kurash, A. N Bochkin, I. Vitez*;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*
**Laser Transformation Hardening of Steels.** Laser transformation hardening experiments have been carried out on three model steel alloys of nominal composition Fe-0,5C, Fe-0,4C-1,0Mn, and Fe-0,5C-1,50Si (wt.%). A 1,5 kW continuous wave laser with a near Gaussian beam and a 4,5 kW continuous wave laser fitted with a beam integration device have been employed. The dimensions of the hardened zones have been characterised and the results compared with calculations made using process models. It is shown that the results from experiment and theory are in broad agreement.

**89. F. A. Kuleshov, V. F. Korzenko, and A. S. Karpov*;** *Modern Welding and Brazing Science and Technology Company, Ternopil; *Plazma Science and Production Company, Ukraine*
**Precipitation Behaviour in Heat Affected Zone of Welded Sainless Steel.** The present work concerns the characterisation of intermetallic phases formed in the heat affected zone of a welded superaustenitic stainless steel of composition Fe-0,01C-2Mn-25Cr-7,5Mo-20Ni-0,5Cu-0,5N (wt.%). Grain boundary precipitates at various distances from the fusion line have been investigated regarding crystal structures, compositions, and particle morphologies. A correlation of precipitation with the temperature history recorded in the heat affected zone was also performed.

**90. V. A. Shaposhnikov, G. L. Kurkotkin, I. Vitez*;** *Kirovograd National Technical University, Kirovograd, Ukraine; *CMS, Croatia*
**Further Analysis of the Monkman-Grant Relationship for 2,5 Cr-1,5 Mo Steel.** This paper addresses these issues to derive an empirical relationship capable of extrapolation. Incorporating unfailed specimens into the analysis substantially altered the predictions obtained from the Monkman-Grant relationship. The intercept of the Monkman-Grant relationship was shown to vary with absolute temperature and this was modelled to allow the relationship to be extrapolated to operating conditions for boiler tubes. A weak linear dependency of variability in rupture life on the minimum creep rate was also identified.

**91. V. F. Vashenko, A. I. Savchenko;** *State Aircraft University, Kharkiv, Ukraine*
**Wear, Tensile, and Fatigue Properties of PVD Coated Materials.** Fracture mechanisms were examined using a scanning electron microscope and an optical microscope. The experimental results show that the Cr base coating possessed far better wear resistance than the Ti base coatings.

**92. A. Ya. Alunin, P. A. Kotrechko, M. A. Kudasov;** *State Aircraft University, Kharkiv, Ukraine*
**Structure and Mechanical Properties of Mg-Al-Ca Alloys Consolidated from Atomised Powder.** Two Mg-Al-Ca alloys (A = Mg-8Al-4Ca; B = Mg-20Al-9Ca, wt.%) have been argon atomised, canned, and then consolidated by extrusion at 270 to 280°C. Alloy B exhibited a compressive fracture strength as high as 620 MPa after 1 h at 280°C while alloy A showed an ultimate tensile strength of 535 MPa and a tensile proof strength of 490 MPa as extruded.

**93. M. L. Prityka, P. I. Yatsenko, I. Vitez*;** *Khmelnitsky State Technical University, Khmelnitsky, Ukraine; *CMS, Croatia*
**Mechanical Properties and Microstructure of Ti–48Al–2W–0·5Si γ-Titanium Aluminide at Temperatures Range 20−800°C.** Five lots of the γ-TiAl alloy Ti-47Al-1.5W-0.4Si (at.%) with slightly varying compositions have been examined by tensile testing and microstructure evaluation. The study has shown a large influence of the microstructure on the tensile properties. The fractographic behaviour has been studied and is related to the tensile properties.

**94. N. L. Gorynin, F. K. Nefedov, I. Mamuzić*;** *A.A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine; *CMS, Croatia*
**Size Distribution of Spray Atomised Aluminium Alloy Powders Produced During Linear Atomisation.** In the present study, the influence of operating variables, such as atomising gas pressure and linear gas atomiser slit width, on the mass median diameter were investigated for linear spray atomisation and deposition of aluminium alloy (Al-1.2Mn-0.6Si-0.7Fe00.15Cu, wt.%). In addition, the influence of atomising gas pressure on the averaged liquid mass flowrate was studied. The results indicate that the averaged liquid mass flowrate increases linearly with the atomising gas pressure differential over the range 260–380 kPa, suggesting that an aspiration effect is present.

**95. M. A. Kuchera, S. A. Yumashev, I. Mamuzić*;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*
**Castability of Directionally Dolidified Nickel Base Superalloys.** Grain boundary cracking during directional solidification of columnar grained nickel base superalloys has been investigated. A quantitative test has been developed that allows a classification of the castability of directionally solidified nickel base superalloys: EI617 showed excellent castability, while EP590 showed severe cracking. A relationship was found between a small nil ductility region, obtained by Gleeble testing, and good alloy castability for EI617 and EP590. A correlation between the eutectic content of the alloy and its cracking tendency was also found.

**96. B. V. Sokurenko, M. D. Medko*;** *NTU of Ukraine "KPI", Kiyv, Ukraine; *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Effect of Thermomechanical Processing and Accelerated Cooling on Microstructures and Mechanical Properties of Carbon and Microalloyed Steels.** A mathematical model has been developed to predict the temperature distribution in the plate during accelerated cooling, taking into account the heat generation of the phase transformation. Effects of chemistry and mill parameters on ferrite grain refinement are explained in terms of nucleation and growth rate.

**97. V. L. Pochinok, M. N. Gadenin, I. Vitez*;** *Modern Welding and Brazing Science and Technology Company, Ternopil, Ukraine; *CMS, Croatia*
**Dynamic Fracture Toughness of Heat Affected Zone of 8Cr–1.5Mo Steel from Instrumented Drop Weight Tests.** The results from the 8Cr–1,5Mo steel were compared with those for AISI grade 403 martensitic stainless steel. The lack of distinctive multiple load peaks in the load–time traces for the latter is attributed to the absence of a steep toughness gradient, owing to a more or less uniform martensitic microstructure in the HAZ.

**98. Yu. A. Korshunov;** *State Aircraft University, Kharkiv, Ukraine*
**Evolution of Microstructure in $\gamma$-Ti–Al Alloys After Thermomechanical Processing.** The microstructures of silicon alloyed γ -Ti–Al alloys containing silicide particles have been studied after thermomechanical treatments to investigate microstructural evolution. Important parameters including temperature, forging strain, and sequence of thermomechanical treatments were systematically studied.

**99. V. V. Burmenko, M. F. Trush*;** *NTU of Ukraine "KPI", Kiyv; *Svarka Science and Production Company, Poltava, Ukraine*
**Effect of Aluminium on Deformation Structure of Highly Stabilised $\beta$ -Ti Alloys.** Alloys of Ti-(24-35)V–14Cr-(1-4)Al (wt.%) were compressed at temperatures in the range 25–600°C. The dislocation structure of the deformed alloys was studied using transmission electron microscopy (TEM). It was found that at room temperature, alloys with Al > 5% were very brittle and could not be deformed plastically.

**100. I. E. Ogudalova, M. D. Motovilenko*;** *NTU of Ukraine "KPI", Kiyv; *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Effects of Grain Size on Development of ∈ Martensite in Co-Cr-Mo Alloy.** In the present work, the development of athermal ∈ martensite during quenching of a low carbon Co-Cr-Mo alloy was investigated as a function of the grain size. In addition, a strain induced transformation from fcc to hcp was exhibited during compressive plastic straining. It was found that grain size exerts a strong influence on the resultant volume fractions of athermal and strain induced ∈ martensite.

**101. S. A. Nikolenko, M. Z. Gordonny, and A. F. Kasheeva*;** *NTU of Ukraine "KPI", Kiyv; *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Influence of Rare Earth Additions on Structures and Properties of Copper Alloys.** Copper based Cu–RE alloys (where RE represents lanthanum, neodymium, or samarium) with alloying content up to 15 wt.% were prepared by chill block melt spinning into ribbons of thickness between 40 and 100 μm. The metastable extended solid solubilities of the rare earth elements were evaluated by measurements of the lattice parameters of the supersaturated solid solutions and significant extension from the equilibrium solid solubility was found for all three alloys.

**102. L. D. Sklyar, V. A. Lyagunov;** *State University of Sea Transport, Odessa, Ukraine*
**Recrystallisation in Al–1,5Mg During Thermomechanical Processing.** A procedure based on quantitative optical microscopy has been used to investigate nucleation and growth of recrystallisation in an Al-1,5Mg alloy. Hot rolling and plane strain compression tests were employed for this purpose, providing strains within the range 0,3-2,3 and strain rates within the range 2,4-4,8 $s^{-1}$, while annealing was carried out at 420°C in all cases. The nucleation kinetics is not site saturated, particularly at low strains, the major discrepancy being observed early during recrystallisaton.

**103. L. N. Grechukha, A. L. Musienko, N. K. Zezenko;** *A.A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine*
**Effect of Heat Treatment on Grain Boundary Microstructure in a Nickel Based Model Alloy.** A nickel based Ni-15Cr-9Fe-0.02C (wt.%) model alloy has been investigated principally by atom probe field ion microscopy and transmission electron microscopy. In the material heat treated at 700°C intergranular precipitates of $Cr_7C_3$ , $Cr_{23}C_6$ and $Cr_2$ (C,N) were observed. The stability of these carbides is discussed. The heat treatment at 850°C resulted in the formation of $Cr_7C_3$ only. Indications of oxygen clustering at GBs and at carbide/matrix interfaces were obtained.

**104. F. K. Trufanov, A. L. Tsvigun;** *A.A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine*
**Interrelation Between Coincidence Site Lattice, Boundary Plane Indices, and Boundary Energy in Nickel.** This paper reports an analysis both by coincidence site lattice (CSL) categorization and interface–plane categorization of a large data set of grain boundary geometry in nickel. The analysis showed that whereas two-thirds of Σ3 and Σ9 CSLs were classed as having 'special' geometry (i.e. related to low energy), very few other CSLs had 'special' geometries. It was found that for Σ3s there was an empirical relationship connecting the frequency of occurrence of specific planes (mostly asymmetrical tilt types on the 011 zone), the average interplanar spacing at the boundary (d(eff)), and the boundary energy.

**105. A. L. Galiulin, M. N. Zverev, M. Jurković*;** *State Aviation University, Kharkiv, Ukraine; *CMS, Croatia*
**Low cycle Fatigue of Low-alloyed Carbon Steel.** The cyclic stress–strain response, low cycle fatigue (LCF) behaviour, and evolution of dislocation structures under LCF loading in the case of a carbon low-alloyed carbon steel are discussed. The experimental LCF life was compared with the life predicted using Tomkins model and the modified universal slopes equation. While the life predicted by aforementioned model showed good correlation with the experimental results, the life predicted using the MUS equation grossly overestimated the life.

**106. K. A. Furs, B. V. Tymyrkhanov;** *A.A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine*
**Effect of Matrix Structure on Physical Properties of an Ductile Cast Iron.** Measurements of thermal diffusivity, specific heat capacity, and density are reported for seven different matrix structures of a ductile iron of composition Fe–3·5C–2,5Si–0,7Mn–0,005P–0,012S–0,25Mo–0,3Cu–0,04Mg (wt.%). These measurements are used to calculate the thermal conductivity over the temperature range 250–600°C. The matrix structures examined were ferritic–pearlitic, martensitic, and austempered. Matrix structure is shown to play a significant role in determining the thermal conductivity of the ductile iron.

**107. L. A. Malashok, A. F. Naumov;** *State University of Sea Transport, Odessa, Ukraine*
**Intergranular Cracking and Corrosion Assisted Fracture Paths in Aluminium Alloys.** Sea water corrosion experiments on aluminium alloy 1915 heat treated to various conditions other than the slightly overaged state in which it is normally used, have revealed several modes of corrosion assisted cracking in the deformed surface layer that results from machining or bruising.

**108. V. P. Ruban, Yu. K. Lysak, N. A. Kazakov;** *NTU of Ukraine "KPI", Kiyv, Ukraine*
**Creep Characteristics in Discontinuously Reinforced Metal Matrix Composites.** Recent developments in the creep characteristics of metal matrix composites at elevated temperatures are reviewed. Creep in this composites is controlled by plastic flow in the matrix materials so that both the matrix alloys and the composites exhibit similar creep properties.

**109. V. A. Kovalenko, N. O. Andrushechko, and M. S. Nazarchuk;** *Modern Welding and Brazing Science and Technology Company, Ternopil, Ukraine*
**Dispersoid Formation and Cast Microstructure in Spray Deposited Al–Li Alloys.** Spray deposition has been used to increase the concentration of dispersoid forming elements in model Al–Li–TM alloys (where TM stands for transition metals). The cast grain structure and the composition and stability of the dispersoids formed after a range of precipitation treatments was investigated. Very fine, nearly uniform, grain structures were obtained in the sprayed billets. It was found that materials with the highest peritectic forming element concentrations showed the finest grain size. Combinations of Zr and Ti gave the best grain refinement.

**110. Yu. V. Duchnovich, F. R. Mykytenko;** *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Effect of Vanadium on Hardenability of Medium Carbon Steel.** The effect of additions of vanadium with simultaneous additions of other carbonitride forming microalloying elements (Ti, Nb, Zr) or Al on the hardenability of steels of composition Fe-0,3C-1.4Mn-(0,005-0,025)N (wt.%) was investigated. The relationships between the hardenability parameters and the calculated austenite composition as well as the amount of undissolved carbonitride were studied. The optimum conditions for increasing the efficacy of vanadium as a hardenability agent were established.

**111. K. L. Dobrovolsky, T. I. Vinokurov, M. Jurković*;** *G.V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine; *CMS, Croatia*
**Microstructure and Shape Memory Properties of Fe–Ru Alloy.** The shape memory properties and microstructure associated with $\gamma$(fcc) → ∈ (hcp) martensitic transformation in an Fe–15Ru alloy have been investigated. The Fe–15Ru alloy showed shape recovery to some extent, but to a lower degree

than in Fe–Mn–Si based shape memory alloys. The lower strength of the matrix, the presence of $\in$ and $\alpha'$ martensites at room temperature, and the higher stacking fault energy in the Fe–15Ru alloy are thought to be responsible for the weaker shape memory effect.

**112. A. Z. Yuzyshin, N. Devčić*;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*
**Slip band Decohesion as Unifying Fracture Event During Fatigue Crack Growth.** It identifies a unit increment of crack growth and provides a source of damage for the process zone ahead of the crack tip. The concept is not material dependent, but does depend upon the concentration of slip into persistent slip bands. An effect of environment on crack growth is expected to follow from its effect on slip band decohesion.

**113. V. A. Vasilenko, A. P. Kurchanina;** *State Aircraft University, Kharkiv, Ukraine*
**Evolution of Microstructure During Heat Treatment of High Carbon Cr–Mo Steel.** Scanning electron microscope and X-ray diffraction studies of the as cast steels have shown that the primary carbides are essentially of $M_7C_3$ type, whereas in heat treated specimens both $M_7C_3$ (primary) and $M_{23}C_6$ (secondary) type carbides have been observed. The relative amounts of these carbides are found to be dependent on the heat treatment temperature. In addition, nucleation of austenite occurs above 920°C and at ~1230°C the matrix transforms entirely to austenite, which is retained completely on quenching to room temperature.

**114. A. M. Kozub, F. G. Zvereva, S. I. Bytchkov*;** *State Aviation University, Kharkiv, Ukraine; *Delta-Composite Science and Production Company, Zaporozye, Ukraine*
**Effect of Microstructural Instabilities on High Temperature Creep of Superalloy EI826.** The elevated temperature creep behaviour of superalloy EI826 has been examined from 950 to 1250°C ($0{,}7–0{,}9T_m$) at constant stresses between 5 and 35 MPa ($\sigma/\mu = 1{,}4 \times 10^{-4}$ to $9{,}5 \times 10^{-4}$). Two complementary strain–time responses were observed. Metallographic evidence indicates that this transitory behaviour is controlled by the interaction between the operative stress, the exposure time, and the rate of grain boundary carbide coarsening.

**115. A. M. Kozub, S. I. Bytchkov*;** *State Aviation University, Kharkiv; *Delta-Composite Science and Production Company, Zaporozye, Ukraine*
**Effect of Aluminium on Crack Growth Resistance of EI826 Superalloy Welds.** The effect of concentration of aluminium in filler alloys on heat affected zone microfissuring in welded cast superalloy was studied. Three fillers, with aluminium concentrations varying from 0,25 to 5,5 wt.%, respectively, were used to weld cast EI826 alloy plates subjected to two different preweld heat treatments. The hardness of the fusion zone as well as the base metal appears to have a significant effect on the cracking susceptibility of the welds made with different fillers.

**116. S. P. Korshunov, T. A. Balayan*;** *State Aviation University, Kharkiv; *Delta-Composite Science and Production Company, Zaporozye, Ukraine*
**Microstructure and Mechanical Properties of EI826 Superalloy Electron Beam Welds.** Bead on plate, full penetration electron beam welds were produced in 2 mm thickness sheets of EI826 superalloy in the solution treated condition. Welds were subjected to an aging treatment with and without post-weld solution treatment. The use of 970°C solution treatment was found to improve the weld properties to some extent, although not to the level of the base metal. The reasons for this behaviour are discussed, correlating microstructures, fracture features and mechanical properties.

**117. V. O. Miloradovrich, T. F. Bogaevsky;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Effect of Manganese Dispersoids on Mechanical Properties of Al–Mg–Si Alloys.** The effects of Mn dispersoids on the mechanical properties in Al–Mg–Si(–Mn) alloys have been studied to develop a new high Mn alloy. Result can be explained by the increasing energy absorption through crack deflections and tortuous crack paths by the Mn dispersoids.

**118. L. P. Onoprienko, T. S. Dankevich;** *G.V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Wide Gap Transient Liquid Phase Bonding of NiAl–Hf to a Nickel Base Superalloy.** The present paper investigates the extent to which this problem can be overcome by the use of a wide gap transient liquid phase bonding process, employing composite interlayers. The paper considers transient liquid phase bonding of single crystal NiAl–Hf to a polycrystalline superalloy EI598 by means of an NiAl–Cu composite preform. The paper contrasts the relative influence of the transient liquid phase process and post-bond heat treatment on joint microstructure.

**119. V. I. Petrichenko, L. P. Rudenko;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Equiaxed Solidification of Al–Si Alloys.** An experimental programme has been undertaken to determine which of the grain formation mechanisms of equiaxed crystals are dominant in the solidification of Al–Si foundry alloys. Small ingots were cast from alloys of varying silicon concentration with and without gauze barriers, using different types of mould materials and different mould preheats. The results show that two mechanisms of grain nucleation are operating.

**120. V. L. Kalmykov, N. G. Chymachenko, M. P. Khmelnitsky;** *State University of Railway Transport, Dnepropetrovsk, Ukraine*
**Thermal Effects Due to Tempering of Austenite and Martensite in Austempered Ductile Irons.** Typical compositions of austempered ductile cast irons in different metallurgical states were studied with the aim of making a detailed assignment of thermal effects seen using differential scanning calorimetry (DSC) to transformations occurring in the alloy phase constitution and microstructure. It is concluded that DSC is a powerful tool for detecting tiny traces of martensite in austempered materials.

**121. V. K. Naumova, R. M. Berestyan;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Improving Parametric Creep Rupture Life of 2,5Cr–1,2Mo Steel.** Linear and non- linear least squares analysis was used to estimate the parametric models and genetic algorithms were used to identify and train the network. All the parametric models produced lifetime predictions for stresses below 55 MPa that were in error by some 25–40% on average.

**122. N. A. Belobrov, N. Jurković;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*
**Prediction of Embrittlement During Aging of Stainless Steel Welds.** Simulated weldments of stainless steel having a ferrite content of 4–6% with three levels of nitrogen (0,02, 0,08, and 0,12 wt.%) were prepared using a modified elemental implant technique. An empirical relation connecting the aging temperature, aging time, and nitrogen content to the lower shelf energy was developed, which can be used to predict the time for embrittlement at a given nitrogen level and aging temperature.

**123. V. A. Beloselsky, L. S. Zubatova;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Creep Behaviour of SiC Reinforced Aluminium Composite at Static and Cyclic Loading.** Static and cyclic creep tests were carried out in tension at 570–670 K on a 20 vol.-%SiC whisker reinforced aluminium ($Al/SiC_w$) composite. The cyclic creep retardation behaviour can be explained by the storage of anelastic strain delaying non-recoverable creep during the onload cycles.

**124. A. A. Shtorm, I. S. Zapashnaya, G. I. Trusevitch, I. Mamuzić*;** *State Pipe Institute, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Cast and Aged Structures of Heat Resistant Steel Solidified in an Electromagnetic Field and under Different Cooling Conditions.** The influences of an applied electromagnetic field and cooling conditions on the as cast and aged structures of centrifugally cast heat resistant HK40 steel tubes were investigated. The results reveal that both the electromagnetic field and the cooling ability of the casting mould have significant effects on the macrostructure morphology and the volume fraction and distribution of eutectic carbides, as well as on the homogeneity of secondary precipitation caused by high temperature aging treatment.

**125. V. M. Zvereva, M. Jurković*;** *State University of Railway Transport, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Fatigue Performance and Microanalysis of Heat Treated KhN35VT Stainless Steel.** The reduced corrosion fatigue performance of a heat treated grade of KhN35VT stainless steel has been quantified using rotating bending fatigue machines. The reduction in fatigue performance has been related to elemental profiles around intergranular and intragranular precipitates and grain boundary segregation measured using EDAX analysis and scanning transmission electron microscopy.

**126. L. F. Karpov, P. I. Tregybov, G. K. Chuchleb;** *Lazer Science and Production Company, Vinnitsa, Ukraine*
**Microstructures and Mechanical Properties of Electron Beam Welded Aluminium–Lithium Plates.** The present work focused on the welding characteristics of electron beam welding in Al–Li plates, evaluated in terms of strength or toughness degradation in post-weld impact and bending tests with loading rates of $10^3$, $10^{-1}$, and $10^{-4}$ $s^{-1}$. The influence of welding parameters, such as welding power, welding speed, and electron beam focus position, on the post-weld microstructures, porosity, and mechanical properties were examined. Finally, given the same post-weld microstructures, the toughness degradation of the weld specimens was worst under high rate impact loading.

**127. D. A. Lopatenko B.A., V. V. Bondarchuk;** *National Aviation University, Kiev, Ukraine*
**Fatigue of Cu–Ni–Si Alloy with Precipitate Strengthening.** The fatigue resistance and tensile properties of a precipitate strengthened Cu–Ni–Si alloy have been investigated. Underaged material exhibited greater work hardening rates than either the peak aged or overaged material. It is proposed that this occurs because the $\delta$-$Ni_2$ Si precipitates can be cut by dislocations, but the significant difference in structure between the matrix and precipitate requires that interfacial dislocations are left behind which resist further cutting.

**128. S. A. Kulesh, H. F. Kusan;** *E. O. Paton Welding Institute, Kiev, Ukraine*
**Friction Welding of 1205 Aluminium Alloy to 304 Stainless Steel Kh18N9T.** The process of friction welding between the aluminium alloy and the stainless steel is proposed to evolve as follows: welding progresses from the outer to the inner region; an unbonded region is retained at the centre of the weld interface with shorter friction time; longer friction time causes the formation of an intermetallic reaction layer at the weld interface; and the reaction layer grows as the friction time increases.

**129. M. P. Onoprienko, N. I. Markovets;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Effect of Magnesium and Silicon and Grain Refinement in Aluminium Alloys.** Grain refinement in Al–Si alloys with silicon contents in the range of 0,3–25 wt.% has been studied in detail with conventional as well as higher level additions of a Al–4,5Ti–1,2B master alloy. A poisoning effect was observed with Al–Si alloys containing ≥ 6 wt.%Si and the extent of poisoning increased with an increase in the silicon content. The present paper also reports the influence of degasser and melt temperature on the grain refining response of Al–Si alloys.

**130. L. K. Onopenko, P. I. Ponomaryov;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Effect of Copper on Precipitation Kinetics and Hardening in Al–Zn–Mg Alloy.** The influence of the addition of copper on the precipitation behaviour of an Al–Zn–Mg alloy at 150°C has been investigated. The addition of copper results in an increase in the stability of Guinier–Preston zones formed at room temperature, and in a decrease in the nucleation temperature for the μ′ phase. It also results in a decrease in the apparent diffusion coefficient for precipitation, and in an increase in the strengthening ability of precipitates.

**131. K. A. Bondarchuk, H. G. Hristenko;** *N. E. Zukovsky National Aerospace University "KhAI"*
**Influence of Titanium and Niobium on Tin Precipitation in Iron Alloys.** In an attempt to manage tin segregation in steel, the formation of intermetallic compounds of tin with niobium, titanium, and aluminium was investigated. Two series of alloys based on Fe, Sn, and Al with either Nb or Ti additions were prepared by arc melting under argon. The level of Nb addition was found to affect the formation of Sn rich compounds. For small Nb additions, no Sn containing compounds were found, whereas the higher Nb alloy exhibited a $Fe_2$ Nb based Laves phase containing about 1 at.%Sn.

**132. S. P. Serenbogen, P. I. Mashtalir, D. Ćurćija*;** *N. E. Zukovsky National Aerospace University "KhAI"; *CMS, Croatia*
**Structure and Microtexture Changes During Solution Nitriding in Ferritic–Austenitic Stainless Steel.** The present paper reports an investigation into the microstructural changes occurring in a ferritic–austenitic duplex stainless steel during solution nitriding. Both microstructure and microtexture modifications as a result of nitrogenation have been studied, in addition to the interaction between solution nitriding, grain growth, and texture. Hence, the texture of the austenite in this region was different from that in the duplex region.

**133. A. P. Sidyachenko, F. I. Homenko;** *N. E. Zukovsky National Aerospace University "KhAI"*
**Fracture Behaviour of Smooth and Precracked Tensile Specimens of Ti5Al2V.** Following the recognition of a significant difference between the susceptibilities to hydrogen cracking of two mill annealed bars of Ti5Al2V, which were of almost identical composition but had very different microstructures, a systematic investigation of the effect of heat treatment on the mechanical behaviour of smooth and precracked tensile specimens was carried out. The observed effects of heat treatment on the critical stress intensities for slow cracking at such hydrogen levels are complicated by the occurrence of microcracks at the propagating crack tip.

**134. A. P. Chushkov, J. Šipalo Žuljević*;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine; *CMS, Croatia*
**The Overaging Kinetics of Al–Zn–Mg–Cu Alloy.** The overaging kinetics of Al–Zn–Mg–Cu alloy at 440–460 K was investigated by electrical resistivity and tensile property measurements, which were supplemented by TEM and differential scanning calorimetry (DSC). Overaging in this alloy system was shown to follow classical coarsening behaviour as characterised by a $time^{-1/3}$ particle size dependence. Precipitate dissolution under non-isothermal conditions (DSC) had an activation energy (~135 kJ $mol^{-1}$) closer to that for diffusion.

**135. O. A. Suprunenko, B. R. Segalov;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Fatigue Resistance and Tensile Properties of Cu–Ni–Si Alloy.** The fatigue resistance and tensile properties of a precipitate strengthened Cu–Ni–Si alloy have been investigated. Underaged material exhibited greater work hardening rates than either the peak aged or overaged material. It is proposed that this occurs because the $\delta$-$Ni_2$ Si precipitates can be cut by dislocations. In spite of the complex structure of the strengthening precipitate $\delta$-$Ni_2$ Si and the higher work hardening rate observed in the underaged Cu–Ni–Si alloy, it is concluded that the above mechanism is operative in this material

**136. T. A. Kozub, B. V. Tsyganenko;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Computational Modeling of Steel Oxide Failure During Tensile Testing.** A coupled thermomechanical model of oxide scale failure based on the finite element method has been developed and applied to high temperature tensile testing. The model allows for the analysis of elastic deformation, viscous sliding along the oxide/metal interface, cracking, and spallation of the oxide scale from the metal surface. The combination of the modelling approach and the high temperature tensile tests allows accurate determination of the temperature range for the transition from through thickness fracture of the scale to sliding of the non-fractured oxide raft.

**137. L. M. Kuroles, F. K. Pyontkovsky, V. Živković*;** *Lazer Science and Production Company, Vinnitsa, Ukraine; *CMS, Croatia*
**Degradation of Microstructure in Plain and Platinum Aluminide Coatings on Superalloy ZhS6U during isothermal oxidation.** Isothermal oxidation at 1100°C of a high activity plain aluminide coating and a platinum aluminide coating, developed by the pack cementation technique, on cast nickel base superalloy ZhS6U has been carried out with the primary objective of systematically understanding the coating degradation process during oxidation. The microstructural degradation of both the plain aluminide and platinum aluminide coatings during oxidation was seen to occur in three distinct stages which, however, differed for each coating. This stagewise degradation, which involves final obliteration of the interdiffusion layer in each case, is discussed in detail.

**138. B. V. Sokolenko, M. D. Medvedchuk*, M. F. Turchak*;** *NTU of Ukraine "KPI", Kiyv; *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Thermal and Electrical Properties of FeNi/Cu Composites.** Powder metallurgy FeNi/Cu composites with low thermal expansivity and high electrical (thermal) conductivity were fabricated. The effects of Cu content, FeNi particle size, sintering temperature, and rolling reduction on the coefficient of thermal expansion (CTE) and electrical (thermal) resistivity were investigated. The results show that the CTE and electrical resistivity were affected by the volume fraction of the components, the particular properties of the FeNi alloy, diffusion between the FeNi particles and the Cu particles, and the distribution of the Cu particles and the FeNi particles.

**139. F. K. Mamonov, R. B. Roytburd, Yu. K. Chugay;** *Slavic State Teacher's Ttraining College, Slavyansk, Ukraine*
**Effect of Nitrogen on the Microstructure and Electrochemical Behaviour of Thermally Aged Stainless Steels.** The effects of nitrogen (680 and 1600 ppm) on the microstructure and electrochemical behaviour of thermally aged type Kh18N9T stainless steels is discussed. The presence of nitrogen resulted in precipitation of mostly $Cr_2N$ and $\chi$(chi) phases in the alloy that contained 1600 ppm of nitrogen, in contrast to $M_{23}C_6$ precipitates in the alloy that contained 680 ppm of nitrogen. The influence of the microstructural evolution and its effect on chromium depletion observed in the present investigation is discussed.

**140. M. V. Veligosha, V. L. Zatsarinniy, N. V. Pochtar;** *State Aviation University, Kharkiv, Ukraine*
**Investigation of Creep-Rupture Properties of Nickel Base Superalloy Under Variable Loading.** The high temperature cyclic creep behaviour of a directionally solidified Ni base superalloy has been investigated and compared with constant load creep data. The presence of the shrinkage pores and presumably the variation in their size and population introduce some measure of scatter in the rupture lives.

**141. V. A. Troepolsky, S. A. Yaremenko;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Effect of Thermomechanical Processing on Microstructure of Al–Cu–Zr alloys.** The role of alloying elements and the effect of prior cold work on microstructural evolution in Supral type alloys during high temperature straining has been investigated by examining a range of binary and ternary alloys containing varying amounts of Cu and/or Zr. The present work is consistent with the importance of strain induced geometrical dynamic recrystallisation in microstructural evolution, and has identified the role of the alloying additions and the processing variables.

**142. B. A. Kucherenko, L. M Bilozir, V. Živković*;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*
**Effect of Phosphorus on Modification of Eutectic Silicon in Al–Si–Mg Alloy.** The influence of the impurity element phosphorus on the modification of eutectic silicon by the addition of strontium was examined by the observation of microstructures, differential scanning calorimetric thermal analysis, a tension test, and fractographic observation. Increasing the phosphorus content of the melt deteriorated the modification of the eutectic silicon and increased the eutectic temperature. Tensile strength and elongation decreased with increasing phosphorus content.

**143. M. L. Prityka, P. I. Yatsenko, J. Šipalo Žuljević*;** *Khmelnitsky State Technical University, Khmelnitsky, Ukraine; *CMS, Croatia*
**Shear Ligament Phenomena in Al–Si Alloys.** Fracture problems in Al–Si alloys involve mixed mode (shear and opening) displacements in the aluminium matrix along the crack surface. Subject to such displacements, fracture must be influenced by the non-planarity of microcracks which depends on many factors including particle and slip orientation. The amount of toughening depends on the ligament length, a ligament toughness parameter representing the work to fracture, the area fraction of the ligament, and the area fraction of frictional contact.

**144. V. F. Vashenko, M. I. Kotov;** *State Aircraft University, Kharkiv, Ukraine*
**Investigation of Fatigue Crack Plastic Zones in Nickel Based Superalloy.** Electron backscattered diffraction (EBSD) techniques have been used to measure the plastic zones of fatigue cracks in a powder, nickel based superalloy with an average grain size of 5 μm. By comparison the dimensions of the plastic zone measured by direct observations of the EBSD pattern quality were very close to the values predicted by elastic–plastic fracture mechanics.

**145. I. N. Andronov, D. Ćurćija*;** *State University of Sea Transport, Odessa, Ukraine; *CMS, Croatia*
**Hydrogen Embrittlement of Shipbuilding Steel in Sea Water.** Hydrogen embrittlement of a copper precipitation strengthened and niobium microalloyed shipbuilding steel on cathodic charging in synthetic sea water has been studied using a slow strain rate technique. The effects of strain rate and potential applied for hydrogen charging have been studied. The results are discussed in the light of the existing models of hydrogen–dislocation interaction and hydrogen induced microvoid coalescence.

**146. M. F. Potapova, M. Z. Gordonny, A. F. Kasheeva*;** *NTU of Ukraine "KPI", Kiyv, Ukraine; *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Mathematical Modelling and Computer Simulation of Nitriding.** Mathematical modelling of matter transmission during gas nitriding has been deduced by a numerical calculation in the present study. In order to solve this problem, is it proposed that the nitrogen potential is dynamically controlled by computer. Under conditions of high nitriding speed, the computer controlled technique used in practical manufacture shows good reproducibility and can control the nitrogen potential accurately, thereby reducing the brittleness of the nitrided layer.

**147. N. I. Martov, V. P. Mitrofanov. A. A. Galkin***; Donetsk Physicotechnical Institute, Donetsk, Ukraine*
**Effect of Thermomechanical Treatment on Mechanical Properties of Dual Phase Steel.** The quantitative effects of the variables used in the thermomechanical treatment of a dual phase steel, in the temperature region of intercritical annealing, have been studied by statistical design of experiments. The adequacies of the equations were assessed by a Fisher *F* test and the accuracies of the equations have been further verified by performing random experiments in the range of variation of the variables. Isoproperty lines have been constructed using the regression equations developed. The equations can predict the properties within the range of variation of the variables.

**148. N. L. Gorynin, V. A. Morozov. A.A. Galkin***; Donetsk Physicotechnical Institute, Donetsk, Ukraine*
**Effect of Grain Size and Carbide Thickness on Impact Transition Temperature of Low Carbon Structural Steels.** In the present work, various laboratory heat treated and commercially processed structural steels were assessed in order to ascertain the validity of the Petch model. The present work also showed that cleavage is associated with the largest carbides in the steel. The modified model also successfully estimated, to within ±10 K, the impact transition temperature of some commercially processed structural steels, of similar carbon content to the laboratory treated steels, but containing much thicker carbides.

**149. N. M. Timofeev, J. Šipalo Žuljević*;** *Modern Welding and Brazing Science and Technology Company, Ternopil, Ukraine; *CMS, Croatia*
**Flow Transitions in Vacuum Arc Remelting.** It show that the structure of an ingot produced by vacuum arc remelting depends critically on the temperature distribution within the liquid portion of the partially solidified ingot. This, in turn, depends on the fluid motion in the pool, since the dominant mechanism for transporting heat is convection. There are three primary sources of motion: buoyancy; Lorentz forces arising from the passage of current through the pool; and Lorentz forces arising from the presence of external inductors. These forces are constantly in competition with each other, and each tends to induce a quite different distribution of velocity and temperature.

**150. M. L. Bozhenko, P. I. Yatsenko;** *Khmelnitsky State Technical University, Khmelnitsky, Ukraine*
**Creep Resistant of Austenitic Stainless Steels.** The precipitation processes have been studied extensively, there remain important discrepancies. It is known that small changes in the chemical composition or thermomechanical processing can profoundly influence the evolution of the microstructure. This review focuses on precipitation in creep resistant austenitic stainless steels, in particular wrought heat resistant grades containing niobium and titanium additions.

**151. S. L. Fomichev, D. Ćurćija*;** *State University of Railway Transport, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Mechanical Properties and Microstructure of High Strength Bainitic Steels.** The results from bainitic rail steels were compared with those for 870 MPa grade pearlitic rails steel. It was found that in the as rolled slow cooled condition rail properties such as fracture toughness, Charpy impact energy, and endurance limit were superior to those of 870 MPa grade pearlitic rail steel.

**152. N. M. Dushek, M. P. Miklashevitch;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Plane Strain Fracture Toughness of Ferritic Structural Steels.** The temperature dependence of the plane strain fracture toughness of a low carbon, fine grain, ferritic steel for structural applications is investigated. The ductile–brittle transition is found to occur in the interval between 150 and 180 K.

The experimental results are interpreted by an analytical model which permits calculation of the plane strain fracture toughness $K_{1c}$ in the brittle domain as a function of the tensile properties and the cleavage fracture stress, making use of a piecewise approximation for the distribution of tensile stress on the crack axis and applying a deterministic fracture criterion at the stress peak.

**153. L. I. Marchenko, D. Ćurćija*;** *Kirovograd National Technical University, Kirovograd, Ukraine; *CMS, Croatia*
**Effect of alumina particle size and thermal condition of casting on microstructure and mechanical properties of stir cast Al-$Al_2O_3$ composites.** In the present research, Al-$Al_2O_3$ composites with 5 vol.-% alumina were produced by stir casting at a temperature of 800°C. Two different particle sizes of alumina were used as 53-63 and 90-105 μm. The microstructure of the samples was evaluated by SEM. In addition, the mechanical properties of the samples were measured, and hence, the optimum temperature and particle size of alumina to be added to the Al matrix were determined. The results demonstrated the positive effect of alumina on improving the properties of Al-$Al_2O_3$ composites.

**154. A. S. Dovzhenko, M. P. Chvertko;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Mechanical Properties and Microstructure of Heat Treated Iron Powder Compacts.** This paper describes the effect of heat treatments on the microstructure and properties of iron powder specimens intended for ac soft magnetic applications at 60 Hz. Iron powder oxidation, wich depends on the heat treatment, reduce the electrical resistivity of the material and efects eddy current loss.

**155. V. O. Goshovsky, S. M. Potyomkin, J. Šipalo Žuljević*;** *Kirovograd National Technical University, Kirovograd, Ukraine; *CMS, Croatia*
**Influence of Nitriding on Fatigue Strength of Chromium-Molybdenum Steels.** This paper describes an investigation into the effects of nitriding, denitriding, and renitriding, on the rotating bending fatigue strength of notched specimens of the quenched and tempered steels 23CrMo12 and 40CrMo4. For nitrided and renitrided specimens an approximately linear relationship was found between the surface hardness and the fatigue strength. The change in macrostresses from compressive to tensile also played a part.

**156. M. P. Baranivsky, A. I. Yatsenko;** *State Aviation University, Kharkiv, Ukraine*
**Strength and Fracture of SiC–Al Composite.** A unidirectional SiC fibre reinforced pure aluminium composite was fabricated by the hot press method. Tensile testing of the SiC–Al was carried out to determine composite and interfacial shear strengths. The results show that the composite strength and the Weibull shape parameter increase with increasing interfacial shear strength. It is concluded that both composite strength and reliability are closely related to the fibre fracture process.

**157. A. P. Baranenko, Yu. B. Glechik;** *Slavic State Teacher's Ttraining College, Slavyansk, Ukraine*
**Serrated Flow Behaviour in Al–9Mg Alloy.** In view of reported anomalies in the serrated flow behaviour of aged Al–8.6Mg alloy, characteristics of serrated flow were investigated in an Al–9Mg alloy after solution treatment as well as after aging. It was found that the alloy exhibited all the usual features of serrated flow except one, i.e. the magnitude of serration increased in the overaged condition after decreasing up to peak aging.

**158. G. V. Mayevsky, V. Živković*;** *State University of Sea Transport, Odessa, Ukraine; *CMS, Croatia*
**Microstructure and Mechanical Properties of C–Si–Mn Steels After Simulated Thermomechanical Processing.** Continuous and discontinuous cooling tests were performed using a quench deformation dilatometer to develop a comprehensive understanding of the structural and kinetic aspects of the bainite transformation in low carbon transformation induced plasticity steels as a function of thermomechanical processing and composition. The optimum mechanical properties were obtained after isothermal holding at 450°C in the niobium steel containing the maximum volume fraction of retained austenite with acicular ferrite as the predominant second phase.

**159. N. A. Kuznetsov, M. P. Pochtar, S. F. Shinkarenko*;** *NTU of Ukraine "KPI", Kiyv; *Goldfin Science and Production Company, Khmelnitsky, Ukraine*
**Effect of Temper Embrittlement and Specimen Size on Charpy Impact Testing of a Cr–Mo–V Steel.** Full and subsize Charpy V notch specimens from several locations of a high pressure–intermediate pressure Cr–Mo–V turbine rotor were tested. It is proposed that the observed specimen size/impact energy/FATT variations with degree of embrittlement arise from sensitivity of intergranular fracture to lineal specimen thickness, since fracture occurs predominantly through a two-dimensional network of grain boundaries.

**160. I. S. Cheshev, A. G. Frumin;** *State University of Sea Transport, Odessa, Ukraine*
**Strain Aging of Pearlitic Steel Wire During Postdrawing Heat Treatments.** The objective of this work was to gain an understanding of the underlying processes that lead to these changes in properties. A 0,85 wt.%C, vanadium microalloyed, fully pearlitic steel was studied. Localised regions of ferrite containing approximately 2,5 at.%C are observed, indicating the presence of Cottrell atmospheres around dislocation lines. Planar regions enriched in carbon are also seen, which demonstrate segregation to ferrite subboundaries. A simple model of the carbon redistribution process is proposed.

**161. A. K. Kuleshov, R. T. Kucherenko, V. V. Voronin;** *Poltava State Technical University, Poltava, Ukraine*
**Synthesis and Characterisation of Free Standing Al–SiC Based Functionally Gradient Material.** In the present study, an aluminium-silicon carbide based functionally gradient material was successfully synthesised using a new technique termed here as gradient slurry disintegration and deposition process. The results of wear rate determination indicated that a difference of ~9,5 vol.% SiC on the opposite faces of the functionally gradient material led to the wear resistance increasing to ~31,5× that of the high aluminium end. An attempt is made to interrelate the processing methodology, microstructure, microhardness, and wear rate results obtained in the present study.

**162. M. N. Kycha, P. I. Grach, L. F. Kafanova;** *G.V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Influence of Silicon on Microstructure, Fluidity, Mechanical Properties, and Fracture of Mg–6Al Alloy.** To investigate the effects of silicon, additions of 0,3, 1, and 1,5% were made to an Mg–6Al master alloy. Two types of $Mg_2Si$ particle morphology were observed: square-like and script. The fracture behaviour of the alloys, which predominantly assumed brittle cleavage and/or quasicleavage failure, was examined by SEM and optical microscopy. The fragile interfaces between the magnesium matrix and intermetallic particles often provided the crack propagation sites.

**163. V. V. Burmenko, A. L. Vedeneeva*, M. F. Trush*;** *NTU of Ukraine "KPI", Kiyv; *Svarka Science and Production Company, Poltava, Ukraine*
**Tensile Stress–Strain and Work Hardening of 35KhN3MA Austenitic Stainless Steel.** In the temperature range 820–1050 K, the Voce equation described the flow behaviour most accurately in the case of the complete range fit of $\sigma - \in$ data at all strain rates. At high temperatures of 1070 and 1120 K, the Ludwigson equation reduces to the Hollomon equation. The variations in different flow parameters of the Ludwigson and Voce equations with temperature and strain rate exhibited anomalous behaviour at intermediate temperatures because of dynamic strain aging.

**164. G. A. Kluev, P. V. Kotenko;** *State Aircraft University, Kharkiv, Ukraine*
**Wear Resistance of Pseudoelastic Ti–Al Alloy.** The present paper reports recent work on pseudoelastic behaviour of a Ti–51 at.-%Al alloy employing a microindentation technique as well as tensile testing methods. In the present work, the wear performances of Ti–51 at.-%Al alloy specimens with different degrees of pseudoelasticity were also investigated, and efforts were made to explain the beneficial effect of pseudoelasticity on the wear resistance of Ti–Ali alloys.

**165. A. L. Naumenko;** *State University of Sea Transport, Odessa, Ukraine*
**Effect of Microstructure on Fatigue of cast Al–6Si–Mg alloy.** The fatigue behaviour of a cast Al–6Si–Mg alloy has been studied. It was observed that the size, number, and position of casting defects influenced the fatigue life very strongly. The analysis is carried out considering only results obtained from sound specimens it is revealed that the heat treatment causes an improvement in the fatigue resistance of the alloy.

**166. A. M. Rabinovitch, P. I. Chushko, V. Živković*;** *Lazer Science and Production Company, Vinnitsa, Ukraine; *CMS, Croatia*
**Rejuvenation Process for Nickel Base Superalloys.** This report reviews published literature on the rejuvenation of nickel base superalloys. The restoration of microstructure and properties to levels equivalent to the original material have been achieved with the use of reheat treatment alone or recovery cycles incorporating both hot isostatic pressing and reheat treatment.

**167. V. I. Vovchenko;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Interrelation Between Hardness and Tensile Properties in Structured Steels.** An attempt has been made to establish a relationship between hardness and tensile properties for various single structured steels: ferrite, pearlite, bainite, and martensite. Regression analysis shows that hardness can be expressed as a function of accessible material parameters such as composition, grain size, and transformation temperatures for various single structured steels within a certain degree of accuracy.

**168. L. M. Safargallin, I. Mamuzić*;** *A. A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine; *CMS, Croatia*
**Microstructure and Tensile Properties of 8Cr–1,5Mo steel.** The influence of different soaking temperatures in the range 970–1620 K (below $Ac_1$ to above $Ac_4$) before oil quenching and tempering, on the microstructure, hardness, grain size, and tensile properties of modified 8Cr–1.5Mo steel has been studied. Strength increased and ductility decreased with further increases in soaking temperatures above $Ac_3$. The formation of $\delta$ ferrite at soaking temperatures above $Ac_4$ improved the ductility. The tensile properties have been correlated with the microstructures.

**169. V. M. Kalmykov, V. P. Burlaka;** *State University of Railway Transport, Dnepropetrovsk, Ukraine*
**Effect of Strain Rate on Fracture Toughness of Structural Steel.** The effect of strain rate on the yield strength and fracture toughness of mild steel was studied in the strain rate range $10^{-5}$–$10^{2}$ $s^{-1}$. The lower yield strength was found to be independent of strain rate in the range $10^{-5}$–$10^{-3}$ $s^{-1}$. Fracture toughness was also found to increase with strain rate up to a value of $10^{-3}$ $s^{-1}$ and subsequently decrease gradually with increasing strain rate.

**170. L. D. Sklyar, A. L. Chuzov;** *State University of Sea Transport, Odessa, Ukraine*
**Effect of Laser Surface Treatment on Corrosion Behaviour of Aluminium Alloy Amg6.** The microstructure, phase, and composition of the modified surface structure were. A reduction in corrosion current density of three orders of magnitude was obtained for the $N_2$ treated material. The superior corrosion resistance of the $N_2$ treated material is attributed to the presence of the chemically stable AlN phase in the surface.

**171. M. A. Krivsha, L. I. Machulenko, I. Mamuzić*;** *G.V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine; *CMS, Croatia*
**Microstructure and Mechanical Properties of a Ti–14Mo Based Beta Titanium Alloy.** Additions of boron, carbon, and silicon have been made to a series of Ti–14Mo based $\beta$titanium alloys prepared by plasma arc melting and subjected to various processing and characterisation techniques. The purpose of these additions was to investigate their grain refining effect in the as cast, as forged, and heat treated states. Despite the microstructural refinement, the ductility of the alloys containing boron and carbon was severely impaired.

**172. V. F. Korzenko, B. S. Sagalevich;** *Pulsar Science and Production Company, Kharkiv, Ukraine*
**Oxidation Resistant Coatings for Titanium Alloys.** This work addresses the development of a coating to protect the titanium alloy VT1-0 from oxidation and alpha case formation. Based on results obtained by different techniques, it is suggested that platinum aluminide is a prospective coating material for preventing alpha case formation and protecting against oxidation in components fabricated from titanium alloy VT1-0.

**173. M. P. Chertok, S. F. Prokhorov;** *E. O. Paton Welding Institute, Kiev, Ukraine*
**Decreasing of Residual Stress by Post-Weld Vibration.** In the present study welded specimens were processed after being cooled to room temperature, with varying amplitude of applied stress and time of vibration. An increase in the applied stress led to a significant decrease in the residual stresses.

**174. L. I. Kozakov;** *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Fatigue of Zn–Al Casting Alloys.** A series of binary Zn–Al and ternary Zn–Al–Cu alloys were produced by permanent mould casting. The fatigue behaviour of the alloys was examined using a rotating bending fatigue machine, which was designed and built for the present work. It was observed that the fatigue strength of the ternary alloys was dependent on their tensile strength, rather than on their hardness. Correlation of the fatigue data showed that Basquin's law can be used to express the fatigue behaviour of these alloys.

**175. A. S. Derkach, A. L Mishakov, D. Jakšić*;** *State Economic-Technological University of Transport, Kyiv, Ukraine; *CMS, Croatia*
**Computer Modelling of Dendritic Grain Structures.** A three-dimensional cellular automaton–finite element model has been developed over the past five years for the prediction of macrostructures formed in casting. The present article briefly summarises the growth algorithm of the model.

**176. M. I. Gudyma, D. Jakšić*;** *Adamant Science and Production Company, Izyum, Ukraine; *CMS, Croatia*
**Behaviour of Binary Al–2Li Alloy at High Temperature, High Strain Forging.** This investigation has demonstrated the utility of coupled computer simulation and constant strain rate, isothermal compression of double cone wedge tests within the dynamic recrystallisation regime. Two models, one statistical, and the other phenomenological, were utilised to predict the grain size variation in the specimen as a function of strain. Both models showed excellent correlation with the experimentally measured grain size data.

**177. Yu. I. Datsenko, D. Jakšić*;** *Plazma Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Processing, Microstructure, and Properties of Mg–SiC Composites.** In the present study, elemental magnesium and magnesium–silicon carbide composites were synthesised using the methodology of fluxless casting followed by hot extrusion. Microstructural characterisation studies revealed low porosity and a completely recrystallised matrix in every material. Results of physical and mechanical properties characterisation revealed that an increase in the amount of SiC particulates incorporated leads to an increase in macrohardness and elastic modulus, which does not affect the 0,2% yield strength and reduces the ultimate tensile strength, ductility, and coefficient of thermal expansion.

**178. A. P. Vasiyunik;** *State Aircraft University, Kharkiv, Ukraine*
**Influence of Boron on Hot Ductility Carbon Low Alloyed Steel.** The influence of boron on the hot ductility of C-Mn-Al-Cr steel has been investigated. It was found that solute boron atoms segregate to austenite grain boundaries and occupy the vacancies induced by deformation. This prevents the formation and propagation of microcracks at boundaries and results in improved hot ductility and a reduced dynamic recrystallisation temperature.

**179. V.P. Furmanchuk;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Effect of Sulphur and Vanadium on Toughness of Bainitic Steels.** The Charpy impact toughness of bainitic steels, in the longitudinal direction, was increased by appropriate additions of sulphur and vanadium. Accordingly, an increase in toughness with additions of sulphur and vanadium may be attributed to bainite packet refinement resulting from the suppression of austenite grain growth and the promotion of intragranular bainite transformation by manganese sulphides.

**180. Yu. K. Lysak, N. A. Mulin;** *NTU of Ukraine "KPI", Kiyv, Ukraine*
**Effect of Thermal Treatment on Microstructure and Impact Toughness of Cast Mg–Al–Mn Alloys.** A study of the effects of heat treatment on an Mg–Al–Mn alloy was carried out. The analysis of structure and solidification defect evolution showed that, despite an increase in void volume fraction and size induced by thermal treatments, a significant improvement of toughness during the crack growth process could be achieved with the appropriate tempers. Marked modifications to high strain rate loading conditions were detected, with improvements of total absorbed impact energy of up to 40 % with respect to the as cast condition.

**181. K. A. Bondarchuk, H. G. Hristenko;** *N. E. Zukovsky National Aerospace University "KhAI"*
**Thermomechanical Fatigue of Nickel Base Superalloy ZhS6U.** An experimental programme was carried out to study the thermomechanical fatigue life of the nickel base superalloy ZhS6U used in gas turbines. This model successfully reflected the temperature and strain rate dependences of isothermal cycling fatigue lifetimes, and the strain–temperature history effect on thermomechanical fatigue lifetimes.

**182. M. A. Popov;** *Adamant Science and Production Company, Izyum, Ukraine*
**Diffusion Bonding of Titanium Alloy to Stainless Steel Wire Mesh.** The feasibility and appropriate processing parameters of diffusion bonding of titanium alloy to stainless steel wire mesh directly and with a nickel interlayer have been investigated. The maximum shear strengths of the joints were 70 and 150 MPa for direct bonding and indirect bonding using a nickel interlayer respectively. Atomic diffusion and migration between titanium and iron are effectively prevented by adding pure nickel as the interlayer metal, and a firm joint is obtained.

**183. A. L. Chumak;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Microstructure of Electromagnetic Stir Cast Grain Refined Iron Base Alloy.** Electromagnetic stirring using multiple induction coils has been investigated as a method of preparing semisolid FC18 alloy. The effects of additions of titanium, zirconium, and boron on the microstructure of the FC18 alloy have also been studied. The additions of titanium, zirconium, and boron also improved the alloy microstructure.

**184. F. L. Kapernaumov, N. A. Mulin;** *State University of Sea Transport, Odessa, Ukraine*
**Fatigue Fracture of Nickel Alloyed Steel.** Fatigue fracture of smooth rectangular specimens was investigated by testing at constant amplitude and zero mean stress, at a frequency of 40 Hz. Two nickel alloyed powder metallurgy steels with different contents of pores and MnS were examined. A dominant fatigue crack origin built up at the region of the largest number of macrocracks.

**185. D. M. Gotsman, I. Mamuzić*;** *Delta-Composite Science and Production Company, Zaporozye, Ukrain; *CMS, Croatia*
**Effect of austenite grain size on isothermal bainite transformation in low carbon microalloyed steel.** The effect of austenite grain size on isothermal bainite transformation in a low carbon microalloyed steel was studied. The results showed that the morphology of isothermal microstructure changes from bainite without carbide precipitation to bainitic ferrite with a decrease in holding temperature.

**186. F. M. Tuchinsky;** *Modern Welding and Brazing Science and Technology Company, Ternopil, Ukraine*
**Effect of Aging on Impact Toughness of Stainless Steel Weldments.** Instrumented impact testing was used to investigate the effects of aging on the impact deformation and fracture of different weldments of a Kh18N9T stainless steel plate and a superduplex stainless steel plate. Both the parent metal and the weldments showed a noticeable decrease in impact energy and in impact yield and maximum loads as the aging time was increased. These weldments were found to be more sensitive to the precipitation of sigma phase than the austenitic stainless steel weldments.

**187. A. D. Medvedev, S. F. Perehodko;** *E. O. Paton Welding Institute, Kiev, Ukraine*
**Welding of Austenitic Stainless Steel.** This study explores an improved method of welding austenitic stainless steel. The method uses two series connected arcs to weld the workpiece simultaneously from opposite sides. In addition to the increased penetration, the use of this method for welding austenitic stainless steel results in improved microstructure in the resultant welds because of an increased columnar to equiaxed transition and a decreased angular distortion, which sometimes induces solidification cracking.

**188. D. F. Kotenko, A. S. Furs;** *Pulsar Science and Production Company, Kharkiv, Ukraine*
**Influence of Coatings on Mechanical Properties of Composites.** Three-dimensionally braided carbon fibre reinforced SiC matrix composites have been fabricated and the effects of coating treatment on the mechanical properties have been investigated. It has been found that pyrocarbon coating can improve the strength of the heat treated carbon fibres. The composites also exhibited a toughening fracture mode.

**189. T. A. Fedorenko, H. I. Zikharev, K. I. Shonin;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Influence of Nickel on Microstructure and Mechanical Properties of Heat Affected Zone of Low Carbon Steel.** In the present study, the effect of nickel along with varying heat input on the microstructure and mechanical properties of the heat affected zone (HAZ) of a low carbon steel was investigated. It was subsequently found that, taking into consideration the microstructure, hardness, and toughness of the HAZ, a lower heat input for a nickel content of 1 wt.% and a medium heat input for nickel contents between 2 and 5 wt.% gave good results.

**190. G. P. Zurabov, F. I. Pisarenko;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Effect of Accelerated Cooling on Microstructure and Mechanical Properties of C-Mn Steels.** Two commercial steels, based on 0,1C-0,8Mn and 0,1C-1,3Mn, were quenched from 900 C to temperatures between 290 and 490°C in a resistance annealing simulator. Different cooling rates ranging from 70 to 480 $Ks^{-1}$ were generated. The microstructures and mechanical properties of these two steels heat treated under different conditions were investigated. The influence of manganese on the microstructures of these two steels was also investigated.

**191. L. I. Pyatetsky, S. K. Poturaev, F. K. Skabichevskiy;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Influence of Heating Temperature on the Austenite Transformation to Pearlite in High Alloy Steels.** Two tool steels designated A1 (based on Fe-0.9C-4.5Cr-5.2Mo-6W-1.5V) and A2 (based on Fe-1.0C-4.5Cr-1Mo-V, all wt.%) were preheated and rolled in three passes to a total reduction of 50% in the range 850 to 1150°C in which alloy carbides are dissolved to varying degree. In A2, TMP at 990°C results in acceleration compared to simply heat-treated and thus a reduction in hardenability. Carbide precipitation prior to the pearlite transformation is also enhanced by the deformation.

**192. G. I. Margarit, D. V. Marchuk;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Microstructure and Properties of Cr—Cu Cast Irons.** A metal quasi-composite, containing copper inclusions within a chromium cast iron matrix was investigated. It has been shown that Cu particles are responsible for improved machineability and wear resistance of Cr cast irons with 8-10 wt.%Cu, since Cu particles break up the network of primary carbides and also act as a solid lubricant.

**193. P. A. Fomichev, and P. I. Mashtalir;** *N. E. Zukovsky National Aerospace University "KhAI"*
**Mechanical Properties and Failure Modes of Carbon Fibre Reinforced Magnesium Composite at Elevated Temperatures.** A randomly orientated short carbon fibre reinforced magnesium composite consisting of high strength carbon fibres in a matrix of magnesium alloy has been fabricated by indirect squeeze casting. Characterisation of the failure modes and composite microstructure was carried out using optical, scanning- and transmission-electron microscopy. The more effective use of the reinforcing phase at elevated temperatures and the general behaviour of the short fibre composite have been discussed in terms of features observed in the materials tested.

**194. M. V. Alekseenko, F. G. Gergel;** *State Economic-Technological University of Transport, Kyiv, Ukraine*
**Bake Hardening in Ultralow Carbon Steel Containing Niobium and Titanium Additions.** The strain aging behaviour of an ultralow carbon steel partially stabilised by additions of titanium and niobium was studied as a function of prestrain, aging temperature, and aging time. Evaluation of the information gained shows that the same bake hardening increment can be achieved under less severe paint baking conditions than those normally encountered.

**195. H. L. Mitrofanov, D. Jakšić*;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine; *CMS, Croatia*
**Failure of Ultra High Strength Low Alloy Steel.** An ultra high strength low alloy steel having the composition Fe-0,25C-1,4Cr-0,8Mo-0,3V-0,1Nb (wt.%), has been developed using the electroslag refining process. In order to understand the failure behaviour of the material, tensile coupons, surface crack tension specimens, compact tension specimens, and pressure chambers were fabricated and tested. To select a suitable failure theory for this material, failure assessment has been carried out on pressure chambers and verified with test results. Fracture analysis has also been carried out on the cylindrical vessels containing axial surface cracks and it was found that failure pressure decreases with increasing in crack size.

**196. H. I. Erofeev, F. A. Kravchenko;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Grain Coarsening Under Small Plastic Strain in Hot Working of Austenitic Stainless Steel.** Hot compression tests were conducted on an austenitic stainless steel to clarify the origin of the grain coarsening phenomenon that is observed for carbon steels deformed slightly at a high temperature. A peculiar, staggered grain boundary was observed as the equivalent plastic strain approached the threshold value for the initiation of grain coarsening.

**197. D. V. Kravchenko, V. L. Tishenko;** *State Aviation University, Kharkiv, Ukraine*
**Estimation of Mechanical Properties of Ceramic Protective Coatings by Nanoindentation.** Multilayer protective coatings of alternate aluminium and titanium diboride $TiB_2$ layers have been tested by nanoindentation to measure both hardness and Young's modulus values. The initial results show that the values obtained depend upon the depth of indentation. Comparison of the nanoindentation results with three point bending tests show how the coating structure influences the results obtained.

**198. D. K. Shulzhenko, A. G. Pisarchuk;** *State University of Sea Transport, Odessa, Ukraine*
**Crack Growth Resistance of an Ultra High Strength Low Alloy Steel.** An ultra high strength low alloy steel having the composition Fe-0,2C-1,4Cr-1,2Mo-0,3V-0,2Nb (wt.%). In order to understand the crack growth resistance of the material, tensile coupons, surface crack tension specimens, compact tension specimens, and pressure chambers were fabricated and tested. The fracture parameters of the material were evaluated from the test data. Using these parameters a failure assessment diagram was generated to quantify the effects of the presence of cracks on material strength.

**199. P. I. Marchuk, O. P. Mirovich, D. Jakšić*;** *A. A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine; *CMS, Croatia*
**Effect of Thermomechanical Treatment on Flow Behaviour, Microstructure and Texture Development of Aluminium Alloy in Semisolid State.** In the present work, an ingot of a commercial aluminium alloyAl-8Si-0.25 Mg, was deformed by rolling; a second ingot was extruded; and a third was cast in such a way as to obtain fine sized dendrites. Simple compression experiments (parallel plates) showed that for high solid fractions (0,70) the extruded material exhibited the highest deformation response among specimens, but when the solid fraction was lower (0,60) the deformation behaviour of as cast, extruded, and rolled specimens was similar.

**200. A. D. Kuznetzov, G. T. Lubchenko;** *Poltava State Technical University, Poltava, Ukraine*
**Surface Cementation 20Kh12VNMF Steel.** The production of dual phase steel structure in the core of surface carburised 20Kh12VNMFcementation steel and the effect of martensite volume fraction on tensile properties have been investigated. Tensile strength increased and ductility decreased with increasing martensite volume fraction

**201. R. N. Furmanchuk, I. M. Latko;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Creep Characteristics of Nickel Base EP747 Superalloy with Subject to Prestraining.** The effect of room temperature plastic deformation on the subsequent creep behaviour of EP747 alloy has been studied. Creep tests were carried out at 750°C and prestraining was conducted in tension up to a level of 7,0 %. Cavity nucleation was found to be associated with stress concentration produced by slip bands. The increased activity of cavitation in prestrained specimens was related to an increased slip band density produced during prestraining.

**202. L. F. Samofalov, V. T. Korzh;** *Poltava State Technical University, Poltava, Ukraine*
**Recrystallisation of Cast Austenite in Stainless Steel.** The experimental results showed that the hot deformation conditions, such as temperature, strain, and strain rate determine the dynamic recrystallisation behaviour for the as cast stainless steel, and the dynamically recrystallised grain size is determined by the deformation conditions and is independent of the strain.

**203. A. S. Korshunov, G. K. Shevelev;** *Lazer Science and Production Company, Vinnitsa, Ukraine*
**Grain Coarsening Resistance in Cold Forged and Carburised Steel.** A series of high nitrogen 0.25 wt. %C steels was melted to evaluate the effects of composition and processing on the isochronal austenite grain coarsening resistance of cold forged compression specimens during simulated carburising. In addition to the effects of grain refining precipitates, the evolution of the ferrite-carbide microstructure and the elimination of microstructural strain before austenitisation have a significant effect on grain coarsening resistance independent of steel composition.

**204. G. L. Bondarenko, O. I. Golovatiy;** *Khmelnitsky State Technical University, Khmelnitsky, Ukraine*
**Nanocrystalline Iron Powder: Consolidation and Mechanical Behaviour.** Iron nanopowders, with an average diameter of <100 nm, were consolidated using plasma pressure compaction. It was found that the compliance of the loading curves was a function of the mesoscale porosity in the specimens. The strain to failure was found to be a function of the porosity on the microscale. The optimal strength and ductility were achieved in specimens in which a fully dense, platelet structure had developed.

**205. E. I. Shorshorov, I. Mamuzić*;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*
**Effect of Sulphur on Impact Properties of Bainitic or Martensitic Steels.** Effects of sulphur addition on the Charpy impact properties of various continuously cooled bainitic steels with different prior austenite grain size, hardness, and content of retained austenite were investigated and compared with martensitic steels. The impact energy, particularly the crack propagation energy, of martensitic steels decreased with increasing sulphur content because the nucleation sites of voids increased with the increase of manganese sulphide inclusions in the ductile fracture region.

**206. F. K. Shtyrov, G. M. Savchenko;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Investigation of Acoustic Emission During Tensile Deformation of Notched Specimens of Kh18N9T Stainless Steel.** Correlation of acoustic emission total counts $N$ with stress intensity factor $K$ and plastic zone size has been examined for data generated during tensile deformation of notched specimens of Kh18N9T stainless steel. Both the steels indicate higher values of m up to macroyielding than those obtained from analysis of acoustic emission data between macroyielding and the stress corresponding to $K_{max}$ values in the experiments.

**207. F. K. Shtyrov, G. M. Savchenko;** *Kirovograd National Technical University, Kirovograd, Ukraine*
**Acoustic Emission Monitoring of Phasic Transformation in Medium Carbon Steel.** This paper concerns acoustic emission measurements during cooling of steel 45 hermomechanical simulator. After austenising at a certain temperature, the studied specimen was cooled down and the root mean square value of the continuous acoustic emission signal was measured. The effect of the austenite grain size on the evolution of the bainitic and martensitic transformation was studied by varying the austenising temperature $T_a$.

**208. P. S. Dumenko, A.F. Tovt;** *State Economic-Technological University of Transport, Kyiv, Ukraine*
**Influence of Carbon on Mechanical Properties of Pearlitic Steels.** The effects of microstructural features, such as interlamellar spacing, prior austenite grain size, and carbon content, on mechanical properties have been investigated for fully pearlitic steels containing 0,5 and 0,8 wt.% C. Hypoeutectoid steels show the superior reduction of area than eutectoid steels in all tested ranges of interlamellar spacing, in spite of the various prior austenite grain size.

**209. P. I. Narovchatov, O. F. Beresteyko;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Effect of Previous Creep Cavitation on Brittle Fracture in Heat Affected Zone of Ferritic Steel Weldments.** Material encompassing the heat affected zone has been removed from a region of a manual metal arc weldment in a CrMoV steel containing creep cavities arising from stress relief heat treatment. Fracture toughness tests using reconstituted Charpy geometry specimens were undertaken at a temperature of 180 K to assess the effect of this damage on the lower shelf fracture toughness. The results are discussed with respect to the predictions of the theoretical model.

**210. P. I. Korshunov, G. L. Shishkov, D. Jakšić*;** *State Aviation University, Kharkiv, Ukraine; *CMS, Croatia*
**Effect of Heat Treatment on Fatigue of Aluminium Alloy.** This paper reports results showing the fatigue behaviour of a aluminium alloy reinforced with 20 vol.% of silicon carbide particles. The effect of quench medium on tensile and rotating bend fatigue strength is reported. Results are correlated with residual stress profiles measured in quenched plates of the material.

**211. F. K. Kruszka, L. I. Maluchkov;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Mechanical Characteristics of Magnesium-Lithium Alloys.** Authors have studied the mechanical properties of Mg-Li alloys produced by high-pressure casting in press-chamber. The assessment technique for the basic strength characteristics obtained under high plastic deformation condition are described. The material fracture toughness is analyzed under quasistatic and dynamic concentrated load conditions.

**212. M. A. Bazhukov, H. G. Flom;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Microstructure and Properties of Cu-based Alloys.** The filamentary composites of copper-silver alloys contained with chromium and rare earth elements have been prepared by cold drawing combined with intermediate heat treatments. The microstructure and properties during cold working have been investigated. With increasing draw ratio, the tensile strength increases, the electrical conductivity reduces and the microstructure refines.

**213. D. V. Baumshtein, I. Mamuzić*;** *Delta-Composite Science and Production Company, Zaporozye, Ukraine; *CMS, Croatia*
**Mechanical Behaviour of Stainless Steel under Warm Working Conditions.** A rational description of the constitutive behaviour of Kh18N9T stainless steel deformed between 870 K and 1120 K, over a wide range of strain rates, is proposed. Results regarding the change in saturation stress with temperature and strain rate indicate that dynamic strain aging effects, associated with negative values of the strain rate sensitivity of the saturation stress, are present in the temperature range 870-1070 K and strain rates of the order 0,1 -10 $s^{-1}$.

**214. G. M. Blumkin D. Jakšić*;** *Delta-Composite Science and Production Company, Zaporozye, Ukraine; *CMS, Croatia*
**Influence of Homogenisation Treatment on Microstructure and Hot Ductility of Aluminium Alloy AL 27.**
**Several homogenisation treatments were applied to direct chill cast ingots of aluminium alloy AL 27, in order to analyse the resulting microstructures developed from these diverse conditions and their effects on the hot ductility of this alloy.** Homogenised samples, which contain αAl-FeSi, exhibited improved ductility. Samples that were water quenched following homogenisation were absent of $Mg_2Si$ precipitates, when these elements remained in solid solution. These exhibited the highest ductility.

**215. L. F. Bazukov, S. G. Podobed;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Effect of Vanadium and Carbon on Microstructure and Mechanical Properties of as Cast Fe–8,25Al Alloy.** The effect of vanadium (1,5 and 3,5 wt-%) addition on the microstructure and mechanical properties of as cast Fe–8,25Al–0,15C alloy has been studied. This significant improvement in the room and high temperature compressive strength may be attributed to solid solution strengthening as well as precipitation hardening by the presence of fine and higher volume fractions of niobium and niobium carbide precipitates, in contrast to the relatively soft $Fe_3AlC_{0.5}$ precipitates present in the Fe–8.25Al–0.15C alloy.

**216. M. Yu. Sokolenko, K. L. Zhukov;** *State University of Sea Transport, Odessa, Ukraine*
**Effects of Tungsten Carbide and Cobalt Particles on Corrosion and Durability of Copper Basis Composite.** The results show that the hardness, wear resistance and static corrosion weight loss of $Cu/WC_p$ composites increase with a decrease of $WC_p$ size or with an increase of $WC_p$ content. Also, the corrosion current density $I_{corr}$ increases with a decrease of $WC_p$ size or with an increase of $WC_p$ content, and the corrosion potential $E_{corr}$ exhibits no specific trend with varying $WC_p$ content and size. The wear corrosion rate increases with an increase in $WC_p$ content, yet shows no direct correlation with $WC_p$ size. On the other hand, $Cu/WC_p/Co_p$ composites exhibit better wear resistance in both dry wear and corrosive wear conditions.

**217. M. P. Demchenko, F. I. Maystrenko;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Degradation of Mechanical Properties of 2.2Cr–1Mo steel by long term service.** Degradation in tensile and creep properties has been investigated for 2.2Cr–1Mo steel, after long term service at 600°C for $1.5 \times 10^5$ h. Creep tests were carried out at 550–690°C for up to about 10 000 h for the long term serviced material. The results are compared with those for virgin material tested for up to 100 000 h. This results in a higher minimum creep rate and a shorter rupture time for the long term serviced material than for the virgin material.

**218. E. O. Ivashko, A. M. Dubenets;** *A. A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine*
**Crack Growth Resistance of a TiAl Alloy.** Crack growth resistanceviour of a two phase TiAl alloy was investigated based on observations of fracture surfaces of three point bending precracked specimens and detailed observations of configuration changes at precrack tips, based on which new findings are presented. The toughening mechanisms, which make the main crack difficult to propagate or cause it to be stopped, are attributed to reducing the tensile stress perpendicular to the interface between lamellae.

**219. L. K. Chumachenko, I. Mamuzić*;** *Kirovograd National Technical University, Kirovograd, Ukraine; *CMS, Croatia*
**Study on effect of residual stress distributions on kinetics of static strain aging after cold rolling.** In the present research, the effect of residual stress distribution on the static strain aging (SSA) phenomenon in cold rolled steel was investigated. The results show that SSA occurs within the cold rolled steel in the employed aging period, and its kinetics is affected by residual hydrostatic stresses. Additionally, the variation in residual hydrostatic stress distribution due to deformation path, e.g. single- and two-pass rolling layouts, slightly affects the activation energy of SSA and changes the kinetics of SSA after cold rolling.

**220. L. F. Malinovsky, R. Križanić*;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*
**Stress induced martensite transformation texture in austenitic stainless steel.** Input data were obtained from the published literature. Calculated pole figures were constructed assuming a variant selection process based on Patel and Cohen's theory, which emphasises that a mechanical component of free energy is the driving force for martensitic transformation at temperatures above martensite start $M_s$.

**221. B. K. Sarayan, A. L. Shufrich***; A. A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine*
**Microstructure and micromechanism maps to optimise useful deformation processing conditions in magnesium alloy.** The present investigation examines the use of microstructure and micromechanism maps to develop a systematic understanding of the various microstructures that evolve in pure Mg and Mg-Al-Ce alloys during uniaxial compression deformation over a range of strain rates and temperatures. The study demonstrates that while conventional process maps delineate safe and unsafe working regimes based on power dissipation, it is the use of the microstructure and micromechanism maps in conjunction with the process maps that provide a more accurate and comprehensive picture of the processing window, which should be used for producing materials with certain defined end use.

**222. Z. A. Ivchenko, V.V. Lunev*, R. Križanić**;** *JSC "Motor Sich", Zaporozhye; *Zaporizhzhya National Technical University, Zaporozhye, Ukraine; * *CMS, Croatia*
**Factors of the mechanical properties of cast titanium alloy VT5L (VT5L-MS).** The results of these studies are an indirect confirmation of the hypothesis that the redistribution of matter-of interstitial impurities (O, N) between the dislocations within the grains and at grain boundary in titanium alloys and their influence on the magnitude of the yield stress.

**223. Iurii Gul, V. Chmeleva, I. Mamuzić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Efficiency of use of stationary and non-stationary coolers at heat treatment of metal products: theory and directions of practical use.** On the basis of use of fundamentals of heat exchange at cooling of metal products the advantages of use of cooling systems with a non-stationary condition of a cooler are shown and the practical examples of efficiency of use of such system in industry are resulted.

**224. Yu. V. Dotsenko, V. Yu. Seliverstov, Y. N. Bura;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Analysis of technological decisions of complex influence on morphology of phases containing iron in the alloys of the system of Al-Si.** Available techniques designed to neutralize negative effect of iron on aluminum alloys properties have been reviewed. It has been shown that the combined use

of aluminum alloys modification and crystallization processes in non-equilibrium for mechanical properties of high-iron aluminum casting alloys improvement is of a great interest.

**225. N. Ju. Kalinina, J. Šipalo Žuljević*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Methods of identification of the structural components of alloys on their color images.** Was developed an algorithm for color segmentation of color images of the microstructure of alloys, which allows to analyze the presence of structural components and their relation in the alloy, found the characteristics of these components.

**226. V. F. Mazorchuk, I. Mamuzić;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Research of the microstructure of cast metal obtained by using floating top insert.**
**The investigations of molten metal (ingot weighing 2 t) obtained by using a floating top insert.** Studies of the microstructure of the metal bars of a serial experimental and showed that the cast metal has a ferrite-pearlite structure with elements widmanstatten structures. Chemical composition of cast steel showed that the ingot obtained by the experimental technology is characterized by a high degree of homogeneity of the steel on the carbon content.

**227. I. M. Galushko, K. A. Dvornikova, M. Jurković*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Calculation of the number of phase constituents in peritectic systems with separate crystallization of phases.** In peritectic systems in which the phases solidify separately both in space and time, the portion of primary precipitates may be predicted by an equation which takes into account the amount of precipitating crystals.

**228. I. M. Galushko, O.V. Studenov;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**Singularity of the local instability process peritectic crystallization.** When studying the peritectic crystallization of Cu +83,08 at. % Ga and Co +76,01 at. % Sn melts the local instability of the process has been discovered, which depends on peritectic reaction heterochronicity at different faces of the basic primary crystal. The explanation of anomalies is connected with content difference of liquid at each face of basic primary crystal in comparison with its average equilibrium value.

**229. I. M. Galushko, V. A. Danilenko, I. Mamuzić;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Criterion for peritectic reaction.** Based on the general fluctuation theory of precipitation, the influence of the internal factor is estimated and the criterion $K = (C_P - C_L) / (C_S - C_P) \lesssim 1$ is suggested which determines the tendency of this system to a peritectic reaction. If this ratio is greater than unity, the system shows a tendency to the reaction. If this ratio is less than unity, the reaction is passivated, and the closer the values of the concentration $C_{P \text{ and}}$ $C_L$ are, the more pronounced this effect is.

**230. O. Levko, K. Kylyvnyk[1*], D. Ćurćija**;** *National Metallurgical academy of Ukraine, Dniepropetrovsk; *NanoEner Technologies, Fort Lauderdale, USA; * *CMS, Croatia*
**The electrochemical properties of $limn_2o_4$ electrodes deposited by the hpvds method of condensation – solidification.** Thin electrodes on the basis lithium manganese oxide spinel had been prepared with High Pressure Vapor Deposition Solidification (HPVDS) method. Proposed proprietary HPVDS method for the production of nanostructured thin-film coatings have ability to embed active powder material (cathode or anode) into the metal substrate resulting in very thin and high energy density electrode. Thin HPVDS $LiMn_2O_4$ electrodes had shown good repeatability, cycleability (800 cycles), low charge transfer resistance and as result good C-rate performance.

**231. Sv. Gubenko;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Formation of contact interaction geterogeneous zones near inclusionmatrix boundaries by laser action.** Peculiarities of steel matrix seturation by elements of non-metallic inclusions during different regimes of laser action were investigated. It was shown the role of that process in formation of local structure of steel matrix near non-metallic inclusions. Presence of cascade zones are evidenced about wave nature of saturation of steel matrix by elements of non-metallic inclusions by laser action.

**232. Sv. Gubenko, S. Pinchuk, E.Belaja;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Influence of non-metallic inclusions on mechanical properties of wheel steel in different mediums.** Influence of non-metallic inclusions on the wheel steel tendency for corrosive cracking and fatigue strength in corrosive mediums was investigated. Testing on fatigue strength in corrosive mediums were shown that more decrease of endurance limit was in experimental steel with sulphide inclusions, which are leaders according to damage influence of corrosive medium on the decrease of endurance limit of wheel steel comparatively air testing.

**233. Sv. Gubenko, S. Pinchuk, E. Belaja;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Influence of non-metallic inclusions and inclusion-matrix boundaries on corrosive damages nucliation in wheel steel.** Influence of non-metallic inclusions and inclusion-steel matrix boundaries on nucleation of corrosive damages in wheel steel in corrosive mediums was investigated. It was shown active influence of interphase inclusion-steel matrix boundaries in the rise of microchemical heterogeneity of wheel steel and development of adsorption and corrosive processes.

**234. Sv. Gubenko, A. Bachurin, E. Chernoivanenko;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Morphologic features of the complex chemical-heat treatment of cast high speed steel.** Phase transformation in cast high-speed steels by complex chemical-heat treatment (decarburization + carburizing) in the solid state were investigated. The effect of the initial structure, temperature and carbon potential of carburization on structure formation in three-phase reaction $\alpha \rightarrow \gamma + C$ was researched. It is shown that isothermal carbonization can cause simultaneous release of carbides and $\alpha \rightarrow \gamma$ transformation, resulting the composite structure was formed in a surface layer.

**235. A. Movchan, I. Mamuzić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Formation of three-phase composite materials of ferritic iron alloys by carburization.** The phase and structural changes of Fe-W-Cr and Fe-Mo-Cr alloys during carbonization were researched. The parameters of carbonization of ferritic iron alloys, which provide formation a fundamentally new material in the studied systems were established. The structure of the natural three-phase composite, that uniformly hardened of carbide's fibers throughout the diffusion layer provides high hardness and wear resistance in the surface material.

**236. V. I. Mazur, S. V. Kapustnikova, S. V. Bondarev, A. Yu. Shport'ko;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Titanium Metal-Ceramic Alloy For Implantology.** New complex-alloying metal-ceramic alloy based on Ti-Si system was developed. Its structure, phase composition and mechanicals properties were studied. Effect of alloying elements on phase transformation and phase morphology was investigated. The effect of chosen alloying set on the most important points of phase diagram of a multi-component system was determined.

**237. V. U. Seliverstov, A. A. Loevskaya, M. Jurković*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Prospects for the use of recycled iron-man-made origin of cold-forming mixtures.** Presents the results of studies of factors influencing the binding properties of phosphate compositions and choice of iron-containing component, and the refractory base in the form of quartz sand for molding and core cold-mixes.

**238. N. P. Rudenko, E. V. Vlasov, J. V. Svisenko***; National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Surface roughness carbon and low – alloy steels after etching and passivation.** Surface roughness carbonand low – alloy steels after the chemical treatment is investigated. These operations are included into the technological cycle of roll metal production. These steels were etched in the solution of a 100 – 200 g/l $H_2SO_4$, 90 – 240 g/l of $FeSO_4$ at 60 – 90°C.

**239. T. M. Myronova, N. Devčić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk; *CMS, Croatia*
**The use of carbide transformations for white cast irons ductility improvement.** Due to the use of carbide transformation in alloyed cementite the new class of alloys has been developed. This class of alloys was named as ductile white cast iron. which were named ductile white cast iron. The above-mentioned processes allows to deform cast iron in industrial environment as well as to manufacture the rolled with improved mechanical properties.

**240. V. I. Mazur, S. V. Bondarev, A. I. Agheyenko;** *National metallurgical academy of Ukraine, Dnepropetrovsk,*
**Morphology Control of Silicon Crystals in Hypereutectic Al-Si Alloy for Optimization of Its Mechanical Behavior.**
**Samples produced by permanent mold casting of binary aluminum alloy with 21 wt.** %. silicon were investigated. Mechanical properties were evaluated by the yield strength, ultimate strength and compressive strain. These parameters were obtained within compression tests at cylindrical specimens. To change the morphology of the excessive silicon crystals isothermal heat treatment was carried out.

**241. N. P. Rudenko, G. I. Shevchenko, I. Vitez*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**On structural transformations of silicon carbide in aluminosilicate media under heating.** Structural transformations of silicon carbide in aluminosilicate media were studied by high temperature X-ray analysis on the Simens D-500 diffractometer (Germany). Medium compositions were chosen as follows: cordierite and enstatite (20 wt %) + anorthite (80 wt %) within the temperature range from 298 to 1520 K. Before heating the substance was subjected to 20-min isothermic holding.

**242. Yu. P. Synytsina, D. Ćurćija*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**The metallographic analysis of iron sulfide thin films which have been obtained using high-speed evaporation method.** The implementation of the method made possible to obtain the films of cathode material up t0 20 μm thickness with good adhesion properties. The thin film phase analysis differs from initial material one: the interference lines corresponded to pyrite and low temperature piritinite of α and γ iron modifications are identified. The phase crystalline structure constituent has been determined using Sheerer equation and equals 10-20 nm.

**243. V. Z. Kutsova, O. A. Nosko, A. O. Kupchinskaya, A. I. Tatskova;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Effect of hydrogen treatment on the density of the hypereutectic silumin ak18.** The object of study were samples of hypereutectic silumin AK18-doped complex B - Sn after hydrogen treatment. It is shown that the hydrogen treatment during 10-20 minutes combined with slow cooling significantly lowers the density of the alloy AK18(B - Sn). By increasing the hydrogen treatment time to 40 - 90 minutes of the density of the investigated alloy increases, regardless of cooling rates. Samples with the maximum density obtained by hydrogen treatment during 40 min in combination with rapid cooling.

**244. V. Z. Kutsova, T. A. Ayupova, A. I. Tatskova;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**The structure and mechanical properties of type ak7 silumins at wedge-shaped samples rolling.** Technological deformability dependences from alloy chemical composition and treatment type are obtained. Deformation rolling influence on structure of AK7ch type alloys of initial chemical composition and one, microalloyed by a strontium-scandium , in cast state and after hydrogen melt treatment is investigated.

**245. V. Z. Kutsova, O. A. Nosko, A. O. Kupchinskaya, A. I. Tatskova***; National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Effect of hydrogen treatment on the density of the hypereutectic silumin ak18.** The object of study were samples of hypereutectic silumin AK18-doped complex B - Sn after hydrogen treatment. It is shown that the hydrogen treatment during 10-20 minutes combined with slow cooling significantly lowers the density of the alloy AK18(B - Sn). By increasing the hydrogen treatment time to 40 - 90 minutes of the density of the investigated alloy increases, regardless of cooling rates. Samples with the maximum density obtained by hydrogen treatment during 40 min in combination with rapid cooling.

**246. V. Z. Kutsova, M. A. Kovzel, A. V.Grebeneva;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Influence of heat treatment on structure, phase composition and properties of high-chromium cast iron.** Structure, phase composition and properties of white high chromium cast iron 28х32н3ф are researched. it is depicted that cast iron at 950°c degree is determined by increasing value of impact strength in accordance with values of strength. comparison with cast stay hardness after heat treatment cast iron increase.

**247. A. A. Kavats, N. Devčić****; National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Modelling of microstructure formation of metallic alloys with external vibro influence.**
**The work is devoted to modeling of the formation of the microstructure of metal alloys.** Developed a simulation model of the formation of the dendritic microstructure of metal alloys. Based on the model the dependence of metal alloys microstructure on external vibro influence was determined. The reliability of results of models application for prediction task solution using statistical hypothesis testing methods for estimation of fractal properties was shown.

**248. V. Yu. Seliverstov, Yu. V. Dotsenko, N. E. Ivanyutina;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Upgrading the poured alloy of A305 at the use of the combined technology of gaz-dynamyc influence and modification.** The studies on the combined gas dynamic effect and modification processes, as applied to improve the properties of A305 castings while crystallizing in the iron mold, have proved that the proposed technology provided for decrease and spherodize iron-containing phases, 15-20% improvement of mechanical properties, and 28% reduction in the volume of casts discarded due to microporosity and bubbles.

**249. N. Polyakova, M. Boyko, I. Mamuzić*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk; *CMS, Croatia*
**The influence structural peculiarities of high-chromium cast iron on it's quality as wear-resistance material.**
**High-chromium cast iron usually is used for two-layer rolling mills rolls production.** Wear-resistance of its samples in different structures states was investigated. The influence of exploitations heating and cooling conditions on their structure and properties were researched. Correlation between the structure and properties of this material was shown. The requirements for the irons structures for increasing the resistance to impact-abrasive wear were defined.

**250. M. O. Matveyeva, V. N. Bespalko, B. V. Klimovich;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Liquation processes inalloy cast ironsof economically chromium.** Significant heterogeneity on a chemical compound and variety of structural components of white cast iron containing 3,93+0,02 % chromium was established. With electronic skanning microanalyzer REMMA 102-02 unequal distribution of chrome and silicon in pearlite different dispersion was revealed. Significant heterogeneity on cementie plates, induced segregation processes during crystallisation and hardening established. Grain boundary cementite was depleted in chromium and manganese, but contains a significant amount of silicon, phosphorus and sulfur. And the central part enriched with Cr and Mn, and of Si, P, S decreases.

**251. S. I. Gubenko, V. N. Bespalko, A. E. Balev;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Influence of non-iron inclusions on the structural heterogeneity of austenite in pipe workpieces at plastic impact.** The studies were carried out on the influence of nonmetallic inclusions in the pipe workpieces made of steel 08Kh18N10T on the structure and technological properties of the pipes received in the pipe unattended installations. Formation of the structure when flashing a pipe workpiece is largely determined by its quality that depends a lot on the content of nonmetallic inclusions in steel. Studies have shown that already in the original pipe workpiece at a substantial ¬ structural heterogeneity can be observed in the cross section of workpiece ¬ that is conditioned by softening steel by different mechanisms.

**252. R. V. Pankov, I. Mamuzić;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Structural transformation during the heat treatment of chromium coatings.** Effect of substrate temperature during vacuum-arc deposition of chromium coatings on the nature of transformations in the coating during subsequent heat treatment was studied by differential thermal and microstructural

analysis. The temperature of the structural transformation decreases with a change in its character after substrate temperature increases to 450°C. The primary recrystallization process with initial temperature ~ 500°C is occur in this case.

**253. V. N. Nadtoka, L. N. Deyneko, R. V. Pankov;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Development of temperature stabilizing process during the deposition of functional coatings to the inner surface of tubular product.** Possible ways of heating and subcooling during vacuum-arc deposition of chromium coatings on the inner surface of tubular products for deposition temperature stabilization were analyzed in this work. The method of using molten salts with a working temperature of 230-550°C for effective deposition temperature stabilization is proposed here. This is allow to prevent softening of the substrate during the vacuum-arc deposition and coating delamination from over- and underheating.

**254. L. Deyneko, O. Lytvynenko, O. Silant'yeva;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Development of the cooling hardening process of petroleum pipes made of alloyed steels and design of the quenching device.** In work the analysis of various ways of hardening cooling, devices for their realization and hardening environments is made. The most effective way of hardening of pipes of petroleum assortment of alloyed and high-alloyed steels is sprayer cooling at which as the cooling environment the water-and air mix is used. At work performance the test bed for check of working capacity of atomizers of a various design is created and constructive-technological parameters of a water- and air atomizer are developed.

**255. K. Novikova, A. I. Mikhalyov;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Investigation of fuzzy clustering algorithms in problems analysis of metallographic image.** In this work, conducted research on modeling images samples wheel metal using a fuzzy clustering algorithm FCM - fuzzy c - means. Metallographic analysis (samples of the metal wheel) was carried out in the bright field of view using a light microscope metallographic "Epiqwant" and "Neofot-21", upgraded by installing a digital video camera «Panasonic NV-CS1» connected to the computer industry.

**256. A. I. Mikhalyov, T. V. Mikhaylovskaya;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**An analysis of the functional coatings formation mathematical models and their adaptation for modeling the deposition of material on PVD-technology.** Studies have shown that digital images of nanostructured coatings have fractal characteristics, so to simulate this process, you should use the fractal model of cluster formation. Among the most promising model for the formation of functional coatings PVD-technology model is a diffusion-limiting aggregation (DLA).

**257. L. M. Lobanov, M. D. Rabkina, V. A. Nekhotyashchiy, A. A. Perepichay;** *E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine, Kiev, Ukraine*
**Investigation and Simulation of Damage Level of Oxygen Cylinder Shells.** A correlation was established between the coercive force and cylinder wall thickness; metallographic and crystallographic features were studied, which confirm the dependence of the coercive force on structure-texture parameters of steel; a geometrical model was constructed and a software package was tried out which implements the procedure of determination of the stress-strain state based on finite element method.

**258. G. V. Tsyban'ov, Yu. P. Kurash , G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine**
**Fretting Fatigue of Low-Carbon and Low-Alloyed Steels.** Investigations conducted into fatigue of low-carbon and low-alloy steels with notches and fretting sites. It is proposed to evaluate the level of damage in this zone by the electric microcurrents flowing across the specimen-pad circuit. These magnitudes for low-alloy steels are shown to be in 5…10 times higher than for low-carbon steels. The results can be used for a comparative assessment of the consistency of the materials under conditions of fretting.

**259. J. Rapalska-Nowakowska, A. Kawałek, H. Dyja, B. Koczurkiewicz;** *Czestochowa University of Technology, Czestochowa, Poland*
**The physical and numerical modeling of thermo-mechanical treatment of complex-phase (CP) steel.** In this paper the results of numerical and physical simulation of thermo-mechanical treatment of experimental complex-phase steel are presented. For computer simulation the commercial program ThermoCalc were used. The characteristic temperature of investigated steel and the size of initial austenite grains were determined. On the samples was also metallographic examination and Vickers hardness testing conducted. The obtained results were used to build a real CCT diagram of steel.

**260. M. Knapiński, A. Kawałek, H. Dyja, M. Kwapisz, B. Koczurkiewicz;** *Czestochowa University of Technology, Czestochowa, Poland*
**Analysis of the microstructure evolution during thermo-mechanical treatment of the steel plates in grade X80-X100.** In the work the results of the physical modeling of plate rolling process of HSLA steel were presented. The simulations were carried out using the Gleeble 3800 device and the anvils set for plane strain compression study. The aim of the simulation were a determination of a influence of used deformation and temperature schedule on obtained final structure of specimens after cooling to room temperature.

**261. I. Okipnyi, P. Maruschak, M. Vovk, P. Pryshlyak;** *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
**Localization of strain in heat-resistant steels at different structural levels.** Macro- and microindentation techniques have been used to study the temperature dependence of deformation microstructures in heat-resistant steels 15Kh2MFA and 25Kh1M1F. Generally, strain degree f surface layer increased with increasing temperature, due to increasing residual deformation on micro-, meso-, and macrolevel. Examples of microstructural control of strain hardening are given.

**262. P. Maruschak, I. Okipnyi, L. Poberezhny, I. Lytvynenko;** *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
**Assessment of damageability of a surface with multiple defects.** The assessment of damageability of a zirconium nanocoating surface with multiple defects with improvement of the technical prediction methods and complex mathematical processing of experimental data was developed. The estimates of the probability characteristics of the nanocoating cracking as informative features of the damageability parameters of the "steel-coating" system were proposed.

**263. M. I. Pidgurskyi, M. G. Greshchuk, V. Homyak;** *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
**Fatigue of Pre-Strain of Low Alloy Structural Steel.** The research has been conducted concerning the influence of plastic deformation of low alloy structural steel ($\sigma_y$=575 MPa, $\sigma_u$=702 MPa, ψ=52,9 %). Levels of material plastic deformation have been equal to 1,5%, 5%, 10%. There has been established that preliminary plastic deformations at levels 1,5% and 5% do not significantly influence the steel durability, while 10% pre-strain causes the decrease of fatigue strength in twice. The fatigue decrease mechanisms have being examined.

**264. A. Nagode, G. Klančnik, G. Kosec*, G. Novak*, L. Kosec;** *University of Ljubljana, Ljubljana, Slovenia; * Acroni d.o.o., Jesenice, Slovenia*
**The investigation of the surface damage of hot plates after black oxide coatin.** The blackening of hot plates has been performed by annealing in special atmosphere comprised of combustion gases in the furnace fired with wood. However, after annealing in the furnace heated at 650 °C for 4 hours red-brown stains have occurred on the surface of hot plates. For the investigation of the surface damage a light microscope, scanning electron microscope (SEM) as well as x-ray diffraction analysis (XRD) have been used. The possible formation of different types of iron oxides during black oxide coating has been thermodynamically explained.

**265. J. Bernetič[1,5], G. Kosec[1], T.Vuherer[2], M. Marčetič[1], M. Rimac[3], Z. Burzić[4], L. Kosec[1], B. Kosec[5];** *[1] Acroni, d.o.o., Jesenice; [2] University of Maribor, Maribor, Slovenia; [3] Metallurgical Institute Kemal Kapetanovic, Zenica, BiH; [4] Military Technical Institute, Belgrade, Serbia; [5] University of Ljubljana, Ljubljana, Slovenia*
**New grade armour steel.** Theoretical and experimental study of new grade of low heavy weight armour steel was carried out. In the experimental part of investigation three plates were heat treated to different states. The first was quenched, the second and the third were quenched and low temperature tempered at 220 and 280°C for 3 hours. Tensile tests, hardness measurements, and an instrumented Charpy test were performed. Metallographic analy-

sis was performed by scanning electron microscopy (SEM) and optical microscopy (OM). Ballistic resistance of all three steel plates were measured, the behaviour of steel was tested using standard armour piercing projectiles.

**266. A. Nagode, B. Kosec, B. Zorc, M. Bizjak, L. Kosec;** *University of Ljubljana, Ljubljana, Slovenia*
**Study of different welding joints on the electric water heater.** In our study we have received different metallic parts cut off from the electric water heater which has been in exploitation for almost 2 years. A tank of water heater is made of stainless steel Grade 304, while the pipes for the cold water supply and hot water outlet are made of copper. A research was mainly focused on the welding joints between different components of the water heater since some of them had been corroding or even leaking.

**267. R. Rudolf[1,2], B. Budič[3], D. Stamenković[4], M. Čolić[5], B. Kosec[6];** *[1] University of Maribor, Maribor, Slovenia; [2] Zlatarna Celje d.d.; [3] National Institute of Chemisty Slovenia, Ljubljana; [4] University of Belgrade, Belgrade, Serbia; [5] University of Defence, Belgrade, Serbia; [6] University of Ljubljana, Ljubljana, Slovenia*
**Rhodium Platings – Experimental Study.** Rhodium (Rh) is used very widely in decorative plating on jewellery of all types, for its intensively white colour, which is generally thought to be as white as the very best silver deposits. Functional uses of Rh deposits include high wear-resistant surfaces on e.g. slip rings and rotary switching contacts of many types. Modern rhodium plating solutions are based on the sulphate or phosphate. Although in theory there are four possible combinations, in practice only three different rhodium electrolytes, are used. These are based on dilutions of rhodium sulphate or phosphate concentrates with added sulphuric or phosphoric acid. These processes will be discussed in this paper.

**268. M. Bizjak, L. Kosec, B. Karpe, G. Dražič*;** *University of Ljubljana; *Jožef Stefan Institute, Ljubljana, Slovenia*
**Microstructural evolution and thermal stability in rapidly solidified copper alloy.** The purpose of the present work is an investigation of rapidly solidified Cu-Fe-Ti-C alloy with the nonperiodic structure, from the microstructural and phase transformation kinetics point of view. Main features of the RS alloy microstructure were investigated with transmission electron microscopy (TEM), with the special attention to crystallization of the amorphous phase. The four-probe electrical resistance measurement method was applied to follow the kinetics of microstructural changes. The rapidly solidified alloy consists of $\alpha_{Cu}$ particles, size between 5 to 10 nm, surrounded by amorphous phase. After heating beyond the 392 ° C, the amorphous phase gradually crystallize. After crystallization of the amorphous phase, the Fe, Ti, and C atoms still remain dissolved in the matrix. At temperature above 738 ° C, the iron and titanium enriched particles start to precipitate.

**269. D. Česnik, V. Gliha*, L. Kosec, M. Bizjak;** *University of Ljubljana, Ljubljana; *University of Maribor, Maribor, Slovenia*
**Control of shape and size during manufacturing of components for automotive industry.** Control over shape and size is one of the most important concerns of the metal processing industry. Therefore, the distortion of steel flat ring type products during fine-blanking and subsequent carbonitriding was investigated. The contribution of fine-blanking, relief of residual stresses, uneven heating and cooling and the formation of carbonitrided cases on the overall distortion were determined. The results were complemented with hardness measurements, residual stresses measurements and observations of microstructure.

**270. A. Smalcerz, R. Przylucki;** *Silesian University of Technology, Katowice, Poland*
**Induction hardening of gears - Pulsing Dual-Frequency concept.** The paper concerns analysis of gears hardening process. The paper concerns one- and two-frequency heating of gears with use of cylindrical inductor. To obtain required temperature distribution several variations of single and combined frequencies for selected gear-wheel configurations were considered. The paper includes calculation models and analysis of: geometry and current intensity as well frequency influence on temperature distribution of the tooth surface. All calculations have been carried out with use of Flux3D simulation program, which enables coupled electromagnetic and temperature fields analysis.

**271. W. Walke, J. Przondziono*;** *Silesian University of Technology, Gliwice; *Silesian University of Technology, Katowice, Poland*
**Electrochemical behavior of guidewires made of X10CrNi 18-8 steel.** The purpose of this study was to evaluate corrosion resistance of wires with differentiated of surface preparation and with differentiated work hardening, used in low-invasive cardiology in sterile environment. The study is devoted to voltammetric and impedance tests, which were used to determine typical features describing corrosion resistance. Obtained results were used as the ground for selecting the way of preparation of the surface of X10CrNi 18-8 steel in order to improve its biotolerance in blood environment.

**272. R. Sunulahpašić, M. Oruč, M. Hadžalić, A. Gigović-Gekić;** *University of Zenica, Zenica, BIH*
**Analysis of the influence of chemical composition and temperature on mechanical properties of superalloys Nimonic 80A.** Investigations which were carried out have included chemical testing and testing of mechanical properties of superalloy Nimonic 80A at room and higher temperatures. Regression analysis was done on the base of chemical analyses and results of mechanical properties. The results of regression analysis are equations by which on the basis of known chemical composition, ie content of main alloying elements Al, Ti and Co, the mechanical properties of materials at room and higher temperatures can be predicted.

**273. A. J. Dolata, M. Dyzia;** *Silesian University of Technology, Katowice, Poland*
**Influence of modification on structure of Al-Si alloy for the purpose of matrix in carbon fiber reinforced composites.** The main aim of the presented researches is develop the chemical composition aluminium alloy for the matrix of AlMMC/Cf composite obtained by infiltration process. For this reason, the matrix must have a number of features in a liquid state as well as after solidification. Selection of alloying additions was made with paying attention to improvement of the carbon fibres surface wettability with liquid metal, necessary to obtain proper strength properties, as well as possibilities of its further thermal treatment. As a base alloy Al-Si was selected and chemical composition was modified by AlMg and AlSr master alloys.

**274. B. Kalandyk, M. Starowicz, M. Kawalec, R. Zapała;** *AGH University of Science and Technology, Kraków, Poland*
**Influence of the Cooling Rate on the Corrosion Resistance of the Duplex Cast Steel.** The results of the influence of the cooling rate of the casting made of the acid-resistant ferritic - austenitic (FA) cast steel, containing 24 % Cr, 5 % Ni, 2,5 % Mo and 2,7 % Cu, on the microstructure and corrosion resistance in 3,0 % solution of NaCl and 0,1M $H_2SO_4$, is presented in the paper. It was found, on the bases of the performed studies of the F-A cast steel at different cooling rates, that differences in the polarization curves occur only in the more aggressive corrosive environment, which is 3% NaCl solution. The reason of such behaviour of the F-A cast steel is the segregation of elements dissolved in austenite and the difference in the volume fraction of ferrite and austenite in the walls of the different thickness (12 and 45mm).

**275. D. Dobrotă, C. Iancu;** *University "Constantin Brâncuşi" Târgu-Jiu, Romania*
**Researches regarding structural modifications that appears in the material of tools used for rubber waste attrition.** In this paper are presented the main structural material changes that occur in different areas, located at different distances from the active surface of tools. Structural changes occurred mainly refers to the transformation of white iron surface layer to gray cast iron and graphite separations appearance, which causes the crack primers and cracking corrosion phenomena in tools material.

**276. D. Dobrotă, C. Iancu;** *University "Constantin Brâncuşi" Târgu-Jiu, Romania*
**Researches on chemical composition and hardness modifications that appears in the material of tools used for rubber waste attrition.** In this paper are presented results of the main changes in the chemical composition of the material, and changes in its hardness. The changes in terms of chemical composition refers primarily to changes in concentration of sulfur and carbon, and in terms of hardness material change is seen a decrease of material hardness that is in direct contact with waste rubber.

**277. T. Bončina;** *University of Maribor, Slovenia*
**Shapes of the icosahedral quasicrystal in melt-spun ribbons.** The shapes of icosahedral quasicrystalline (IQC) particles in alloys based on the Al-Mn-Be alloy system were determined in melt-spun ribbons. The sizes of quasicrystalline particles ranged from few tenths of nanometres up to 1 μm. It

was discovered that icosahedral quasicrystalline particles preferentially grow in the three-fold directions and they have the tendency for faceting and adopting the shape of pentagonal dodecahedron. The evolution of quasicrystalline shapes is systematically presented.

**278. D. Bombač, M. Fazarinc, G. Kugler, P. Cvahte*, P. Fajfar, M. Terčelj;** *University of Ljubljana, *Impol, d.o.o, Slovenska Bistrica, Slovenia*
**Wear progress on bearing surface of nitrided dies for aluminium hot extrusion with two different bearing lengths.** Reconstruction of wear progress of most exposed parts of the bearing surfaces of dies for aluminium hot extrusion was carried out;i.e. die with a short and die with a longer bearing surface. The die with the longer bearing surface exhibited longer service time, both in terms of quantity of the extruded material, as well as in the length of the extruded profile. In the case of shorter bearing surface the transition zone occurs close to the exit edge. Two different routes of initial wear progress on area at the exit edge of bearing surface were observed.

**279. M. Knap, P. Fajfar, M. Terčelj, U. Krušič*;** *University of Ljubljana, *Metal Ravne,d.o.o., Ravne na Koroškem, Slovenia*
**Optimisation of steel properties through chemical composition with neural netvorks.** Nowadays huge efforts are carried on into the optimisation of steelmaking process. Produced steel grades must achieve prescribed mechanical and other metallurgical properties at lowest possible price.The main goal of this work is to define most influential alloying elements and to prescribe limits for each of them. Because of enormous data base convectional statistical analyses cannot be applied the neuronal networks was successfully used.

**280. P. Fajfar, M. Fazarinc, B. Žužek, M. Terčelj;** *University of Ljubljana, Slovenia*
**Implementation of newly developed tests with heated and internally cooled tool steel samples for different applications.** In this study two new tests were developed, i.e., with continuous internal water cooling as well as discontinuous internal water and air cooling. It was proved that the first type of testing is appropriate for simulating the time course of the temperature at a selected depth of a thermally loaded, hot-working die surface layer, i.e., the temperature field on the die surface layer. The second type of testing is appropriate for a study of the thermal fatigue resistance of a tool material.

**281. V. A. Ivchenko;** *Institute of Electrophysics, Yekaterinburg, Russia*
**Research of nanostructure states in the ion-implanted Pt.** The effect of formation nanostates in subsurface volumes of Pt in result of implantation of ions of $Ar^{+}$($E$=30 keV, $F$=$10^{16}$-$10^{18}$ $sm^{-2}$) is established by the method of field ion microscopy. This phenomenon is observed on distances not less, than 60 nm from the irradiated surface of metal (at $F$=$10^{18}$ $sm^{-2}$). The sizes of nanoblocks both on irradiated surface, and in subsurface volume of the Pt are certain.

**282. S. V. Konovalov, S.V. Vorobyev, S. V. Gorbunov, D. A. Bessonov, I. A. Komissarova, Yu. F. Ivanov, V. E. Gromov;** *Siberian State University of Industry, Novokuznetsk, Russia*
**Evolution of dislocation substructures in fatigue loaded stainless steel processed by high-intensity electron beam.** Electron-beam processing of the sample faces of 08Cr18Ni10Ti steel is carried out and multicyclic fatigue tests are conducted. The increase in 3.44 times of fatigue durability of the modified by an electron beam steel is revealed. It is established that the reasons of fatigue durability increase of the irradiated steel is a grain and subgrain structure refinement, particle dissolution of carbide phase in the surface layer.

**283. N. P. Leonova, D. V. Shangina, N. R. Bochvar;** *A. A. Baikov Institute of Metallurgy and Material Science, Moscow, Russia*
**Preparation and investigation of the copper-chromium alloys after different regimes of the thermo-mechanical treatment.** Using arc melting and successive hot working the low-alloyed copper-chromium alloys were prepared. The strength properties, microhardness and electric resistivity of them were investigated after initial thermal treatment (quenching or annealing), after cold rolling and successive ageing, after severe plastic deformation and successive ageing. It was shown the difference in the change of strength and electric resistivity of the copper-chromium alloys depending on initial thermal treatment, used plastic deformation and ageing temperature.

**284. E. V. Li, S. A. Nikulin, A. B. Rozhnov, V. A. Belov;** *National University of Science and Technology "MISIS", Moscow, Russia*
**Structure factors of embrittlement of zirconium alloys after high temperature oxidation.** In the present work structure changing of E110 alloy is analysed after alloying of electrolytic-based alloy with oxygen and iron and decreasing of impurity content by means of adoption of the sponge basis. It has shown that type of "ex-β"-layer microstructure and quantity and dimensions of hydrides significantly influence on residual ductility and fracture of samples. The greater fraction of so-called "basket-wave" structure and quantity and dimensions of hydrides, the lower alloy ductility and fracture is more brittle. The share of so-called "basket-wave" structure and number and size of hydrides depend on the alloy chemical composition, especially on the amount of impurities.

**285. V. A. Ermishkin, N.A. Minina, P. Tomaio[*], N.L. Fedotova[**];** *Baikov Institute of Metallurgy and Material's ScienceMoscow, Russia; [*]National Polytechnics Institute, ESIME-Zacatenco, Mexico; [**]Bardin Central Scientific Research Institute of Ferrous Metallurgy, Moscow, Russia*
**Stady of the crystallization of amorphous alloy on the basis of system Zr-Fe-B by the method of atomic power microscopy and photometric annalysis of structural images.** The surfaces of the amorphous alloy film samples with a width of 10 mm. and with a thickness of 0,07 mm, obtained by quenching fusion on the being fast-turned copper disk were. As a result conducted investigations it is established: both methods give the practically identical kinetic laws of variation in the parameters, which characterize phase transition "amorphous state- crystalline".

**286. Nikulin S.A., Belomyttsev M.Yu., Khatkevich V.M., Rogachev S.O., Rozhnov A.B.;** *National University of Science and Technology «MISIS», Moscow, Russia*
**Dispersion strengthening of 0,08 %C-17,0 %Cr-0,8 %Ti steel by "internal" nitriding.** Experimental method of dispersion strengthening of sheet samples of ferrite stainless 0,08 %C-17,0 %Cr-0,8 %Ti steel by "internal" nitriding is developed and tested. The nitriding of samples at temperatures above 1000 ºC were performed. It is shown that nitriding with subsequent annealing provides a uniform distribution of dispersed nitrides with an average size 60x160 nm in the structure. Mechanical properties of the samples after nitriding and subsequent annealing higher by factor 1,8-2,0 (at 20 and 700 ºC) in comparison with non-nitrided state.

**287. I. N. Ovchinnikova, O. P. Chernogorova, E. I. Drozdova;** *A.A. Baikov Institute of Metallurgy and Materials Science, Moscow, Russia*
**Superelastic hard carbon formed from fullerenes under pressure for the reinforcement of wear-resistant low-friction metal-matrix composite materials.** Superelastic hard materials with a high hardness-to-elastic modulus ratio are advantageous in terms of wear resistance and tribological properties. The particles of superelastic hard carbon phase were obtained from fullerenes at a pressure of 5 and 8 GPa at temperatures of 800-1200 K (i.e., above the temperature limit of the stability of fullerene molecules) in the mixture with Co powders. The reinforcement of cobalt by the superelastic hard carbon particles obtained at pressures of 5 and 8 GPa increases the abrasive wear resistance by a factor of ~40 and ~140, respectively, and simultaneously decreases the friction coefficient almost by a factor of two.

**288. E. A. Lukyanova, T. V. Dobatkina, L. L. Rokhlin, I. G. Korolkova;** *A.A. Baikov Institute of Metallurgy and Material Science RAS, Moscow, Russia*
**Phase equilibria in the Mg-Y-Gd-Sm system alloys.** Character of the phase equilibria at different temperatures in the Mg-rich alloys containing yttrium, gadolinium and samarium were studied. The boundaries of magnesium solid solution area and the phase areas adjoining to it were established. Investigation indicated the solubility of samarium in solid Mg to decrease with increasing sum of even contents of yttrium and gadolinium and lowering temperature. No ternary compound in the studied part of the Mg-Y-Gd-Sm system is formed. A number of the relevant partial polythermal and isothermal sections of the Mg-Y-Gd-Sm phase diagram were constructed.

**289. S. A. Nikulin, A. B. Rozhnov, M. V. Koteneva;** *National University of Science and Technology "MISIS", Moscow, Russia*
**The study of chemical composition and structure of oxide films in zirconium alloys.** In this paper the composition and microhardness of oxide films in zirconium alloy (Zr-1%Nb) samples after corrosion tests in water under the conditions: T = 360 º C, P = 18,6 MPa, τ = 600 days, were analyzed.In this work the following research methods: atomic emission spectroscopy, scanning electron microscopy, microhardness measurements on CSM Micro

Indentation Tester, were used.The concentration dependence of the distribution of chemical elements and microhardness over the thickness of the oxide films was determined.The microstructure of the films was analyzed.

**290. S. V. Konovalov, F. A. Filipiev, L. B. Zuev, D. I. Danilov, I. A. Komissarova, V. E. Gromov**; *Siberian State University of Industry, Novokuznetsk, Russia*

**Contact electric potential influences of the microhardness of metals.** The effect of the electric potential on the microhardness of aluminum, zirconium, and ferrosilicon was studied experimentally. The effect of the proper electric potential applied to a sample is compared with the effect of the potential induced by the contact potential difference upon contact with metals with a different electron work function. These two types of electrical action are revealed to be qualitatively equivalent to each other. It is established that these effects can markedly (up to 15 %) change the microhardness of the metals.

**291. A. I. Rudskoy, G.E.Kodzhaspirov;** *St. Petersburg State Polytechnical University, St. Petersburg, Russia*

**Effect of thermomechanical control processing on structure and corrosion-mechanical properties of AISI 321 steel.** The effect of Thermomechanical Control Processing (TMCP) on fine structure (dislocation density, fragments evolution an etc.), recrystallization, carbide transformations and tendency toward intercrystalline corrosion (ICC) and corrosion-mechanical strength of AISI 321 type steels is described. It's shown that the corrosion rate increases with an increase in proportion of recrystallized material. This connection is explained by an increasing of the level of local microstresses, which may be arranged structurally in the form of partial disclinations and aggravate ICC. A new test procedure was developed for estimating the corrosion-mechanical strength of steel.

**292. I. I. Vedyakov;** *P.D. Odesskiy, A.A. Egorova. The Central Scientific and Research Institute of Building Structures named after V.A. Koucherenko. Moscow, Russia.*

**Strength of structural steels in large sections, used as the elements of unique construction projects.** Modern technology of metallurgical production allow for rolling and forging large cross sections that can be cost-efficient if used as elements of unique steel structures. For example, beam profiles with parallel faces of beam flanges with a thickness of latter up to 125 mm, $\sigma t = 450$ N/mm$^2$, KCV-40 $\geq$ 35 J/cm$^2$ are used in frames of high-rise buildings as columns and beams; large axis with the diameter of over 500 mm of medium-carbon steel with $\sigma t = 700$ N/mm$^2$, KCV-40$\geq$ 27 J/cm$^2$ are used as parts of suspension used in over-tribunes covers of stadiums. When assessing the strength of major elements it is necessary to consider the scale factor and the destructive effects associated with this factor.

**293. S. A. Nikulin, V. G. Khanzhin, S. O. Rogachev, V. Yu. Turilina;** *National University of Science and Technology «MISIS», Moscow, Russia*

**Delayed fracture of hydrogen embrittlement steels by bending.** The delayed fracture resistance to hydrogen embrittlement of 35KhGM (Russian standart -35ХГМ) and 33 KhM1F (Russian standart - 33ХМ1Ф) steels was investigated. Based on the results of a comparative analysis of the mechanical behavior of materials under four-point bending and uniaxial tension by measuring the acoustic emission and fractography, the differences in the mechanism and kinetics of fracture of steels were shown.

**294. S. A. Nikulin, V. A. Markelov, A. Yu. Gusev, A. B. Rozhnov, M. Yu. Zadorozhnyy, S. O. Rogachev, T. A. Nechaykina;** *National University of Science and Technology «MISIS», Moscow, Russia*

**Method of fatigue testing of small-sized samples of zirconium alloys on dynamic mechanical analyzer.** Test method for low-cycle fatigue strength of small-size flat specimens of zirconium alloys using dynamic mechanical analyzer Q800 was developed and tested. Low-cycle fatigue tests were performed on samples of size 30x3x0,7 mm at 25 and 350ºC for soft loading scheme for a symmetric transverse bending at frequency of cycling 0,5 Hz to destruction of the samples. Curves of fatigue tests at various temperatures were obtained and the characteristics of fracture patterns were analyzed. It's shown that the method provides good reproducibility.

**295. Z. Burzić, Dž. Gačo*, F. Islamović*, M. Burzić**;** *Military Technical Institute, Belgrade, Serbia; *University of Bihac, Bihac, Bosnia and Herzegovina; **University of Belgrade, Belgrade, Serbia*

**Influence of operating conditions on integrity of welded joint X20 high alloyed steel.** The aim of these investigations was to establish the effect of operating conditions of base metal and welded joint, X20 CrMoV 12-1 (X20) high alloyed steel. The results of these investigations should provide practical contribution to assessment of quality of base metal of the components of welded joint of steel X20, aimed at revitalization i.e. assessment of structural integrity and extension of service life of vital components, high-alloy steel thermal power plants operating at elevated temperatures.

**296. L. Rancel, M. Gomez, E. Escudero, S. F. Medina;** *National Centre for Metallurgical Research (CENIM-CSIC), Madrid, Spain*

**Study of phase transformation in medium carbon microalloyed steels.** Several 35CrMo4 and 38MnV7 steels with different additions of Ti, Nb and V were manufactured by Electro-Slag Remelting. The influence of alloying and microalloying elements on phase transformation at different cooling rates was studied and the continuous cooling transformation (CCT) diagrams were plotted. In order to optimise the heat treatment and to improve the mechanical properties, the range of cooling rates leading to a fully bainitic microstructure was determined. In these steels, it is technically important to know the microstructures obtained when cooling rates after thermal treatment close to air-cooling are applied. Finally, recommendations about chemical composition and heat treatment are proposed.

**297. D. Klobčar, L. Kosec, A. Pietras*, J. Tušek;** *Faculty of Mechanical Engineering, Ljubljana, Slovenia; * Instytut Spawalnictwa, Gliwice, Poland*

**Microstructure and mechanical properties of fsw and mig welds of casted aluminium alloy AlSi12.** A comparison of MIG and Friction Stir Welding (FSW) of 4 mm thick EN AC 44300 casting aluminium alloy were done. FSW was done with selected tool geometry at constant tilt angle and with varying tool rotation speed and welding speed. MIG welding was done using pulsed welding, cold metal transfer welding and with a combination of pulses. Specimens for tensile test, bending test, toughness test and for microstructure analysis were prepared. Microstructure was observed on a light microscope under the polarised light source. A Vickers micro-hardens was measured across the weld. FSW welds have superior microstructure and mechanical properties.

**298. M. Rimac, M. Oruč, S. Muhamedagić;** *University of Zenica, Zenica, BIH*

**The structure of metallic coating NiCrAlY applied by Diamond Jet process on iron-based superalloy A286.** One of processes of surface improvement of superalloy based on iron is by applying mettalic coating by Diamond Jet process. The paper presents the study of microstructure of NiCrAlY metal coating which is by procedure HV0F and by Diamond Jet process applied on iron-based superalloy labeled as A286. We studied the austenitic matrix, strengthen gamma prime phase and oxide phases $Al_2O_3$, $Cr_3O_4$, and $Y_2O_3$.The impacts of these phases on the coating properties are given in this paper too.

**299. I. Samardžić, B. Despotović*, D. Bajić**;** *University of Osijek, *Termoenergetska postrojenja Ltd., Slavonski Brod, Croatia, ** University of Podgorica, Montenegro*

**Weldability of modern low alloyed steels for elevated temperature application in steamboiler components production.** The paper presents basic materials for application in steam boilers at elevated temperatures. Special emphasize is given on low alloyed Cr-Mo steels predicted for elevated temperatures application. In that sense, the weldability of modern T/P 23 and T/P24 steels is explained and supported with results of practical experiences. Besides appropriate main welding parameters, in research into weldability of these steels it is important to determine preheating and interpass temperature, as well as parameters of post weld heat treatment. Properties of relatively new developed low alloyed steels are compared with conventional T/P 22 steel (13CrMo4-5).

**300. B. Despotović, D. Bajić*, I. Samardžić**, A. Čikić***;** *Termoenergetska postrojenja Ltd., Slavonski Brod, *University of Podgorica, Montenegro, ** University of Osijek, Croatia, *** High technical school in Bjelovar, Croatia*

**Accelerated weldability investigations of modern high alloyed martensitic steels for ateam boiler components application.** The paper provides basic information on modern high alloyed martensitic steels (over 9% Cr) suitable for high temperature application in steam boilers. Besides overview

of materials and their properties (VM12, T/P 91, E911 and T/P 92), the paper deals with comparison of these materials and conventionally used X20CrMoV12-1 steel, which was often used for high temperature application in creep sensitive and scaling corrosion sensitive range. The authors presented results on accelerated investigation of weldability of modern high alloyed martensitic steels, supported by some practical results from workshop.

**301. M. Dunđer, D. Bajić*, I. Samardžić**, M. Horvat***;** *University of Rijeka, University of Podgorica, Montenegro, ** University of Osijek, Slavonski Brod, Croatia, ***University of applied sciencies in Varaždin, Croatia*

**Weld thermal cycle simulation of HSS S960QL.** The paper presents results of weldability investigation of high strength steel S960QL performed on specimens after weld thermal cycle simulation on Smitwed simulator. It presents the plan of experimental investigation, as well as procedure of accelerated weldability tests. The steel is used for heavy constructional machinery components production (frames and manipulators of dredges, cranes, railway vehicles, etc.). Obtained data will contribute to knowledge on weldability of this type of steel, which is suitable for constructions due to its benefits (reduction of weight, materials and energy savings, etc.).

**302. D. Bajić, I. Samardžić*, I. Kladarić*, Š. Klarić*;** *University of Podgorica, Montenegro, *University of Osijek, Slavonski Brod, Croatia*

**Activating flux application at stud arc welding in bridge constructions production.** An application of activating flux at arc welding processes can result with significant penetration improvement. This paper presents experimental investigation of activating flux application at arc welding processes. Special emphasis is put to stud arc welding processes in bridge constructions and steam boiler thermal insulation production. Besides welding parameters, the authors provided photographs of appropriate cross-section of weldments.

**303. B. Mateša, I. Samardžić, M. Dunđer*, A. Pintarić**;** *University of Osijek, Slavonski Brod, *University of Rijeka, Rijeka **University of applied sciencies in Vukovar, Croatia*

**Effect of cladding procedures on mechanical properties of heat treated dissimilar joint.** *The specimens plated by different cladding procedures (hot rolling, submerged arc welding –surfacing using strip electrode (SAW) and explosion welding) are heat treated by annealing (650°C through 2hours).* Charpy impact energy testing as well as shear strength testing of clad joints is performed. Statistical analysis of testing results is elaborated and significance of cladding procedure and heat treatment influences on stated mechanical properties are established.

**304. M. Katinić, D. Kozak*;** *Petrokemija d.d. Kutina, *University of Osijek, Croatia*

**Numerical analysis of axial through-wall cracked cilinders under a creep conditions.** Fracture mechanics *C** parameter used to describe the creep crack growth, can be calculated using finite element method or estimated by either the reference stress method or GE/EPRI method. For the numerical calculation by finite element method, with the known geometry of the structure and known load of the structure, it is necessary to know the relevant elastic properties and creep properties of materials. This paper presents a numerical model for calculation of *C** parameter in the case of axial through-wall cracked cylinders under an internal pressure. The behavior of the material in the steady state secondary creep is described by an idealized constitutive relation known as Norton`s law.

**305. D. Kozak, Z. Marković*, T. Baškarić;** *University of Osijek, Slavonski Brod, *HEP-Toplinarstvo d.o.o., Osijek, Croatia*

**Corroded pipe integrity assessment according to SINTAP procedure.** SINTAP procedure gives a comprehensive approach to assessing the integrity of structural components with damage. In this investigation SINTAP procedure has been applied to the hot water pipe with detected corrosion damage that is in operation for more than 15 years of centralized hot water system, in the City of Osijek. It is a steel pipe Φ 273 x 5 with the measured corrosion damage of 1,5 mm in depth and 68 mm in length, which is loaded in the exploitation of internal overpressure of 12 bar. Performed analysis based on the FAD approach given in SINTAP procedure shows that for a specified load and measured size of the pipe corrosion damage is still running deep into the safe area and there is no danger of leak.

**306. M. Burzić, M. Manjgo*, D. Kozak**, R. Prokić-Cvetković, O. Popović;** *University of Belgrade, Serbia, *University of Mostar, BiH, **University of Osijek, Croatia*

**The effects of dynamic load on behaviour of welded joint A-387 Gr. 11 alloyed steel.** For completely realization of cause and manner, crack initiation and crack propagation in welded joint of steel A-387 Gr. 11 Class 1, it is necessary to establish how heterogeneity of structure and different mechanical properties of welded joint constituents affect on crack initiation and propagation, and fatigue crack growth. Critical locations, regarding integrity of welded joint can be formed in HAZ and WM. Crack initiation and growth caused by variable loading in the form of Paris law curve is today generally accepted, since it describes micromechanical behaviour of growing crack. During the testing of Charpy specimens for V-2 notches in BM, WM and HAz, it is assessed the influence of structural heterogeneity in welded joint influence on total impact energy and fatigue crack rate parameters, and Paris relationships.

**307. V. Pecić, R. Marković, Š. Klarić;** *University of Osijek, Slavonski Brod, Croatia*

**Structure and properties changes of martensitic steel X10CrMoVNb9 1 due to heat input during welding.** Materials with properties like high enduring strength and creep resistance (to endure long working cycle in extreme conditions) are necessity in thermal power stations components production. Due to microstructural properties and high temperature endurance, the X10CrMoVNb9 1 is often used. As welding is mostly used joining process in production of boiler plants, the influence of welding cycle (heat input) on the properties of weldment of X10CrMoVNb9 1 steel is investigated. Metallographic and mechanical tests are conducted on the samples before and after the welding.

**308. A. Milinović, D. Krumes, I. Kladarić;** *University of Osijek, Slavonski Brod, Croatia*

**Research of boride layers growth kinetics on C45 carbon steel.** This study reports an evaluation of borides formed on C45 steel. Pack boronizing has been carried out in temperature range 870 – 970 °C with durations 4 – 8 h. Average thickness of boride layers ranges from 60,6 to 181,2 μm. Through application of basic laws of diffusion, values of frequency factor and activation energy have been determined and practical empirical expression for boronizing of C45 has been derived. Also analyzed is the change of volume share of boride phase concerning cross section of the layer. Based on volume share of boride phase as well as measured microhardnesses of base material and boride phase, change of cross sectional layer hardnesses is determined and analyzed.

**309. V. Marušić, Đ. Španiček*, Ž. Rosandić;** *University of Osijek; *University of Zagreb, Zagreb, Croatia*

**Media influence on the properties of fiber reinforced polyester laminates.** Polyester laminate panels are made of different composition and thickness. Different layers of glass fibers ("mat"), and "roving", as well as matrix of polyester resin with additives and calcite have been used as reinforcing links. The influence of the media is particularly evident in conditions of appearance of voids on the surface reinforce-matrix. Presence of larger number of cavities and holes are indicators of non-homogeneity. It has been concluded that mechanical and technological properties of polyester laminates depend not only upon composition but also on homogeneity of structure.

**310. B. Mateša, I. Samardžić, M. Dunđer***; *University of Osijek, *University of Rijeka, Croatia,*

**Effect of cladding procedures on mechanical properties of heat treated dissimilar joint.** *The specimens plated by different cladding procedures (hot rolling, submerged arc welding – surfacing using strip electrode (SAW) and explosion welding) are heat treated by annealing (650 °C through 2 hours).* Charpy impact energy testing as well as shear strength testing of clad joints is performed. Statistical analysis of testing results is elaborated and significance of cladding procedure and heat treatment influences on stated mechanical properties is established.

**311. D. Šoštarić, M. Dunđer*, I. Samardžić***; *University of Osijek; *University of Rijeka, Rijeka, Croatia;*

**Quality monitoring at fusion welding of polyethylene high-density pipes.** The paper presents the main parameters of fusion welding and their Off - line analysis of Polyethylene high-density (PE-HD) pipes. By direct measurements of voltage and current at the coupler, inductive and the resistant character changes in amplitude modulation waveforms of the measured signal are observed. In early measuring device analyzes the scanned parameters

with certain types of fittings and compares them with the tested and measured parameters is done by welding machines. There can be seen the time delay or "dead time" when the system analyzes the parameters and dimensioned regulatory function of the system.

**312. M. Buršák, J. Michel';** *Technical University of Košice, Slovakia*
**Influence of the strain rate on the mechanical and technological properties of steel sheets.** The paper analyses the influence of strain rate on the behaviour of un-alloyed steels with Re (yield strength) in the range of 210 … 550 MPa in the deformation process. By increasing of strain rate ranging from 10–3 to 2,5·102 s–1 the ratio Re/Rm is increased, whereas it was observed more intensively for steels with the lower value of Re. By increasing of strain rate up to 1 s–1 are IE values of tested steels increased, whereas the ratio Re/Rm was equal 0,82. After exceeding of this strain rate was the ratio Re/Rm increased and IE value is remarkable decreased.

**313. J. Lozanović Šajić, M. Burzić, K. Čolić;** *University of Belgrade, Belgrade, Serbia*
**Applications of Different Materials for same parts of Turbocharger.** In this paper, the characteristics of a completely different materials used in the specific field of automotive industry. Discussed the properties of ceramics, as well as new material for the purpose these and special bronze alloy, which have been used for some time, but on this occasion it should be noted that the characteristics of bronze for the purpose in the field of automotive continuously improve which is also discussed in this paper. In addition to application in the automotive industry, given the possibilities of application to other industrial grade marine, aviation, hydroelectric, etc.

**314. E. Olejnik, A. Janas, A. Kolbus, B. Grabowska;** *University of Science and Technology, Krakow, Poland*
**Effect of carbon addition on functional and mechnical properties of the Ni3Al phase.** Casting technology was applied and research was carried out on two alloys based on the Ni3Al phase with variable carbon content of 0,2 and 1,25 wt. % C, respectively. Resistance to abrasive wear, Friction coefficient and Vickers microhardness were determined. An increase in resistance to abrasive wear and microhardness of alloy containing 1,25 wt. % C was observed. The coefficient of friction was determined, which for the alloy with increased carbon content was much lower than for the alloy containing 0,2 wt. % C. Structural changes were reported to have some effect on functional and mechanical properties of the examined alloys.

**315. M. Babič, P. Kokol*, M. Milfelner**, P. Panjan***, S. Babič***; Emo-orodjarna d.o.o.; *University of Maribor; **Tic-Lens d.o.o.; ***IJS Ljubljana, Slovenia*
**Fractal image on robot laser hardened tool steel.** This article describes the fractal structure of the robot laser hardened tool steel. It describes the results of previous work, research and experience gained in robotic laser hardening of metal. Fractal geometry is based on the idea of invariance of magnification, which means that the observed picture of the same regardless of where how you look powerful microscope. In the second part we looked at samples under a variety of zoom and search for fractal patterns. Pooled results were compared and analyzed. Finally, we optimized all parameters and graphically presented. Robot laser hardening is used in automotive, military and aerospace industries.

**316. M. Babič, P. Kokol*, M. Milfelner**, P. Panjan***, J. Babič***; Emo-orodjarna d.o.o.,; *University of Maribor; **Tic-Lens d.o.o.; ***IJS Ljubljana, Slovenia*
**Deformation of robot laser hardened alloys GGG 60.** Laser hardening is a metal surface treatment process complementary to conventional ame and induction hardening processes. A high-power laser beam is used to heat a metal surface rapidly and selectively to produce hardened case depths of up to 1,5 mm with the hardness of the martensitic microstructure providing improved properties such as wear resistance and increased strength. We will find parameters of robot laser hardened cell, because we will reduce deformations. We observe a micristructure of robot laser hardened patterns. We find plastic and elastic deformations.

**317. M. Babič, P. Kokol*, M. Milfelner**, P. Panjan***, S. Babič***; Emo-orodjarna d.o.o.; *University of Maribor; **Tic-Lens d.o.o.; ***IJS Ljubljana, Slovenia*
**Rougness surface of point robot laser hardnend specimens.** C haracterization of surface topography is important in applications involving friction, lubrication, and wear (Thomas, 1999). In general, it has been found that friction increases with average roughness. Roughness parameters are, therefore, important in applications such as automobile brake linings, floor surfaces, and tires. In microstructure of robot laser hardenend speciment we have rougness surface. We focus on point robot laser hardened speciment standard code of DIN standard 1.7225 with different temepratures $T \in [800, 2000]$ °C. We make measurements with profilometer. At the end it is presented the geometry of rougness surface of the point robot laser hardening.

**318. D. A. Skobir Balantič, F. Vodopivec, B. Žužek***; Institute of Metals and Technology Ljubljana, Slovenia*
**Nucleation and growth of M23C6 carbide particles in low carbon chromium-molybdenum-vanadium steel.** In this work, the nucleation of M23C6 particles is explained with formation of nuclea on iron carbide particles as increase of chromium content in iron carbide. The nucleation and growth of M23C6 particles is related to a competition of effects of carbide Gibbs free energy and solubility product as well as concentration (activity) and diffusion afflux of carbide forming elements in solid solution in ferrite. A simple method is proposed for the calculation of average particles spacing and average size of carbide particles.

**319. G. G. Pisarenko, A. M. Mailo, O. V. Voinalovich***; G. S. Pisarenko Institute for Problems of Strength, Kyiv, Ukraine*
**Relation between the nonuniformity of distribution in the generalized damage parameter measured in local areas of the D16T alloy surface layer and the life during fatigue.** It is found that the kinetics of fatigue damage to the surface layer of the alloy under investigation determined through the generalized damage parameter is of a cyclic nature. The position of the first extremum corresponds to the relative number of life cycles in the range of about 10 %, whereas the last extremum occurs in the range of 80-90 %.

**320. T. Frączek, M. Olejnik***; Częstochowa University of Technology, Częstochowa, Poland*
**Model of unconventional glow discharge nitriding of technical titanium.** In the work the analysis of the influence of different parameters of the ionitriding process in $H_2 + N_2$ atmosphere on the properties of the surface layer of the technical titanium Ti99.2. It was found that the process of cathode nitriding and use of active screen leads to an increase in the concentration of nitrogen in the surface layer and the relative volume of the nitrides. A factor which determines qualitative and quantitative characteristics of phenomena which occur in the presence of the active screen is high concentration and high level of energy of nitrogen ions which interact with base material during nitriding.

**321. R. Samur;** *Marmara Üniversitesi Teknik Eğitim Fakültesi Metal Eğitimi Bölümü, Istanbul, Turkey*
**Effect of heat treatment on the wear and corrosion behaviors of a gray cast iron coated with a Colmonoy 88 alloy deposited by HVOF thermal spray.** The present work has been conducted in order to determine the influence of the heat treatment, on the wear and corrosion behaviors of a gray cast iron substrate coated with a Ni base coating deposited by high velocity oxygen fuel (HVOF) thermal spray. The coefficient of friction and wear resistance of coatings were obtained using a reciprocating wear tester by rubbing a 10 mm diameter steel ball on the coatings at normal atmospheric conditions. Corrosion tests were performed by potentiodynamic polarization measurements in a 3 wt.% NaCl solution. It is observed that different wear and corrosion behaviors take place in the coatings obtained by the diverse processes.

**1. B. Karpe, B. Kosec, T. Kolenko, M. Bizjak;** *University of Ljubljana, Slovenia*
**Heat transfer analyses of continuous casting by free jet meltspinning device.** New method for determining contact resistance through variable heat transfer coefficient is introduced which takes into account physical properties of the casting material, process parameters and contact time/length between molten material (melt puddle) and chilling wheel and enables cooling rate prediction before experiment execution. From the results can be concluded, that those process parameters which determine the thickness of the melt puddle in the downstream and consequently the ribbon thickness have major influence on cooling rate of the ribbon. In the case of continuous casting, heat balance of the wheel is calculated and influence of the chill wheel cooling mode on cooling rate of metallic ribbon is analyzed.

**2. B. Oleksiak, L. Blacha;** *Silesian Technical University, Katowice, Poland*
**Kinetics of lead removal from the Cu-Pb-Fe alloy by barbotage with inert gases.** Discussion of the of kinetics of lead removal from the Cu-Pb-Fe alloy by barbotage with argon and helium. The values of the mass penetration coefficient for the liquid and solid phase as well as the mass transfer coefficient were calculated for the temperatures of 1 473 K and 1 548 K, and for the gas flow rate of $5{,}55 \cdot 10^{-6}$, $6{,}94 \cdot 10^{-6}$, $8{,}33 \cdot 10^{-6}$ and $9{,}72 \cdot 10^{-6}$ $ms^{-1}$.

**3. Z. Gulišija, A. Patarić, M. Mihailović;** *Institute for Technology of Nuclear and Other Raw Materials, Belgrade, Serbia*
**The possibility of increasing production efficiency of al alloys applying electromagnetic field.** The relationships between electromagnetic frequency, microstructure and mechanical properties of continuous casting aluminum alloys were studied in this paper. EN AW 2024 and EN AW 2007 aluminum alloys ingots were produced by electromagnetic continuous casting process. The microstructure and mechanical properties of as cast ingots were examined. The results showed that electromagnetic field, especially low frequency electromagnetic field, greatly influenced the microstructure and mechanical properties of as cast ingots. The significant energy savings and product quality can be achieved by the application of a proper frequency.

**4. B. Oleksiak, G. Siwiec***; Silesian Technical University, Katowice, Poland*
**Removal of lead from the industrial and synthetic Cu-Pb-Fe alloy with argon barbotage.** Results of research on removal of lead from synthetic and industrial Cu-Pb-Fe alloy with argon barbotage are presented. For examinations was taken a synthetic alloy and industrial alloy coming "Glogow II" Copperworks. As basic research equipment was used a pipe resistance furnace enabling heating of samples up to 1 473 K. Examinations were made in 2 test series. The 1 series was performed on the synthetic alloy, while in 2 series was used an industrial alloy. All series were conducted at 1 473 K and with gas flow $5{,}55 \cdot 10^{-6}$, $6{,}94 \cdot 10^{-6}$, $8{,}33 \cdot 10^{-6}$, $9{,}72 \cdot 10^{-6}$ $m^3 \cdot s^{-1}$.

**5. P. Bigoš, J. Kuľka, M. Mantič, J. Čurilla***; *TU, Košice; *U.S.Steel, s.r.o. Košice, Slovakia*
**Continual Measuring of Local Stress Values on Shell of the Blast Furnace Hearth and of Total Shell Expansion.** This paper deals with installation of strain gauges on the external surface of the blast furnace shell in two rows, whereas there will be defined 8 measuring points in every row. The final result is evaluation of data obtained during up to 45 days of the operation. In this papers are commentary and discussions to measured time behaviours. The main purpose of this measuring was investigation of impact of salamander on blast furnace shell expansion after its lay off, cooling and next starting of operation.

**6. G. Fedorko, A. Pribulová*, P. Futáš*, D. Baricová*, P. Demeter***; *Technical University of Košice, Slovakia*
**Compacting of fly dusts from cupola and electric arc furnace.** Dust emissions arise from thermal and chemical or physical processes and mechanical actions. Two kinds of fly dusts from cupola furnaces (hot and cold blast cupola furnace) and fly dust from electric arc furnace were used by experiments. They were pelletized only with addition of water and briquetted with different addition of water glass, bentonite and cement.

**7. R. Przyłucki, S. Golak, B. Oleksiak, L. Blacha***; Silesian Technical University, Katowice, Poland*
**Influence of an induction furnace'selectric parameters on masstransfer velocity in the liquid phase.** This article is an analysis of the results obtained under the tests aimed at determination of the influence exerted by the current frequency of an induction furnace on the mass transfer coefficient for liquid metallic phase.

**8. A. Samolejová, R. Lenort, P. Besta, J. Feliks***; *VŠB – Technical University of Ostrava, Czech Republic; *AGH University of Technology and Science, Cracow, Poland*
**A hybrid decision support system for iron ore supply.** The objective of this article is to design the decision support system for iron ore supply which would efficiently reduce uncertainty and risk of that decision-making. The article proposes a hybrid intelligent system which represents a combination of different artificial intelligence methods with dynamic simulation technique for that purpose.

**9. B. Oleksiak, A. Blacha***; Silesian Technical University, Katowice and Gliwice, Poland*
**Study of silver removal from scrap jewellery by way of the flotation process.** This article is a discussion on the proposed solution of using the flotation process to separate metals from non-metallic components present in the scrap generated while jewellery goods are being ground. For the sake of the studies analysed, a dedicated laboratory station was established.

**10. E. Ragan, J. Dobránsky, P. Baron, T. Olejár***; Technical University in Košice, Prešov, Slovakia*
**Materials on dies for pressure die casting.** In the contribution the stress of die materials of thermal fatigue is defined and material life is derived theoretically and compared with the measured values. The important properties of the die materials as thermal conductivity, coefficient of thermal expansivity, modulus of elasticity and mechanical properties are described. Binding to it single die materials as carbon steels and chrome-tungsten steels are analyzed. As the perspective die material for pressure die casting of ferrous metals appears molybdenum with regard to advantageous properties.

**11. T. Lis, K. Nowacki***; Silesian Technical University, Katowice, Poland*
**Options of utilising steelmaking dust in a non-metallurgical industry.** Recycling of by-products of the steelmaking process in electric arc (EAF) furnaces is an important activity from the perspective of environmental protection as well as the steelmaking industry itself. This article is a discussion concerning the selected research results in terms of utilisation of steelmaking dusts containing 4 - 12 % of zinc in manufacture of cement bricks, ceramic construction materials as well as coloured glass products. The research conducted has implied that using steelmaking dusts in non-metallurgical industries is both possible and reasonable.

**12. D. Burchart-Korol, J. Korol, P. Francik***; *Central Mining Institute; *Czestochowa University of Technology, Poland*
**Application of the new mixing and granulation technology of raw materials for iron ore sintering process.** This paper presents a new technology for preparing the mixture for iron ore sintering process. The nature of component mixing and granulation has been discussed. The application of the intensive mixer in the preparation of the process components has been shown. The results of the analysis of the sintering mixture granulation process using laboratory installation for mixing and granulation have been presented.

**13. J. Chen, H. F. Sun, W. M. Lin, Y. L. Shi*, G. L. Yi***; *Taiyuan University of Technology, China*
**Gravitational segregation of liquid slag in large ladle.** The process of gravitational segregation makes liquid steel slag components occur differentiation. And it shows that the upper part slag in the slag ladle contains higher CaO; and the lower part slag contains higher $SiO_2$. The content of MgO (5,48 %) in the upper part slag is higher than that of the lower part (2,50 %), and only $Al_2O_3$ content of the upper and the lower part slag is close to each other.

The difference of chemical compositions in the slag ladle shows that there is gravitational segregation during slow solidification of liquid steel slag, which will has some impact of the steel slag processing on the large slag ladle.

**14. K. Janovská, Š. Vilamová, P. Besta, A. Samolejová, E. Švecová, I. Vozňáková***; VŠB – Technical University of Ostrava, Czech Republic*
**Analysis of energy demandingness of metallurgical production.** The article suggests the possibility of using methods of structural analysis to calculate the direct and complex consumption and, on the basis of this calculation, are can determine the energy demandingness of the individual metallurgical technologies.

**15. R. Pyszko, M. Příhoda, P. Fojtík, M. Kováč***; Technical University of Ostrava, Czech Republic*
**Idetermination of heat flux layout in the mould for continuous casting of steel.** The paper deals with research of the heat transfer in the mould of continuous casting and the thermal boundary condition determination using combination of measurement and the inverse technique of numerical simulation. Layout of the heat flux at the mould working surface is derived by the original experimental and numerical simulation procedure, using the software package Procast. A database of the heat flux layouts was built for various values of casting speed and steel chemical composition for purpose of determination the boundary condition for on-line modelling.

**16. J. Kijac, R. Sladíková, B.Buľko, T. Borovský***; Faculty of Metallurgy, Technical University of Košice, Košice, Slovakia*
**The nitrogen content management in the oxygen converter steelmaking.** The influences of individual elements on the properties of solution of nitrogen in the metal bath, on the process of nitrogen dissolution in connection with decarburisation process and also influences of some important factors on the possibilities of nitrogen regulation during the refining period were investigated in this work. The path for production of steel with regulated nitrogen content relies on the combination of knowledge of nitrogen thermodynamics, mechanism and kinetics of nitrogen sorption and desorption, together with possibilities of steel melt properties prediction and also with metallurgical actions leading to the control of required chemical composition.

**17. P. Besta, A. Samolejová, K. Janovská, R. Lenort, J. Haverland***; Technical University of Ostrava, Ostrava, Czech Republic*
**The effect of harmeful elements in production of iron in relation to input and output material balance.** The main objectives of blast-furnace operators include maximum production of pig iron of required chemical composition at minimal cost. This can be ensured only in case of quality raw material basis and trouble-free operation of blast-furnace. Both parameters are influenced by the concentration of undesirable elements. These are mainly heavy metals and alkaline carbonates. The article deals with the analysis of material balance of zinc and selected alkaline carbonates contents in the input raw materials and output products of the blast-furnace.

**18. A. A. Minea***; Technical University gh. Asachi Iasi, Romania*
**Experimental and numerical simulation analysis of heat transfer on a closed enclosure.** The main objective of this work was to evaluate the behavior of an oval heated closed enclosure, when variable radiant panels were introduced. The experimental investigation showed that their efficiency was depending on their position. An experimental investigation, as well as numerical simulation was carried out. The experimental findings were also compared to the simulation results and a reasonable agreement was observed. Finally, based on the results of this study, a correlation was developed to predict the inner configuration for heat transfer enhancement of an oval furnace.

**19. M. Martinez-Hernandez, A. Juarez-Hernandez, M. Ayala Vera, J. Ayala-Cazares, M. Hernandez-Rodriguez***; Universidad Autónoma de Nuevo León, México*
**Optimization of the investment casting process.** Rapid prototyping is an important technique for manufacturing. This work refers to the manufacture of hollow patterns made of polymeric materials by rapid prototyping technologies for its use in the preparation of ceramic molds in the investment casting process. This work is focused on the development of a process for manufacturing patterns different from those that currently exist due to its hollow interior design, allowing its direct use in the fabrication of ceramic molds; avoiding cracking and fracture during the investment casting process, which is an important process for the foundry industry.

**20. B. Gajdzik, R. Wieszala***; The Silesian University of Technology, Katowice, Poland*
**Measurements of the communication noise level on the internal roads of the manufacturing metallurgical enterprise.** This publication shows the results of measurements of the noise level emitted by the motor trucks on the internal roads of the steelworks. The research was conducted on one of the busiest internal roads of metallurgical enterprise ArcelorMittal Poland in Dąbrowa Górnicza. The enterprise conducts the whole production cycle and is the biggest steel producer in Poland. On the premises of the steelworks there were five points of measurements marked where the noise level is measured and the results were compared with the acceptable noise levels defined in the norms.

**21. A. Haxhiaj, E. Haxhiaj****; University of Prishtina; *American University in Kosovo, Republic of Kosovo*
**Optimization of the melting process of electrical furnaces in drenas.** Roasting of charge which consists of Drenas and Albanians ore is done at about 950°C. Also, article has the experimental analyses that modify some parameters of the production which are the reduction of quantity of limestone and the increase of quantity of quartz in the charge. The paper analysis the possibility of mixing the ore from Kosova with lateritic ore from Albania with the aim of reducing the acidity of weight which is loaded in the electrical furnace. The composition of the furnace must satisfy the ratio 1:10 of ore from Kosova and Albania.

**22. D. Golubović, P. Kovač*, M. Gostimirović*, V. Pucovsky*, D. Ješić*****; Faculty of Mechanical Engineering, East Sarajevo, BIH; *University of Novi Sad, Serbia; **University of Banja Luka, Bosnia and Herzegovina*
**Wear intensity of diferent heat treated nodular cast irons.** In the paper we investigate the relationship between the wear intensity of two nodular cast irons and their heat treatment conditions. Disks tempered by austempering and isothermal procedure were used. The wear test was realized by using Pin and Disk tribometer. Measurement of the disks wear, after the contact for duration of 30 min, was done by the PQ meter. The quantity of the wear products in lubricant is determined by the PQ index. The best wear resistance posses the disk isothermally tempering with 30 minutes holding at 390 °C temperature.

**23. B. Oleksiak, G. Siwiec, A. Blacha – Grzechnik****; Silesian University of Technology, Department of Metallurgy, Gliwice and Katowice, Poland*
**Application of the flotation process in the silver recovery from the wastes generated during the silvery semi-products manufacturing.** In this work, the results of the flotation process application in the silver recovery from the wastes generated during the silvery semi-products manufacturing, are shown. The flotation process parameters, i.e. time of process, rotation frequency, gas flow rate and flotation reagents, were optimized.

**24. C. Kolmasiak***; Czestochowa University of Technology, Czestochowa, Poland*
**Kinetics of chromium evaporation from heat-resisting steel under reduced pressure.** This paper describes a kinetic analysis of the process of chromium evaporation from ferrous alloys smelted under reduced pressure. The study discussed comprised determination of the liquid phase mass transfer coefficient as well as the value of the constant evaporation rate. By applying these values as well as the values of the overall mass transfer coefficient estimated based on the relevant experimental data, the fractions of resistance of the individual process stages were established.

**25. Blacha L., Łabaj J.***; Silesian University of Technology, Katowice, Poland*
**Factors determining the rate of the process of metal bath components evaporation.** This paper provides a discussion on the impact of selected factors on the rate of the process of evaporation of volatile metal bath components. The main determinants of the evaporation process are considered to be the pressure inside the metallurgical aggregate, type of the gaseous atmosphere, rate of the bath mixing as well as its composition.

**26. O. P. Vasilega, N. I. Grechanyuk, V. G. Zatovskyi;** *I. N. Frantsevich Institute for Problems of Materials Science, Kiev, Ukraine*
**Obtaining Alloy Powder CoCrAlYSi by Duplex Technology.** The aim of this paper is obtaining alloy powder Co-(20 – 30 % mass.)Cr(8 – 14 % mass.) Al(0,5 – 1,8 % mass.)Y(2 – 4 % mass.)S, by duplex technology. Chemical composition of the powder was obtained in different region of the powder, by the assist dispersion analyzer. The content of the oxygen in powder is 0,08 % mass., what less then in powder obtained by another methods obtaining powder, such as, atomization.

**27. L. A. Rokhlin, D. I. Matrosov, I. Mamuzić*;** *Kurdumov Institute for Physics of Metals, Kyiv, Ukraine; *CMS, Croatia*
**Effect of Microsegregation on Quantity and Morphology of Secondary Phases During Solidification of Al-Fe-Si Alloys.** The effect of varying solidification conditions and evolution of solute element distribution on the microstructural evolution of Al-Fe-Si alloys has been investigated. Microsegregation calculations show that solute distribution in α-Al will influence the Fe/Si ratio in the liquid at the onset of the eutectic reaction.

**28. A. D. Grechukha, K. L. Prishvin, G. I. Podobed;** *State University of Railway Transport, Depropetrovsk, Ukraine*
**Influence of Aging on Quality index of an Al–Cu Casting Alloy.** When the Al–Cu casting alloy AL16 is aged, a plot of the tensile strength versus the elongation to fracture follows a circular pattern. This is in contrast with Al–Si–Cu alloys, which show a linear relationship between the two parameters when aged. The circular pattern shown by the quality index results from the transition from the high Q value of the underaged condition to the low Q value of the overaged condition.

**29. M. I. Shpak, L. F. Volnenko;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine*
**Metallurgy of Ultralow Carbon Bake Hardening Steels.** Classical strain aging theories still have relevance to modern ultralow carbon chemistries, although the drastically reduced carbon contents of these steels can influence the kinetics observed during bake hardening. Further research into the influence of processing conditions on the metallurgy of these steels is required if they are to be successfully produced in industrial conditions.

**30. M. A. Bushuev, J. S. Zusman;** *National Technical University "KhPI", Kharkiv, Ukraine*
**Evolution of Microstructure in Continuous Casting of Nickel Based Superalloy EI652.** The evolution of microstructure in the nickel based superalloy EI652 was investigated for the vertical continuous casting of small cross-section rods (10 mm dia.), using several microstructural characterisation techniques. A physical model is presented to explain the influence of casting parameters on microstructural evolution on the continuous casting of this alloy.

**31. V. V. Karpov, V. U. Karpov, I. Vitez*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Reception of cast porous alloys – gazers.** It is necessary to consider that at crystallization the ingot of gazar increases in volume, there is liberation of gas. Constant contact of a liquid phase of crystallizing metal with a gas phase is thus necessary. For reception of the set structure gazar it is necessary to provide the directed heat-conducting path from liquid metal.

**32. V. V. Karpov, S. I. Gubenko, V. U. Karpov;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Features of destruction gazars.** The plastic current of metal leads to a bend of an initial surface of a pores, there are sliding lines. In places of crossing of systems of sliding, there are micro cavities. Near to micro cavities cracks that promote viscous destruction of crosspieces, origin of the main crack and to destruction gazars at loadings develops.

**33. Sv. Gubenko, R. Križanić;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Melting and crystallization of non-metallic inclusions under laser treatment of steels.** Mechanism of melting and crystallization of non-metallic inclusions in contact with steel matrix during laser treatment was investigated. It was shown this processes are connected with abnormal mass transfer in hyper-nonequilibrium conditions, formation areas with big dislocation density, and also electonic and electomagnetic interaction between nonmetallic inclusions (normal, nanophase, quasieutectic) and steel matrix.

**34. R. V. Kiriya, D. D. Braginec, D. Tkalčić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Adaptive control by an usrednyayushim bunker working in the conditions of coal mines.** The task of adaptive control by an usrednyayushim bunker working in the mode of maintenance of protective layer of load in a bunker is put and decided. The algorithm of adaptive control by an usrednyayushim bunker working in the conditions of mountain enterprises is got.

**35. L. H. Ivanova, L. A. Shapran, A. J. Hitko, V. I. Shlyapin;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Rare earth metals in cast iron roll.** Individual conformities to the law of influencing of five rare-earth metals – samarium, gadolinium, yttrium, cerium and lanthanum on carbide formation of white and grey cast irons for forming rolls have been established. It enables ground of type of basis of complex modifier with the purpose of achievement of necessary of material of forming rolls.

**36. V. T. Kalinin, N. V. Syslo, I. Vitez*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Studies on the use in the manufacture of iron nano-modifier grinding balls.Application nano-modifier for modifying the production of pig iron grinding balls can improve their hardness and wear resistance due to increase in bleached layers and structure refinement.**

**37. V. I. Masur, S. V. Bondarev, A. S. Svetlichnaya;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Formation Of Structure And Properties Of Permanent Mold Castings Of Binary Al-Si Alloys During Solidification Under The Melt Flow Conditions.** Castings of binary Al-Si alloys with silicon content 1…21 wt % were produced by fast-filling bottom-poured chill. The influence of temperature, exposure time of the melt in the furnace and the usage of particular extension within the special method of casting on the structure formation of the castings was determined.

**38. V. V. Gnatushenko, A. A. Kavats;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine.* **Modeling of object extraction from digital photogrammetrical images very high resolution.**
**In this paper a methodology and results of object extraction from an photogrammetrical images, is introduced.** The main novelty of this paper is the use of a high number of geometric image features which allows to characterise several classes of objects with different geometric properties using a supervised learning approach.

**39. A. A. Zhegur, S. I. Repyakh*, J. Šipalo Žuljević**;** *"Research and Technical Enterprise" New machines and technology ", Dnepropetrovsk; *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; * *CMS, Croatia*
**On reducing the cost of preparation of ceramic shell molds for casting.** The most promising avenue for reducing the cost of the preparation of ceramic shell molds for casting is the use of special thin ceramic shell molds made on the basis of quartz sand and glass of liquid.

**40. J. Paniotov, V. Mameshin, A. Gritsenko, S. Zhyravleva;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Simulation the side bath blowing slag opposite jets.** The simulation of the horizontal blowing opposite jets of gas under the liquid level was conducted. It was defined that at small values of the impulse of jets, each of which forms the individual cell circulation with formation downstream of the central zone. Based on the simulation results can provide an optimal scheme of filing the charge materials.

**41. A. Petrenko, V. Shatokha, I. Sokolovskaya;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**A study on the kinetics of reduction of composite pellets.** Reduction of composite pellets, containing iron ore material and coal was studied by using thermogravimetry method. The data on the Arrhenius triplet have been obtained for different coal grades. Effect of coal to ore ratio on the reduction process was also studied. Obtained results allow for the optimisation of the pellets composition as well as for selection of types of solid fuel, suitable for production of studied material.

**42. M. A. Rybalchenko, V.I.Golovko, A.A.Verkhovskaya;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Forming of charge on a conveyer with the use of wavelet-analysis of radio-location signal.** Spectrology of signals applied presently with the use of fast Fourier transformation (FFT), appears effective not enough in the task of operative determination of level of material on a conveyer, as time of treatment in every point of measuring of 2,5-3s and conveyer for this time will pass 5-6m (distance between the craters of 18m, speed of moving of conveyer of 2m/s). Next step for the increase of speed of calculation of wavelet spectrum is development of parallel algorithm.

**43. R. V. Usenko, D. Tkalčić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Viscosity phosphate slurry to produce ceramic shell molds.** The results of the research is based mathematical model to the value of the relative error of 2,5% to calculate the viscosity of the conditional suspension prepared on the basis of phosphoric acid and ash Dnieper power station.

**44. S. I. Repyakh, I. Mamuzić*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk; *CMS, Croatia*
**Wax model for casting.** The effect of wax casting, casting ceramic shell mold and metal alloy on the accuracy of size, curvature and surface roughness of the casting. It is established that the influence of equity dimensional accuracy of wax patterns cast on the accuracy of the sizes made of them thin-walled castings, 50 ... 75%. The most high and stable dimensional accuracy, minimum distortion and low surface roughness of the least observed in castings made of wax, containing not less than 40 ... 50% by volume of material with amorphous structure.

**45. M. A. Rybalchenko, V. I. Golovko, N. Devčić*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk; *CMS, Croatia*
**Management features by the processes of mixing of materials on a conveyer.** The executed analysis of efficiency of processes of forming of portions showed that actual task of management mixing of components of charge on length of portion in complete not decided for lack of operative information about the process of forming multicomponent portions.

**46. O. S. Naumov, G. V. Fomenko*, D. Ćurćija**;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine, *SHEI «Ukrainian State Chemical-Technological University», Dnepropetrovsk, Ukrain; **CMS, Croatia*
**Working out of structures of astringents compositions with use of a waste of a metallurgical complex.** Research work is directed on working out of structurally of astringents compositions hydraulic, air and autoclaved hardening, including a waste of a metallurgical complex. As a result of work possibility of use of the specified waste in compositions of cement, concrete, gypsum and a silicate brick is established, and also their optimum dosages are defined.

**47. I. V. Golub, Y. A. Onasenko, D. E. Sedov***; National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**Modeling of the production of refractory products.** For optimization of manufacturing the refractory products it has been proposed to use the methods of simulation, the errors of which are less than 1%. Using a model in the research allows to optimize the duration of the technological process, to reduce the number of defective products and improve the control over the bottlenecks while producing new refractory products.

**48. B. M. Bojchenko, K. G. Nizjaev, A. N. Stojanov, L. S. Molchanov;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk*
**New technologies of the converter processes.** Technologies of authors are modernized with the increased expense of scrap due to new two-stage lance. Mathematical models are created with the programmable bringing of heat-carrier. Exact composition of cast-iron and steel is provided in a ladle by renewal of elements from oxides by means of electric arc.
**During the campaign of converters by turns the different lance for blowing out was used, their firmness is increased up to 1000 melting.**

**49. K. G. Nizjaev, B. M., Bojchenko, A. N. Stojanov, L. S. Molchanov;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**Development of initial composition mix for the receipt of SHS-refractoriess.** Results of the thermodynamic analysis of aluminium-thermal SHS-processes course are presented. The terms of their flowing are determine. The method of initial mix calculation is developed for the receipt of SHS-composites. The opportunity of MgO application as inert additive is considered by the production of SHS-composites. The calculation of compositions of initial mixes is conducted for the receipt of SHS-refractories in the systems $Al_2O_3$-$TiB_2$, $Al_2O_3$-BN, $Al_2O_3$-VN, $Al_2O_3$-$TiB_2$-BN, $Al_2O_3$-VC.

**50. K. G. Nizjaev, B. M. Bojchenko, A. N. Stojanov, L. S.Molchanov;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**Calculationof charge composition for the production of exothermic magniferous briquettes.** It is confirmed by information received at the analysis of the deterioration refractories mechanism. The calculation of charge composition is executed for the production of exothermic briquettes, intended for desulfuration of pig iron. It is shown, that an expense of briquettes in relation to pig iron in a 120 tons ladle is in limits from 2.6 t to 1,45 t or from 0,022 to 0,012 kg/t of liquid metal.

**51. B. M. Bojchenko, K. G. Nizjaev, A. N. Stojanov, L. S. Molchanov, I.V.Sinegin;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**The slag modes comparison of actual technologies of the converter melting.** Four possible technologies of the converter melting conducting are considered: ordinary technology, littleslag technology, technology with remaining in the converter of final slag and flush-off intermediate, technology with remaining of half of final slag, without a flush-off intermediate. It is determine, that the most rational technology is the technology with remaining in the converter of final slag and flush-off of intermediate. This technology provides the best indexes of melting.

**52. B. M. Bojchenko, K. G. Nizjaev, A. N. Stojanov, I. V. Sinegin;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**Research of slag fusion conductivity with the purpose of study the possibility of influence on refractories and slag interaction process.** The made researches confirmed the main ideas of the ionic theory of slag fusions structure that with the increase of temperature the fusion conductivity of slag rises practically evenly on all areas except a small expulsion. The received results confirm a possibility of electric influence on system for regulation of electrochemical reactions processes proceeding on the border of refractory-slag.

**53. B. M. Bojchenko, K. G. Nizjaev, A. N. Stojanov , I. V. Sinegin;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**The influence of the electricity on resistance refractory to slag.** The experiment was successfully made in order to receive value of amperage and voltage need for increasing resistance of refractory. This method allows essential raise resistance of refractory.

**54. L. V. Kamkina, Y. V. Stovba, R. Križanić;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Physico-chemical analysis of nonequilibrium phase interactions in obtaining high-carbon ferromanganese.** At treatment of arrays given is there a function of exp at smelting of carbon ferromanganese $\Delta G/RT$ related to maintenance of leading element in a metal - Mn. At stationary motion of process size of the system a metal-slag on elements is saved. On this basis the actual (non-equilibrium) coefficients of distributing of elements are expected between a slag and metal. With their use worked out balance equations and used for the construction of static mathematical model. A design is conducted and set row of factors which influence on the booty of manganese.

**55. M. I. Gasik, V. L. Zubov, J. Šipalo Žuljević;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Problem questions of physics and chemistry of the concentration of radionuclides in the slag charging materials smelting ferrosilicon.** The effective specific activity of Ra-226, Th-232 and K-40 radionuclides in charging materials and casting products of FS65 ferrosilicon was defined, the results were summarized; radiation and heath safety estimation of ferrosilicon slimes was presented in accordance with radiation safety standards; the method of defining slag multiplicity as well as managing certain technological parameters of ferrosilicon casting using the data on radionuclides' effective activity were presented.

**56. M. I. Gasik, A. I Panchenko, A. S. Salnikov, A. V. Zhadanos;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Investigation of changes in the oxygen content of bearing steel ШХ15СГ-В during secondary treatment at the facility of its electric furnace ladle-oxide-fluoride slags.** The basic provisions of the authors developed an innovative technology of the bearing of electric ШХ15СГ-В, and the results of calculating the activity of the components of the oxide-fluoride slag melts on the theory of AG Ponomarenko when processing the metal in the ladle furnaces with double fire refining slag of lime and fluorspar.

**57. D. A. Kovalev, N. D. Vanyukova, M. V. Yagolnik, A. U. Hudyakov;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Study of process of drying pellets containing a carbon .Drying of iron-ore pellets, containing a hard fuel was investigated experimentaly.** Mathematical description of process was conducted and models (polynomials), which describ dependence of duration of drying and quality of dried up pellets

on maintenance of hard fuel, bentonite and temperature of drying, are got. The graphic and analytical analysis of influence of the indicated factors is executed on the basic technological parameters of process of drying of ore-fuel pellets.

**58. D. A. Kovalev, A. P. Popovskaya, M. V. Yagolnik;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Investigation of the strength of briquettes from mill scale, cement-bonded.** The major objective of this work is to develop cold bonded briquetting technology to use the recycling of mill scale. The influence of humidity on the strength of cold bonded briquettes, using cement as binder, was studied experimentally. The test results indicate that cold bonded briquette strength 5,78 MPa is feasible at levels of humidity up to 6.% of the total charge weight.

**59. M. O. Matveyeva, A. A. Makarova, N. V. Dvornikova;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Formation ofhigh-carbonphasesin cast ironalloyed manganese.** The object of study in this work were cast iron, alloyed manganese in an amount from 1,4 to 3,10% and the processes of structure in them. Increasing the content manganese in the iron cast contributes to supercooling. It leads to a change shape and size of inclusions graphite from lamellar to interdendritic, and then to the formation of cementited eutectic. An increase in branching of graphite at increase over its content needed to neutralize the influence of sulfur.

**60. M. O. Matveyeva, B. V. Klimovich, V. V. Klimovich;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Influencethe qualityof the burden andparameters of melting on the structure andpropertiesof cast iron.** Take into consideration many-factors of process receive of casting alloyed. Results is present about investigations of study hereditary of binding between king using alloying composition and structure of cast iron, and also influence of process smelting and temperature of overheating on structure and property of cast. It is established that the speed of structural change in multicomponent melts are not large, melts are characterizes by persistence over a long period of microscopic ordered regions.

**61. S. I. Gubenko, V. N. Bespalko, E. V. Zhilenkova;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Influence of thermoplastic impact on the modification of borides phases in the high-chromium steel used in nuclear power.** Studies have shown that during hot deformation the diffusive interaction with the matrix of borides leads to a change in not only form but also in the structure of borides, which may further the localization of tension in the particles and their destruction.

**62. A. G. Velichko, M. A. Rybalchenko, V. I. Golovko, O. N. Kukushkin, A.A. Verkhovskaya;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Wavelet-analysis in the tasks of control of metallurgical production.** For the decision of task of operative control of level of material in a metallurgical production the traditional method of fast Fourier transformation appears not effective. The new method of calculation of distance is offered to the purpose, based on continuous wavelet-transformation, allowing to conduct the effective spectrology of radio-location signal short undulating functions.

**63. N. P. Rudenko, J. Šipalo Žuljević*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Kinetics of cathode processes on iron and steels in acid etchant.** The analysis of cathode processes on iron and steels in $H_2SO_4$-$FeSO_4$ systems in temperature interval of 25 – 50°C has shown that total cathode process rate is determined by set of equations of independent partial reactions such as hydroxonium ion discharge, ferro-ions electric precipitation and iron ionization by chemical mechanism.

**64. I. A. Solov`eva, V. S. Tereschenko, A. S. Golubitsky, O. V. Sergeeva,m D. Tkalčić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Prediction planned targets extended periods of melting.** The technique of determining planned targets of time filling and melting to improve the reliability prediction process in an electronic scheduling system portfolio. A program that implements this technique, developed by analyzing the current production of open-hearth shop. Computer program for calculating the time of production processes open-hearth shop integrated into the program scheduling of open-hearth shop.

**65. A. Štrkalj, Z. Glavaš, V. Mikulić;** *University of Zagreb, Faculty of Metallurgy, Sisak, Croatia*
**Methods of wastewater treatment in metallurgical industry.** Water that had been used for a specific purpose, and thereby collect additional pollution that caused a change in their physical, chemical and biological properties is called wastewater. There are numerous processes that can be used to clean up waste waters depending on the type and extent of contamination. Most wastewater is treated with primary, secondary and tertiary treatment processes. Wastewater is generated in metallurgical industry, resulting in the blast furnace, the steel-works, foundry, rolling mill and at other facilities. Wastewater is treated by the primary and secondary procedures.

**66. Z. Glavaš, A. Štrkalj;** *University of Zagreb, Faculty of Metallurgy, Sisak, Croatia*
**Modelling of microstructural features and mechanical properties of ductile iron by using artificial neural networks.** This paper presents the application of artificial neural networks in the production of ductile iron. Backpropagation neural networks were established to predict the microstructural features (ferrite and pearlite content, nodule count, graphite nodularity) and the as-cast impact toughness of ductile iron castings using the thermal analysis parameters as inputs. The generalization properties of the developed artificial neural networks are very good, which is confirmed by a very good accordance between the predicted and the targeted values of the microstructural features, i.e. as-cast impact toughness, on new data sets that were not included in the training data sets.

**67. C. Kolmasiak, Z. Skuza;** *Częstochowa University of Technology, Częstochowa, Poland*
**Behaviour of coal in smelting reduction process.** New methods of the pig iron production without coke are developed. In these methods various kinds of coal replace the coke. The full substitution of coke by coal is feasible only in an installation other than a blast furnace. Various publications, advertising these methods emphasize that every quality of coal can be used. In reality the suitability of each applied coal must be investigated. In the presented work such' investigations are described. Besides the ash content, humidity and volatile matter content, influencing the calorific value, some properties of the coal occurring during heating, can cause various difficulties.

**68. Z. Skuza, R. Prusak, C. Kolmasiak;** *Częstochowa University of Technology, Częstochowa, Poland*
**Characteristics of iron and steel industry in terms of membership in the European Union.** This article presents an attempt to analyze the impact of global conditions on the functionality of the steel industry country - a member of the European Union. The paper presents data describing trends and phenomena occurring in the global steel industry, and selected economic indicators describing the economic situation, which allowed the comparison of local changes with the trends disclosed in European and global scale.

**69. V. Grozdanić***; University of Zagreb, Sisak, Croatia*
**Modelling of solidification of Al-slab cast with DC method.** On the basis of mathematical model a new equation for temperature distribution in AlMg4,5Mn0,7 - slab cast with vertical DC (Direct Chill) method in zone of cooling by spraying with water is obtained. From this equation the time of cooling of surface to selected temperature can be deduced. The model is verified using program package ProCast.

**70. P. Popovich, S. Sikorskyi;** *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
**Experimental kinetic investigation of the fatigue cracks development of steelwork in ammonia water.** The research deals with the kinetic investigation of the fatigue cracks development in the parent metal and welded carbon constructional steelwork. Experiment took place in corrosive environment which encloses aqueous solution of N - 0,50%, P - 0,25% i K 0,60%. The results of crack resistance of cyclic model taken from the parent metal are compared with the metal samples of heat-affected zone in ammonia water. So, the outcome of experiment is the following: $K_{fc}$=67MPa·$M^{1/2}$; $K_{th}$=11MPa·$M^{1/2}$; $K_{fc}$=64MPa·$M^{1/2}$; $K_{th}$=14MPa·$M^{1/2}$.

**71. T. Rybak, P. Popovich, S. Sikorskyi;** *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
**Interaction modeling of fine-dispersed free-flowing environment with vertical spiral steel surfaces.** The article deals with analytical investigation of interaction of vertical spiral steelwork with the fine-dispersed free-flowing environment. Mathematical models of motion of elements in the environ-

ment including a function of weight, inclination and reference frequency in three-dimensional space are offered. The geometrical and constructional properties of the interaction for optimal machine-building design are determined.

**72. B. Karpe, B. Kosec, I. Anžel*, B. Markoli, M. Bizjak;** *University of Ljubljana, Ljubljana, Slovenia; *University of Maribor, Maribor, Slovenia*
**Mathematical modeling of heat transfer phenomena in free jet melt spinning process.** An inovative mathematical model of heat transfer in free jet melt spinning process of metallic materials is developed. The calculations show that contact resistance between metal melts and substrate has a great influence on calculations of melt cooling and wheel heating rate, and mast not be neglected, even if its value is very low. In our model, new method for determining contact resistance through variable heat transfer coefficient is introduced which takes into account physical properties of the casting material, process parameters and contact time/length between metallic melt or metallic ribbon, and substrate, respectively, and enables cooling and solidifying rate prediction before the experimental execution.

**73. B. Kosec[1], S. Senčič[2,1], B. Karpe[1], H. Schwarzova[3], I. Budak[4], A. Nagode[1], R. Rudolf[5], J. Hodolič[4], M. Soković[1];** *[1] University of Ljubljana, Ljubljana; [2] KOVA d.o.o., Celje; [3] University of Central Europe, Skalica, Slovakia; [4] University of Novi Sad, Novi Sad, Serbia; [5] University of Maribor, Slovenia*
**Waste Management in Foundries – Case Study.** In the last years waste management in foundries is gaining a higher ecological and economical importance. Waste is becoming an increasingly traded product, where excellent profits can be made. Due to the cost reduction and successful business operation in companies, waste has to be regenerated and used again as a material to the maximum possible extent. Such research is long lasting and expensive and it is, at the same time, a great challenge for companies. In the frame of our research, a case study of waste management in the testing Slovenian foundry was carried out. The testing foundry was awarded with certification of the environmental management system according to the standard ISO 14001 and confirmed its environmental credentials.

**74. B. Kosec[1], J. Zaletel[2,1], M. Bizjak[1], H. Schwarzova[3], I. Budak[4], M. Soković[5];** *[1] University of Ljubljana, Slovenia; [2] Post Office Ljubljana; [3] University of Central Europe, Skalica, Slovakia; [4] University of Novi Sad, Serbia; [5] University of Ljubljana, Ljubljana, Slovenia*
**Temperature regime in the shrink wrapping machine for printed matters.** The heat losses through the bottom of the heating tunnel for thermal contraction of polyethylene foil is the technical problem in optimising of the shrink wrapping machine for printed matters in the despatch department of the Post Office Ljubljana. The improvement has been achieved by insulating the bottom of the heating tunnel by the insulation plates. On the basis of the temperature measurements, the calculation of heat losses, the limitations due to the construction of the heating tunnel and the warranties, and the requirements of the process itself, the optimal thickness of the insulation plates has been chosen.

**75. H. Kania, K. Nowacki, T. Lis;** *Silesian University of Technology, Katowice, Poland*
**Influence of powder density on liquid slag layer thickness in the concast mould.** In the paper, the results of measurements of the liquid slag layer thickness in the concast mould for different forms of powders of the same chemical composition are presented. The largest thickness of liquid slag layer was obtained for formed mould powders.

**76. J. Łabaj, M. Słowikowski, W. Żymła*, J. Lipart;** *Silesian University of Technology, Katowice, Poland; *l'École Centrale Paris, France*
**The research on reactivity of alternative carbon reducers.** The paper presents the research results of reactivity for three types of reducers which can be used alternatively with coke: soot, anthracite dust and fine coal. The obtained results of thermogravimetric analysis conducted in temperature up to 1 100°C enabled to determine the kinetics of gasification process of carbon materials. The results prove the possibility of application of the tested materials in the selected reduction process for the production of metals.

**77. A. Fornalczyk, M. Saternus;** *Silesian University of Technology, Katowice, Poland*
**Platinum recovery from used auto catalytic converters in electrorefining process.** This paper presents possibility of removing platinum from the used catalytic converters applying copper as a metal collector in pyrometallurgical methods. The catalytic converters carrier was grinded and melted with the copper. During the research Cu-Pt alloy was casted as a cathode. Such cathode was electrically refined in order to recover platinum. Obtained results were discussed.

**78. M. Saternus, A. Fornalczyk;** *Silesian University of Technology, Katowice, Poland*
**Selective purification of PGM metals obtained from hydro- or pyrometallurgical treatment of used auto catalytic converters.** Used auto catalytic converters contain PGM metals such as platinum, palladium and rhodium. After such treatment the solution or metal collector with PGM metals is obtained. In the paper the review of such methods were presented together with their characteristics and main advantages and disadvantages. Classical precipitation, solvent extraction, solid–phase extraction, chromatographic separation, separation of a reduced PGM feed, leaching solutions with reactive extraction are the examples of these methods.

**79. S. Golak, R. Zagorski;** *Silesian University of Technology, Katowice, Poland*
**Model and optimization of electromagnetic filtration of metals.** Electromagnetic buoyancy force causes the movement of non-conducive particles in a conducting liquid under electromagnetic field. The phenomenon allows filtration of small inclusions from molten metals. The paper presents a mathematical model of the filtration process under alternating electromagnetic field and methodology of a maximization of its efficiency. As a result optimal solutions of the filter for liquid aluminum are presented and discussed.

**80. J. Willner;** *Silesian University of Technology, Katowice, Poland*
**Influence of physical and chemical factors on biological leaching process of copper from printed circuit boards.** The article presents the results of the research regarding the biological leaching of this metal from electronic wastes components in the form of printed circuit boards . The purpose of the study was to evaluate the influence of some physical and chemical factors (e.g. pH, oxidation-reduction potential) on bioleaching process and efficiency of copper transfer from solid phase into solution. Bioleaching experiments were carried out with pure cultures of *Acidithiobacillus ferrooxidans.* The obtained results were discussed.

**81. B. Panic;** *Silesian University of Technology, Katowice, Poland*
**Model investigations 3D of gas-powder two phase flow in descending bed with consideration radial distribution of flow. Investigations of physical modeling.** The results of experimental investigations concerning radial distribution of bed particles, powder accumulation in bed and static pressure were presented in this paper. To realize this research physical model of gas-powder two phase flow with descending bed was projected and constructed. In 3D model "static" powder (with its radial distribution) at the tuyere level and in the higher part of bed was measured. The influence of bed particles, powder and gas radial distribution on values of interaction forces between flow phases and phenomena occurring in investigated system was defined.

**82. R. Zagórski, S. Golak***; Silesian University of Technology, Katowice, Poland*
**Modeling of solidification of MMC composites during the gravity casting process.** Gravity casting of the metal matrix composites reinforced with ceramics (MMC) into sand mould is a process gaining in popularity. The paper presents a model of the process taking into account solidification process and its influence on distribution of reinforcement particles. The computer calculation has been carried out in 2D system with the use of Navier-Stokes equations. The Volume of Fluid approach (VOF) and enthalpy method have been used to model the air-fluid free surface (and also volume fraction of particular continuous phases) and the solidification of the cast, respectively.

**83. T. Merder;** *Silesian University of Technology, Katowice, Poland*
**Effect of casting flow rate on hydrodynamic conditions of liquid steel in tundish.** Article presents results of numerical simulation of steel flow and mixing in real two strand tundish working in on of polish steelworks. In calculation different casting flow rates were tested. AnsysFluent code was used for numerical simulation of 3D turbulent steel flow in tundish for steady and transient conditions. As a result of calculation spatial velocity fields and

steel turbulence intensity were obtained. Research was complemented by residence time distribution – typical for analyzed calculated. Whereas basing on F curves the kinetic of steel mixing were estimated.

**84. L. Blacha;** *Silesian University of Technology, Katowice, Poland*
**The loss of alloy components in the melting process of Ti-Al-X alloys in a vacuum induction furnace.** The paper presents the research results which determinate the concentration changes of the basic alloy components in Ti-Al-V and Ti-Al-Nb system in the course of the meling process conducted in the vacuum induction furnace. Harmful phenomenon of aluminum evaporation from these alloys has been observed. The evaporation significantly lowers the properties of the obtained alloys. The type of material for the applied crucible proved to affect considerably the composition of the melted alloys. Modern vacuum induction furnace was used in the research where the pressure during the process reanged from 101325 to 0,1 Pa.

**85. B. Oleksiak, G. Siwiec, A. Blacha-Grzechnik;** *Silesian University of Technology, Katowice, Poland*
**Recovery of precious metals from waste materials by the method of flotation process.** The paper presents the research results of precious metals recovery such as silver and platinum from waste materials by the method of flotatiaon process. Used ceramics exhaust catalysts as well as the wastes from silver jewellery polishing process have been subjected for analysis. The scope of the research the research included the selection of foaming the reagents collecting reagents as well as pH regulator. Optimal gas flow rating and rotor speed have been also determined.

**86. G. Siwiec, B.Oleksiak;** *Silesian University of Technology, Katowice, Poland*
**The effect of temperature upon the evaporation kinetics of aluminium from Ti-Al-V alloys.** The paper presents the research results on the evaporation process of aluminum from Ti-Al-V liquid alloys. The research has been conducted in the Seco-Warwic vacuum induction furnace. On the basis of the obtained results of aluminum concentration changes in liquid bath it was possible to estimate the values of aluminum mass transfer coefficient. The tests have been performed at the pressure of 1 023 Pa and the temperature range between 1973 - 1223 K.

**87. J. Pieprzyca;** *Silesian University of Technology, Katowice, Poland*
**Hydrodynamic conditions of the liquid steel flow in tundish influence on forming the steel ignots' primary structure.** This article presents results of the research, that applies to influence of the liquid steel mixing method in tundish on steel ingots' primary structure. Study of the flow conducted on physical model of the triple-stranded tundish, which provided results formed as RTD curves. Generated curves were put together with primary structure's metallographic test results of the individual cast strand's cast in actual CCM. That listing allows to valuate influence of the liquid steel mixing method in tundish on steel ingots' primary structure quality.

**88. K. Janiszewski;** *Silesian University of Technology, Katowice, Poland*
**Industrial application of liquid steel filtration out of dispersed nonmetallic phase in the CC machine.** In the aspect of planning steel filtration process in an intermediate ladle of the CC device, a model testing of steel flow and mixing in an intermediate ladle with an equivalent constructional solution of multi-hole ceramic filter has been conducted. This research also presents the results of industrial tests of steel filtration with multi-hole ceramic filters, previously reduced with Al. The obtained results of filtration have proved that this method may be used as an effective and cheap way of steel filtration from non-metallic inclusions.

**89. V. Grozdanić***; University of Zagreb, Sisak, Croatia*
**Mathematical model of hot tears in continuously cast steel.** Hot tears are a problem that appears in continuously cast strands, during solidification process, and here these phenomena are formulated and investigated. The criteria for beginning of hot tears in Al-alloys are derived in the literature and applied for continuously cast steel. The influence of the carbon content in the system Fe-C-P and Fe-C-S with respect to the sensitivity of the alloy to hot tears is investigated. Finally, when implemented in a FEM model of continuously cast steel and using the CALCSOFT package, these criteria may predict cracks in the strand centre of continuously cast steel.

**90. V. Grozdanić;** *University of Zagreb, Sisak, Croatia*
**2-D mathematical model of the solidification of steel casting of relatively complex geometry in sand mould.** In the paper is shown two-dimensional mathematical model of solidification and cooling steel castings in sand mould which is based on the conductive heat transfer. Mathematical model is solved with implicit alternating direction and Saulyev explicit finite difference method. A good agreement is observed. On tehe basis of isosolidus movement it can be observed the points of possible defect occurrence, i.e. points which solidified last. Also it is defined the solidification time. The results obtained enable that on modern and scientific way improves solution of rational prediction of points where is possible defects occurrence.

**91. N. Husáková, G. Fedorko, V. Molnár, I. Vasková, D. Fecko;** *TU of Košice, Slovakia*
**Disposal of shrinkage occurrence in the castings with the use of computer simulation.** Shrinkage located in the castings are considered as foundry errors, because they create cavities in the castings, which are not filled with metal and thus they decrease mechanical properties of the castings and these castings then need to be removed and again re-used as reversible material. This causes the considerable losses of time and financial costs in the process of castings production. The main priority of modern foundries should be the effort to produce sound and errorless castings.

**92. E. Kardas;** *Czestochowa University of Technology, Czestochowa, Poland*
**The analysis of quality of ferrous burden materials and its affect on the parameters of blast furnace process.** The analysis of the effect of the quality of ferrous burden materials on the parameters of blast furnace process is presented in this paper. First, the quantitative and qualitative analysis of pig iron and ferrous burden materials used in blast furnace process will be made. The chemical composition is the basic quality parameter taken into consideration. Then, the dependence of parameters of process on the quality parameters of burden materials will be calculated.

**93. A. Konstanciak;** *Czestochowa University of Technology, Czestochowa, Poland*
**The effect of blast furnace coke quality on the possibility of its use.** In the paper behavior of the blast-furnace coke in the high temperature was presented. Comparative analysis of the chemical composition of the blast-furnace coke and the heat treatment of it were done. Factors M10 and M40 with the thermo-abrasiveness for chosen cokes were compared. The influence of ash content of the coke on the blast-furnace bed permeability was defined. Usefulness of the coke to blast-furnace process was also defined.

**94. M. Warzecha;** *Czestochowa University of Technology, Czestochowa, Poland*
**Numerical analysis of the non-metallic inclusions distribution and separation in a two-strand tundish.** The article presents computational studies of non-metallic inclusions separation in a two-strand industrial tundish during steady-state casting. Tundish capacity is 7.5 t. First, flow structure in the tundish was investigated with using water model of the industrial tundish in a scale 1:2. The experimental results regarding RTD characteristics were used to validate numerical model. With validated model particle distribution and separation in the two-strand tundish were investigated numerically. For modeling the separation of particles at the fluid surface, a modified boundary condition has been implemented.

**95. K. Gryc, B. Smetana, M. Žaludová, P. Klus, K. Michalek, M. Tkadlečková, J. Dobrovská, L. Socha, P. Faruzel;** *VŠB – Technical University of Ostrava, Czech Republic*
**Thermal Analysis of High Temperature Phase Transformations of Steels.** The paper is devoted to the discussion of results obtained during first series of experiments realised under conditions of newly formed Laboratory for Modelling of Processes in the Liquid and Solid Phases. The results from studying of the high temperature phase transformation of steels are done in the frame of applied research – cooperation with steel plants.

**96. L. Socha, J. Bažan, J. Morávka*, P. Machovčák**, A. Opler**, P. Styrnal***, K. Gryc, M. Tkadlečková;** *VŠB – TU of Ostrava; *Material & Metallurgical Research s.r.o., **VÍTKOVICE HEAVY MACHINERY a.s.; *** JAP TRADING s.r.o., Czech Republic*
**The Effect of Briquetted Fluxing Agents on Steel Refining in Ladle.** In the steel industry, a number of fluxing agents based on $Al_2O_3$ are used which are produced in different forms. This paper shows plant results and experience with the utilization of briquetted and sintered fluxing agents based on $Al_2O_3$.

Proper plant heats with refining processes realized under the conditions of steelwork Vítkovice heavy machinery a.s. Objective of the heats consisted in assessment of the plant results with utilization of two types of fluxing agents on the course of desulphurization during the secondary metallurgy.

**97. M. Tkadlečková, K. Gryc, P. Faruzel, B. Smetana, K. Michalek, J. Dobrovská, L. Socha, P. Klus, P. Machovčák*;** *VŠB – Technical University of Ostrava, *Vítkovice heavy machinery, a.s., Ostrava, Czech Republic*

**Verification of Thermo - Physical Parameters of Numerical Model of Filling and Solidification of Heavy Steel Ingot.** The paper devotes a verification of setting of calculation parameters of numerical simulation of filling and solidification of a 90-ton heavy steel ingot in the ProCAST simulation programme. The aim of numerical modelling realized under the conditions of VSB-TU Ostrava and in Vítkovice heavy machinery a.s., especially focused on minimization of macro-segregation. In cooperation with the Department of Physical Chemistry and Theory of Technological Processes were experimentally studied the thermo-physical parameters of steel, such as temperature of liquidus and solidus.

**98. M. Dyzia, A. J. Dolata;** *Silesian University of Technology, Katowice, Poland*

**Castability as a criterion of selection the matrix alloy for AlMMC/Cf composites obtained by GPI process.** Selection of the alloy as a matrix for the manufacture of AlMMC/Cf requires not only analysis of physico-chemical phenomena in the system liquid Al-carbon fiber, but also take into account the specificity of selected manufacturing processes. Proper modification of alloy chemical composition allows to improve fluidity and ability to fill the mold. The introduction of inoculants allows extension of time in which the liquid metal can infiltrate the preform. As preliminary criterion of evaluation of the modification results of test of castability was accepted.

**99. P. Malatynska;** *AGH University of Science and Technology, Krakow, Poland*

**The influence of carbon content on change of peritectic reaction in stainless steel.** Subject of investigation, was the influence of carbon content on stages of peritectic reaction. Calculation was carrying out of course solidification stainless steel in quaternary system at constant content of chrome 18% and nickel 9%, whereas (and) changing content of carbon from 0,01 to 0,06 %. It by utilization program PANDAT, it was showed, that the growth of concentration of carbon increase segregation of chrome, and the same change course of solidification in real conditions.

**100. T. Lis, P. Musiał, K. Nowacki;** *Silesian University of Technology, Katowice, Poland*

**Methods of preparation for recycling of deposits containing iron oxides.** The metallurgical industry is one of the largest sources of wastes. Some of them, however, owing to their content of metals such as zinc or iron, may become valuable secondary raw materials. In order to achieve that purpose, they require appropriate preparation. This article provides a discussion on the methods of preparation of scrap from steelworks, namely deposits containing iron oxides, enabling their recycling.

**101. K. Nowacki, P. Musiał, T. Lis;** *Silesian University of Technology, Katowice, Poland*

**Mechanism of an acoustic wave impact on steel during solidification.** Acoustic steel processing in an ingot mould may be the final stage in the process of quality improvement of a steel ingot. The impact of radiation and cavitation pressure as well as the phenomena related to the acoustic wave being emitted and delivered to liquid steel affect various aspects including the internal structure fragmentation, rigidity or density of steel. The article provides an analysis of the mechanism of impact of physical phenomena caused by an acoustic wave affecting the quality of a steel ingot.

**102. M. Łucarz;** *AGH – University of Science and Technology, Krakow, Poland*

**Factors determining the effectiveness of thermal reclamation of moulding and core sands.** The paper presents the results of the research on the impact of different parameters of the fluid thermal reclamation appliance on the effects of thermal reclamation. The research was carried out on some used moulding and core sands. The aim of the experiments was to determine the optimal conditions for the process of obtaining reclaim characterized by qualities similar to those of the initial sand grains. Since the amount of gas and electricity needed for the process was registered, it was possible to evaluate the quality of the reclaim with particular focus on the amount of energy used. The findings of the research are included in the paper.

**103. M. Łucarz;** *AGH – University of Science and Technology, Krakow, Poland*

**Research on the process of thermal reclamation with the application of different construction solutions of a thermal reclamation appliance.** The paper presents the results of the research on the process of thermal reclamation carried out in the experimental appliance constructed according to the author`s idea. Comparative research was done according to different set points of the universal thermal reclamation appliance. The findings provide directions for the research on the optimal conditions for thermal reclamation of various types of moulding and core sands. The process has a very important aspect both for economic and ecological reasons because of the costs of thermal reclamation and the emission of hazardous compounds to the atmosphere due to the of combustion of organic resins.

**104. J. Kolczyk, J. Zych;** *AGH University of Science and Technology, Krakow, Poland*

**Rheological properties of ceramic slurries with colloidal binders used in the investment casting technology.** The article presents results of analyses of ceramic slurries made using materials currently tested in this technology, i.e.: colloidal silica (Ludox AM and Ludox SK) as a binder and $Al_2O_3$ as the ceramic matrix material. Rheological properties were studied for slurries whose proportion of the (technologically justified) solid phase amounted to: 73%, 74%, 75%. The impact of the solid phase proportion on the thickness of subsequent coats applied to the wax model, the dynamic viscosity and the density was determined. The article presents the results achieved and an assessment of the suitability of individual ceramic slurries for the investment casting technology.

**105. A. Bobrowski, B. Stypuła, B. Hutera, A. Kmita, D. Drożyński, M. Starowicz;** *AGH University of Science and Technology, Krakow, Poland*

**FTIR spectroscopy of water glass - the binder moulding modified by ZnO nanoparticles.** The subject of the paper is the determination of the influence of the colloidal nanoparticles of zinc oxide on the structure of sodium water glass. Nanoparticles of zinc oxide in ethanol solvent were introduced into the water glass. The modification and structural changes were determined by means of the FT-IR absorption spectra. In order to determine the kind of influence: binder-modifier the spectroscopic FT-IR analysis of samples of a fresh binder and of a binder hardened for 24 h in the air was performed by means of the spectrometer Digilab Excalibur with a standard DTGS detector.

**106. M. Holtzer, B. Grabowska, S. Żymankowska-Kumon, D. Kwaśniewska-Królikowska, R. Dańko, W. Solarski, A. Bobrowski;** *AGH - University of Science and Technology, Krakow, Poland*

**Harmfulness of moulding sands with bentonite and lustrous carbon carriers.** Procedures have been developed to determine the volume, rate and composition (particularly BTEX: benzene, toluene, ethylbenzene and xylenes and PAHs (polycyclic aromatic hydrocarbons)) of gas evolution from moulds and cores prepared with various binders as a means of harmfulness of moulding sands. The rate of gas evolution from green sands with four different lustrous carbon carrier and BTEX content were determined. The gas evolution rates are highest in the range of about 20 to 30 s after contact with molten metal. In practice during the first 200-250 s the total emission of gases generated in investigated samples occurred. The main emitted component from the BTEX group was benzene.

**107. J. Kaminska, J. Danko;** *AGH - University of Science and Technology, Krakow, Poland*

**The study of the granulation process of dust generated in bentonite sand processing station.** The paper presents the results of the investigations of granulation process of foundry dust generated during the mechanical reclamation of the used bentonite sands and dust generated in sand processing station and then extracted by a dust extraction system. The studies included the manufacture of granules with specific dimensional and strength parameters. The study was conducted in three angles of tilt of the granulator bowl: $40^0$, $45^0$. For each of the tested angles five rotational speeds of the bowl were tested: 5, 10,15,20 and 25 rot./min. The results allowed us to provide the most favorable parameters of the process of granulation.

**108. D. Nowak, K. Granat, M. Stachowicz;** *Wroclaw University of Technology, Wroclaw, Poland*
**Research on possibility of using microwaves to determine binder content in moulding sands.** The paper presents results of preliminary examinations of possibility to measure binder content in traditional moulding sands using a new method employing electromagnetic waves. The presented examinations were carried-out with use of an innovative test station, the so-called microwave slot line. The measurements of binder content in moulding sand were based on the results of power balance investigation of microwaves affecting the specimen. An advantage of the suggested, new method of binder content measurement is short measuring time.

**109. D. Nowak, K. Granat, M. Stachowicz, M. Pigiel;** *Wroclaw University of Technology, Wroclaw, Poland*
**Possibility of using microwave heating in disposal process of thermosetting sandmixes.** The paper presents a semi-industrial reactor designed for microwave disposal by incinerating waste moulds and cores made of thermosetting moulding sands. A possibility was found of efficient and quick incineration of residues of cores or moulds prepared in this technology, left after casting and separated from the sandmix. The carried-out tests proved that the applied equipment employing microwave heating permits efficient control of the incineration process. Results of preliminary research on microwave heating indicate that incineration of waste moulds and cores based on phenolic-formaldehyde resins is an efficient method of their disposal.

**110. M. Stachowicz, K. Granat, D. Nowak;** *Wroclaw University of Technology, Wroclaw, Poland*
**Evaluation of dielectric hardening method of sandmixes containing hydrated sodium silicate in manufacture of high-quality small- and medium-size casting cores.** Moulding sands containing hydrated sodium silicate still find their application at numerous casting manufacturers worldwide. The subject-matter of the paper covers a very topical problem of possible restriction of shortcomings of this type sandmixes by proper selecting their components and using innovative microwave heating. It was proved that the sandmixes subject to quick dielectric drying show significantly lower residual strength, which gives this method priority over traditional energy-consuming processes of casting core manufacture.

**111. F. Zupanic, T. Boncina, B. Markoli*;** *University of Maribor, Maribor, Slovenia; *University of Ljubljana, Ljubljana, Slovenia*
**Development of Quasicrystal-Strengthened Casting Al-alloys.** This contribution presents how a hierarchical microstructure can be created, consisting of constituents of different sizes that produce various types of strengthening and make the propagation of cracks more difficult. The basic microstructure consists of two phases: α-Al and i-phase. In the presentation, it will be attempted to explain the ability of i-phase to strengthen an aluminium matrix and to make the crack formation and growth more difficult.

**112. T. Večko Pirtovšek, M. Petrič, P. Mrvar M. Terčelj;** *University of Ljubljana, Slovenia*
**Microstructures and cooling rates during solidification of M42 HSS ingot.** Time courses of temperatures during solidification of ingot from M42 high speed steel (HSS) have been simulated by FEM using ProCast program. Microstructure of the solidified HSS is very sensitive on cooling rates and for selected cooling rates typical microstructures were characterized. At higher cooling rates, i.e. about 1.8K/s average size of eutectic cells are in range about 25μm while at lowest cooling rate, i.e. about 0.18K/s these value are around 145μm.

**113. D. Malindžák, M. Straka, I. Koštial;** *Technical University of Košice, Slovakia*
**Push furnaces heating optimization by logistics.** In the paper is described one possible solution of the optimal sequence by applying a new charging strategy for push furnaces. Main idea is charging slabs to push furnaces not individual slabs but in the batches of slabs.

**114. B. Derin, O. Altinordu, M. Alkan, S.Sonmez, O. Yucel, V. Sanin*, D. Andreev*, V. Yukhvid*;** *Istanbul Technical University, Istanbul, Turkey; *ISMAN, Chernogolovka, Moscow Region, Russia*
**Production of Ni, Co, Cr based cast alloys via SHS Method under Normaland High Gravity Conditions.** In this study, some experiments were carried out to produce Ni, Co, Cr based cast alloys via via self-propagating high temperature synthesis methods by investigating the effects of normal and high gravity conditions. The FactSage 6.2 Thermochemistry software was use to simulate the. SHS-processes were carried out in the open/closed crucibles (a = 1-g) and also in radial centrifugal machines (a = 1 -400-g). At the end of SHS experiments, a good separation between multi-phase alloys and slag phases were obtained. SEM and XRD analysis of the samples were carried out to identify the compositional characteristic of phases.

**115. J. Tušek, Marko Hrženjak*, A. Skumavc, D. Klobčar;** *University of Ljubljana, Ljubljana; *TKC Laboratory and Welding Klinik d.o.o., Ljubljana, Slovenija*
**Burn- off rate of the chemical elements from the filler material during laser and TIG welding.** The energy input and dilution during welding process depends on welding process and its parameters. In order to find the burn-off rate of cehmical elements from filler materials, different diameters from 0,5 to 1 mm and chemical compositions of the wires were tested. Chemical analysis, structural and mechanical properties of the weld metal were observed through this study.

**116. A. Skumavc, J. Tušek, M. Kalin*, D. Klobčar;** *University of Ljubljana, Ljubljana; *Center for Tribology and Technical Diagnostics, Ljubljana, Slovenia*
**High temperature wear resistance of laser and TIG welded claddings.** The resistance on high temperature erosion wear of Nd-YAG and TIG welded claddings was evaluated. Different filler materials were cladded on base metal W. Nr 1.2344. The lab scale test that reproduces the tribological behaviour of the tools during casting process helped to evaluate the applicability of filler materials and two repair welding techologies. SEM was used to study wear tracks. The microstructure and chemical analysis of the weld was observed and Vickers hardenss of the weld was measured.

**117. D. Klobčar, J. Tušek, A. Skumavc, A. Smolej;** *University of Ljubljana, Ljubljana, Slovenia*
**FSWP of aluminium alloy 5083.** A comprehensive research of Friction Stir Welding and Processing (FSWP) of 4 mm thick 5083 aluminium alloy was done. A plan of experiments was prepared using design of experiments. We have changed a tilt angle, tool geometry and tool rotation and welding speed. Specially designed tensile test specimens were sectioned from the weld. The microstructure was prepared for observation on a light microscope under the polarised light source. A Vickers micro-hardens was measured across the weld. The results show the influence of FSWP process parameters and tool geometry on the formation of microstructure, mechanical properties and formability under superplastic conditions.

**118. J. Dańko, R. Dańko, A. Burbelko, M. Skrzyński;** *AGH - University of Science and Technology, Krakow, Poland*
**Core blowing process - Assessment of core sands properties and preliminary model testing.** Various methods developed by several researchers, including the authors own attempts, allow to assess core sands properties on the basis of special technological tests projecting the process into a laboratory scale. The developed criteria defining a degree or a filling ability factor provide a better possibility of assessing the core sand behaviour during flowing and core box filling, which indicate the value and structure of the obtained compacting decisive – after hardening – for strength and permeability. The mentioned above aspects are analysed – on the basis of authors' own examinations - in the hereby paper.

**119. D. Baricová, P. Demeter, A. Pribulová, B. Buľko;** *Faculty of Metallurgy, Technical University in Košice, Košice, Slovakia*
**Utilizing of the metallurgical slag for production of cement-less concrete mixtures.** The most abundant secondary product originating in the metallurgical process is furnace slag. Total amount of accured slag, also its chemical, mineralogical, physical – chemical properties and similarity with natural stones predestinate its utilisation in different fields of industry. The contribution deals with production of cement – less concrete mixtures, where the main parts were formed by blast furnace granulated slag grinded and different gravel slag from blast furnace, oxygen converter, electric arc furnace, and also cupola furnace. As activators of solidification were tested different kinds of water glass.

**120. A. Pribulová, D. Baricová, P. Gengeľ*;** *Technical University in Košice, Košice, Slovakia; *Nemag Slovakia, Žiar nad Hronom, Slovakia*
**Influence of foundry dust on sand mixtures quality.** Foundry belongs to industry sector creating huge amount of wastes. Except used sand mixtures the bigest quantity of the foudry wastes represents foundry dust. Sand mixtures preparation and mould production are the foundry shops with the high-

est dust production. Main goal of the contribution is to determine influence of different portions of foundry dust on quality (compression strength, shearing strength and perbeability) new and used bentonite sand mixtures.

**121. Š. Klarić, H. Hadžiahmetović*, S. Kladarić**;** *University of Osijek, *University in Sarajevo, BIH, **University of Applied Science in Slavonski Brod, Croatia*

**Flux-cored arc welding process - changes of the weld joint geometrical properties due to welding with different types of flux-cored wire.** Different factors have influence on the weld properties and also on geometrical appearance of weld joint. The selection of the electrode type in flux cored arc welding process, as in all electric arc welding processes is of great importance. In this research, the weld bead geometry changes (weld join reinforcement) at FCAW process with regard to heat input and the type of *flux-cored* wire are analyzed.

**122. P. Konjatić, D. Kozak, J. Sertić;** *University of Osijek, Slavonski Brod, Croatia*

**On the fracture behavior of the heterogeneous welded joint.** This paper presents investigation of flaw influence, primarily in form of crack, on the fracture behavior of the heterogeneous welded joint. Investigation was done on butt welded I joint subjected to bending. This welded joint was repaired and in repair welding process additional weld material is implemented in weld producing heterogeneous welded joint with two weld materials and one base material. All yield load solutions are obtained numerically, using finite element method, and compared to yield loads of the same construction but made of homogeneous material.

**123. B. Grabowska, M. Holtzer, R. Dańko, M. Górny, A. Bobrowski, E. Olejnik;** *AGH – University of Science and Technology, Krakow, Poland*

**New BioCo binders containing biopolymers for foundry industry.** Possibilities of cross-linking of new polymer binders from the BioCo group, their hardening in moulding sands at the application of cross-linking agents both physical and chemical, are presented. Their thermal stability was determined. The investigated moulding sands with the BioCo binders are easily knocked out and have a good susceptibility for mechanical reclamation processes. Experimental tests performed in the foundry plant confirmed the laboratory results of their suitability as moulding sands binding agents. The produced castings met all qualitative requirements.

**124. V. Václavík, V. Dirner, T. Dvorský*, J. Daxner**;** *Institute of Environmental Engineering, VŠB - Technical University of Ostrava, **D&Daxner Technology, Ltd., Ostrava, Czech Republic*

**The use of blast furnace slag.** The paper presents the results of experimental research that dealt with the substitution of finely ground blast furnace slag for Portland cement in the course of simple concrete manufacturing. Physical and mechanical properties of experimental concrete mixtures based on finely ground blast furnace slag were observed.

**125. A. A. Minea***; Technical University Gheorghe Gsachi from IASI, Romania*

**Experimental and empirical technique to estimate energy decreasing at heating in an oval furnace.** In this paper an experimental and empirical methods are proposed to estimate the heat transfer enhancement in industrial heating processes in oval furnaces. An investigation was conducted to study the suitability of inserting radiant panels of different positions and radiation surface. Two case studies were considered. The maximum energy saving was obtained for case 5: 32,89 % off from the standard experiment (with no panels). The minimum energy saving was obtained for case 10: 11,72 % off from the standard experiment (with no panels). Finally, based on the results of this study, a correlation was developed to predict the inner configuration of an oval furnace.

**126. E. Ragan, P. Baron, J. Dobránsky, M. Kočiško;** *Technical University of Košice, Seat in Prešov, Slovakia*

**Dynamic of taking out modling parts at injection molding.** Most plastic parts used in automobile production are manufactured injection molding. Quality of the plastic processing at injection molding depends also on taking out molding and on the manipulators for it. Task of this contribution is to theoretically describe a transport of molding taking out after injection molding.

**127. P. Besta, A. Samolejova, K. Janovska, M. Lampra, R. Lenort***; VŠB – Technical University of Ostrava, Czech Republic*

**Evaluation of benefits resulting from innovation of input raw materials dosing process in sintering.** Production of blast furnace sinter is especially significatn cost item here. The presence of grate sintered in charge, i.e. return sinter from 12 do 22 mm in size, can have fundamental impact on the technical and economic indicators of the sintering process. Grate sinter can be used as a foundation layer under the sintering mixture, to increase air permeability of charge and to improve the gas-dynamic conditions. The article analyzes the impact of grate sinter on the sintering process, based on an analysis of the acquired production indicators within the scope of the research in question.

**128. K. Kostúr***; Technical University Košice, Slovakia*

**The System for Indirect Measurement Temperature in LD Converter.** Temperature at steel making process in converter is very important variable and it is not continually measured during this process, because there are not suitable sensors available. Every measurement of temperature means the breaking of processes in steel converter and decreasing productivity. The proposed system enables continuously to measure a temperature of the melt. The essence of an indirect measurement is based on two types of models. There are used deterministic and stochastic models. The system continuously measures six different independent variables (e.g. converter gas pressure, converter gas composition, its temperature, etc.) and computes temperature of melt in individual time steps. The currently adapted model of indirect measurement achieves long-term deviations from the temperatures measured with a thermocouple at the level app. 0,85 %.

**129. S. Biernat, A. W. Bydałek***; Jan Amos Komenski State School of Higher Vocational Education, Leszno, *West Pomeranian University of Technology, Szczecin, Poland**

**Applied of the optimization program to determination slag refinement ability in processes of refinement cast alloys.** This article contains information concerning of defining refinery qualities of the slag based of the thermo-physical and thermodynamical data and of the optimization programme engaging all of the physics chemical influence of the slag in processes of melting copper alloys. The database, in system SQL, it will be accessible in aim fuel make-ups by different users. The proposed results, ranges of areas on graphs of phase equilibria's, demonstrative on the optimum values and - the initiation of the new data the gathered base will be built in system of open base enabling.

**130. T. Wyleciał, H. Radomiak, D. Urbaniak***; Częstochowa University of Technology, Częstochowa, Poland*

**Modeling of the process of coal grinding.** The use of coal in the metallurgical industry, similarly as in the whole national economy, is often preceded by its pre-treatment. Coal is mined in the form of sizeable lumps, but, being in such a form, it cannot be combusted, sintered, or gasified. Therefore, it needs to be appropriately grinding. In the paper results of the numerical assessment of the grain size of the coals grinding, numerical computations were performed and then compared them with grain size analysis results.

**131. A. Zdeněk***; VŠB - Technical University of Ostrava, Faculty of Metallurgy and MaterialEngineering, Ostrava-Poruba, Czech Republic*

**Changes in morphology of inclusions in steel under the top slag without calcium.** This paper aims to focus on the issue, whether inclusions in steel change their morphology without addition of calcium. Evolution of inclusions under top slag is monitored in conditions of atmospheric pressure and vacuum. Change of the chemical composition of inclusions during processing is discussed and then a mechanism for the conversion of inclusions during processing is proposed. For this purpose samples from steel and slag were taken at different treatment periods. The steel samples were subjected to chemical and metallographic analysis of inclusions.

**1. D. Noskievičová, R. Kucharczyk***; *VŠB-TU Ostrava; *Evraz Vítkovice Steel, a.s., Vítkovice, Czech Republic*

**Effective application of statistical process control (SPC) on the lengthwise tonsure rolled plates process.** This paper deals with the effective application of SPC on the lengthwise tonsure rolled plates process on double side scissors. After explanation of the SPC fundamentals, goals and mistakes during the SPC implementation, the methodical framework for the effective SPC application is defined. In the next part of the paper the description of practical application of SPC and its analysis from the point of view of this framework is accomplished.

**2. W. Fracz, F. Stachowicz**; *Rzeszów University of Technology, Poland*

**Determination of the forming limit diagram of zinc electro-galvanized steel sheets.** Forming limit curves (FLC) of deep drawing steel sheets have been determined experimentally and calculated on the base of the material tensile properties following the Hill, Swift, Marciniak-Kuczyński and Sing-Rao methods. Only the FLC modeled from a singly linear forming limit stress curve exhibits good consistence with experimental curve. The quantitative X-ray microanalysis was used to determine cracking limit curve (CLC) of electro-galvanized steel sheet. The change in zinc layer (and base sheet metal) thickness was used as a criteria in calculation of the CLC.

**3. M. Kršulja, Z. Car, H. Radelja**; *University of Rijeka, Croatia*

**Behaviour of X5 CrNiMo 17-12-2 material during deep drawing process.** The subject of this paper is investigation of steel X5CrNiMo 17-12-2 in a deep drawing process. Material and mechanical properties are investigated in order to obtain a number of parameters that are needed for the deep drawing process. Tolerances for final product dimensions were taken and a procedure for deep drawing process was calculated. Tooling was modelled with *Solidworks* software. Experiments were performed in order to determine functionality of tooling, feasibility and influential factors on process uncertainties.

**4. R. Lenort, R. Klepek, A. Samolejová**; *Faculty of Metallurgy and Materials Engineering, VŠB – Technical University of Ostrava, Czech Republic*

**Heuristic algorithm for planning and scheduling of forged pieces heat treatment.** The paper presents a heuristic algorithm for planning and scheduling of forged pieces heat treatment which allows maximizing the capacity exploitation of the heat treatment process and the entire forging process. The experimental work has made it possible to elicit the general rules for planning and scheduling of the heat treatment process of forged pieces which reduce losses caused by equipment conversion and setup times, and which increase the throughput of this process. The HIPO diagram was used to design the algorithm.

**5. G. Ryzińska, R. Śliwa**; *Rzeszow University of Technology, Poland*

**The theoretical and experimental researches of pb-al composite materials extrusion.** The work presents the analysis of the character of a simultaneous plastic flow of composite material of a hard core- soft sleeve structure. Experimental research work using model composite material Aluminium-Lead and theoretical analysis allowed to identify the initial cracking conditions, its character and localization, depending on geometrical parameters of the composite materials and the extrusion ratio value. It has been shown that the higher the parameters' values are, the longer the flawless extruded product is (cracking appears in the further stages of the process).

**6. E. V. Vorob'ev, T. V. Anpilogova;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*

**Kinetics of Unstable Deformation of Structural Alloys in Liquid Helium.** The numerical-analytical method for studying the low-temperature jump-like deformation of metals has been developed. Phase diagrams, characteristics of the kinetics of the deformation jump, dependences between deformation and its derivatives are obtained. Velocity and acceleration at the deformation jump are shown to attain high values and cause significant impact loads.

**7. A. A. Lebedev, V. P. Lamashevsky, I. V. Makovetsky;** *G. S. Pisarenko Institute for Problems of Strength, Kiev, Ukraine*

**Influence of the Stress State Type on the Deformation and Strength of Heat-resistant Steels.** This paper analyzes the results of the experimental investigation on the combined action of the temperature and stress state type on the deformation and fracture behavior of heat-resistant steels such as 38KhMYuA steel of the ferrite-pearlite class and Kh25N20S2 steel of the austenitic class. Based on the analysis of the experimental results, the recommendations are given on the selection of the deformation models and criteria for the material ultimate state that take into account the temperature and force conditions for operation of real structural elements.

**8. T. A. Zhmachenko, F. O. Kristopchuk, I. Mamuzić;** *National Technical University "KhPI", Kharkiv, Ukraine; *CMS, Croatia*

**Computational Modelling of Effects of Roll Gap Geometry in Hot Rolling.** The effects of initial slab thickness, reduction, roll diameter, and speed on the rolling load, torque, temperature distribution in the stock, and redundant shear strain have been computed for rolling of Kh18N9T stainless steel. Two new concepts – the 'net shear angle' and the 'average shear strain' of a rolling pass have been introduced to quantify the degree of inhomogeneity in deformation. Finally, the results are compared with those of similar rolling theories.

**9. V. O. Parashanov, S. M. Karpov, and A. F. Baluev;** *Kirovograd National Technical University, Kirovograd, Ukraine*

**High Temperature Deformation of 12Kh18N9T Stainless Steel.** A constitutive description for AISI 12Kh18N9 stainless steel deformed at elevated temperatures in a wide range of strain rates is proposed. The overall constitutive description proposed in this manner requires only four material parameters besides an expression for the temperature dependent shear modulus of the alloy.

**10. N. I. Martov, V. P. Mitrofanov;** *A.A. Galkin Donetsk Physicotechnical Institute, Ukraine*

**Evolution of Dislocation Structure Induced by Cyclic Deformation in a Cobalt Base Superalloy.** Cyclic deformation has been carried out on a directionally solidified cobalt base superalloy at room temperature in air under the control of different total strain amplitudes. Observations show that a large number of stacking faults and fault intersections are formed in the initial hardening stage, and this leads to the initial hardening of the alloy.

**11. K. M. Safargalov, M. S. Polonsky*, M. Jurković**;** *A. A. Galkin Donetsk Physicotechnical Institute, *National Academy of Sciences of Ukraine, Donetsk, Ukraine; **CMS, Croatia*

**Evolution of Microstructure and Plastic Stability During Superplastic Flow in a 1201 Aluminium Alloy.** Superplastic behaviour and microstructural evolution were examined at 800 K for strain rates in the range $2 \times 10^{-4}$–$2 \times 10^{-3}$ $s^{-1}$ in a 1201 aluminium alloy. In addition, the variation of the strain hardening and plastic stability parameters with strain was investigated based on experimental grain growth and cavitation data. The highest plastic stability parameter was attained at $2 \times 10^{-4}$ $s^{-1}$, although the strain rate sensitivity was the lowest for the strain rate range investigated.

**12. A. K. Kuleshov, R. T. Kucherenko, D. Ćurćija*;** *Poltava State Technical University, Poltava, Ukraine; *CMS, Croatia*

**Influence of Titanium on Hot Ductility of C–Mn–Al Steels.** The hot ductility of a series of C–Mn–Al steels with nominal compositions of Fe–0,15C–1,5Mn–0,25Si–0,005N with Ti additions of 0–0,04% (all compositions and percentages given in this paper are in wt.% unless otherwise stated) has been determined over the temperature range 1150–750°C. A regression equation was obtained which showed that the best ductility was obtained when the cooling rate was slow, the particle size coarse, and the N and Al levels low, in order to limit the volume fraction of the detrimental TiN and AlN precipitation.

**13. A. A. Chyorny, V. P. Demchenko*, N. Devčić**;** *Pulsar Science and Production Company, Kharkiv; *A.A. Galkin Donetsk Physicotechnical Institute, Donetsk, Ukraine; **CMS, Croatia*

**Hot Plane Strain Compression Testing of Aluminium Specimens.** The paper demonstrates the current status of the work by presenting the algorithms behind new software that has been developed for interpretation of raw force–displacement data in a logical and consistent way.

**14. I. S. Cheshev, E. G. Ermokhina;** *State University of Sea Transport, Odessa, Ukraine*
**Structure and Properties of Superplastically Formed Aluminium Alloy 1205.** The effect of back pressure and forming pressure on thickness distribution, cavitation, grain growth, surface topography, and corrosion properties was studied in superplastically formed aluminium alloy 1205 pans. The operation of such shear surfaces also resulted in the formation of both steps at the surface of the deformed sheets and threadlike fibres at sliding grain boundaries.

**15. L. T. Borisoglebsky, A. S. Gordeev, N. Devčić*;** *Plazma Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Fabrication of Alumina Dispersion Strengthened Copper Strips by Internal Oxidation and Hot Rolling.** Cu–Al alloy strips were internally oxidised without using any oxidant powders by a surface oxidation method. Several of the internally oxidised alloy strips were stacked and bonded by rolling at high temperatures. The bonded strip was cold rolled to achieve tensile strengths of 480–540 MPa and yield strengths of 470–520 MPa with thermally stable mechanical properties.

**16. V. A. Tymchenko, B. R. Sigalov, N. Devčić*;** *State Pipe Institute, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Temperature Changes Occurring During Extrusion of Metals.** The temperature as an extrusion emerges from the die is the parameter determing both surface quality and properties. This technical note compares the various techniques used to calculate this parameter and gives an assessment of their practicality.

**17. V. P. Furmanchuk, J. Šipalo Žuljević*;** *G. V. Kurdumov Institute for Physics of Metals, Kyiv, Ukraine; *CMS, Croatia*
**Deformation of Aluminium Alloy AL20 in Semisolid State.** During semisolid deformation of aluminium alloy AL20, as the deformation strain increases, the deformation stress first increases to reach a peak value, then decreases to a minimum value, after which the stress increases towards the end of the deformation. The deformation stress increases as the deformation rate increases at the beginning of the deformation. The degree of segregation is the highest at the middle deformation temperature.

**18. G. V. Berezyanko, V. Yu. Chukhno, I. Mamuzić*;** *State Pipe Institute, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Behaviour of Metal Flow in the Spreading Extrusion Process.** To examine metal flow behaviour experimentally in the spreading extrusion process, a round billet is spread by means of a spread ring and extruded through a die opening wider than the internal diameter of the container. In spreading extrusion, the extrusion load is reduced by about 30% in comparison with basic extrusion. As a result, the metal flow balance markedly worsens, due to an increase in the size of the plastic deformation zone and frictional resistance acting on the spread ring wall.

**19. V. M. Ivanchenko, F. N. Kravets. Kirovograd National Technical University, Kirovograd, Ukraine**
**Oxide Layer Formation and Banding in High Chromium Rolls.** A mathematical model for black oxide layer thickness of a high chromium iron roll was established on the basis of the oxidation mechanism and oxide layer structure. It is shown that the black oxide layers, formed on the roll surface, induce the formation of cracks which propagate easily along $M_3C$ and $M_7C_3$ carbides resulting in their final separation from the roll surface during the rolling process.

**20. A. M. Grechishkina, G. I. Piskun, V. Živković*;** *State University of Railway Transport, Depropetrovsk, Ukraine; *CMS, Croatia*
**Transformation of Textures in Hot Rolled Microalloyed Steel.** Texture development during thermomechanical processing of a newly developed ultrahigh strength microalloyed steel was investigated, with particular attention to through thickness texture gradient. A considerable texture gradient was evident, particularly in the 1/2 depth compared to the other three positions (surface, 1/8 depth, 1/4 depth). The recrystallisation texture of austenite, $\{100\}\langle 001\rangle$, transformed into $\{100\}\langle 011\rangle$ component in the ferrite indicated an increase in intensity with increase in depth.

**21. Yu. A. Korshunov, I. Mamuzić*;** *State Aircraft University, Kharkiv, Ukraine; *CMS, Croatia*
**Strain Hardening and Steady State Deformation of Al–Mg Alloys.** A new approach to the modelling of work hardening during plastic deformation of pure fcc metals has recently been proposed by the present authors. In the present work this model is further developed by including the effects resulting from grain boundaries, elements in solid solution, and the presence of non-deformable precipitate particles. The result is a work hardening model and associated computer code, capable of providing the stress–strain behaviour for a given solid solution alloy under any combination of constant strain rate and temperature.

**22. M. I. Chukhray, H. Yu. Vainshtok*, A. F. Kashuba*;** *NTU of Ukraine "KPI", Kiyv; *Plazma Science and Production Company, Khmelnitsky, Ukraine*
**Deformation of Aluminium Bronze at High Temperature .** Hot compression tests were carried out on commercial Cu–9 wt.%Al alloy to test the effect of the deformation conditions on high temperature deformation characteristics and the final structure of the hot deformed material. Dynamic recrystallisation of the material was found to operate at deformation temperatures above ~900 K. Nucleation and growth of recrystallised $\alpha$ grains were observed for specimens deformed at temperatures below ~1000 K. In particular, post-deformation water quenching of the specimens resulted in martensitic transformation within pre-existing $\beta$ grains. Moreover, local coherent iron particles were detected within $\beta$ and neighbouring $\alpha$grains.

**23. A. N. Diobazov, G. I. Chuzhov;** *State Economic-Technological University of Transport, Kyiv, Ukraine*
**Ultrahigh Strength Hot Rolled Microalloyed Steels.** Ultrahigh strength hot rolled microalloyed steels of yield strength 700 and 750 MPa with ferrite-bainite microstructure have been developed. Impact toughness of ~140 J at -40°C and a ductile-brittle transition temperature of less than approximately -70°C have been obtained in steels of gauge ~2,5 mm.

**24. A. M. Kalayda, V. P. Zhezhera;** *Lazer Science and Production Company, Vinnitsa, Ukraine*
**Hot Ductility of Low- and Microalloyed Steels.** The as cast hot ductility of low C-V, low C-V-Nb, and niobium microalloyed steels has been investigated using in situ melted tensile specimens, which were subjected to cooling rates and strain rates found typically in thin slab casting. The as cast ductility of low C-V and low C-V-Nb steels was superior to that as of cast peritectic C-Nb steel as well as reheated peritectic C-V and peritectic C-V-Nb steels.

**25. D. A. Kuznetsov, I. Mamuzić*;** *Plazma Science and Production Company, Khmelnitsky, Ukraine; *CMS, Croatia*
**Effect of Fine Grained Ferrite in Surface Layers on Fatigue Behaviour of Low Carbon Steel Plates.** Low carbon steel plates with fine grained ferrite in the surface layers produced industrially by a special thermomechanical controlled process have been tested to investigate the effect of ferrite grain refinement on the fatigue behaviour of steel plates. Fatigue fractographs were observed and analysed using a scanning electron microscope. The fatigue properties were obviously improved for the special plates with fine grains in the surface layers.

**26. M. A. Balakan, I. Mamuzić*;** *State Aviation University, Kharkiv, Ukraine; *CMS, Croatia*
**Effect of Plastic Deformation on Microstructure and Poperties of Al-Cu Alloy.** Microstructures and mechanical properties of as cast and as rolled Al-Cu alloys have been investigated. 3D micrographs of the as rolled alloy containing 10 wt.%Cu indicates that the shape of lead particles changes from globule-like to dishlike. The values of UTS and percent elongation for as rolled Al-Cu alloys maintain higher than that for as cast Al-Cu alloys. The wear tests show that to minimise the friction and wear, an optimum amount of about 15 wt.%Cu is desirable in the studied Al-Cu alloy.

**27. T. M. Myronova, D. A. Ruden, I. Mamuzić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk; *CMS, Croatia*
**The influence of matrix structure on the deformed cast irons properties.** The white cast irons toughness and strength are greatly increases after shaping execution. These alloys plastic deformation became possible due to the ductile effect which means the phase transformations increasing in carbide constituent. The ductile cast irons wear-resistance could be additionally increased in 2,5-4 times after deforming by heat-treatment execution.

**28. V. P. Zhuravel, A. O. Karasik, I. Mamuzić*;** *State enterprise «Science-research trumpet institute», State higher educational institution «Ukrainian state himiko-technological university», Dnepropetrovsk, Ukraine; *CMS, Croatia*

**Technological processing at hot pressing of pipes.** Most often in the course ofhot pressing of pipes glass greasings which on a hot surface form a viscous dividing layer are applied. It is established, that surface clearing before greasing drawing raises quality of pipes which press. Better qualityof metal pipes is received at clearing by alkaline solutions with polymeric phosphates of various structure and use of glass greasings with superficially – active oxides.

**29. T. L. Karasik, M. Jurković*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**Researchof sheetings for processing of metals by pressure at heats.** It is established, that efficiency of protective action of three-componental glasses of system $SiO_2 – K_2O –$ RO worsened with maintenance growth in them RO, andof curves of dependence $lg\eta = f$ (% RO) has shown, that viscosity decreases at replacement RO among: BeO → MgO → CaO → SrO → BaO. Maintenance RO to 10% gives positive result at high-temperature protection alloys with the titan.

**30. Vl. Gnatushenko, Vict. Gnatushenko, I.Dmitrieva;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*

**Information technology of quality control in metal forming.** The new information technology for the assessment of sheet metal components in terms of shape accuracy and strain distribution has been developed. Further investigations have to be made to synchronize the CCD-cameras and projector units. An alternative method may be the contemporaneous overlapping of colored grids, which presupposes the use of different optical filters and modifications of the image acquisition software algorithms.

**31. A. M. Dolzhanskiy, O. S. Yermakova, O. B. Lomova***; I. N. Lomov; National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*

**Theoretical calculation of wire heating in roller scale-breaker while drawing process.** The phenomenon of wire significant heating alternating bending of the roller scale-breaker before drawing was experimentally revealed. Theoretically, based on energy balance, temperature dependences of the metal in roller process according on the main parameters (number of rollers and their diameter, velocity, friction conditions etc.) were defined. It allowed offering of advanced modes for drawing metal deformation and technological lubricant composition.

**32. S. R. Rakhmanov, V. L Topolov, M. Jurković*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**The dynamics of unsteady processes in helical rolling mill drives.** The dynamics of the main drive helical rolling mill with a view of time-dependent behavior of the universal spindles was further developed. Conditions for the unstable operation of the drive working rolls, consisting of universal spindle with dual hinges are established.

**33. A. M. Dolzhanskiy, Y. A. Petl'ovanyy;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*

**Investigation of surface defects deformation during steel wire-rod drawing.** To assess the deformability of the steel rod with a diameter of 6.5 mm with longitudinal surface defects on its surface artificially transverse and longitudinal incisions trapezoidal shape the depth and width 5...30% of the diameter were applied. The limits of individual breakdowns and regularities of forming patterns of surface defects in metals with different degrees of drawing were revealed. Account of these data contributes to the stability of drawing blanks with defects in production setting.

**34. A. M. Dolzhansky, A. O. Zhadan, I. N. Lomov, O. B. Lomova;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*

**Wire's quality improving at wire-drawing.** The wire-rod deformation technology in many-rollers device that does not require lubricants was realized. This allows for the appropriate products to reduce flaking of all coatings at their subsequent application on the wire surface, welding carburizing reducing, improving reinforcements adhesion in concrete.

**35. V. F. Balakin, I. A. Solov`eva, A. S. Golubitsky, O. V. Sergeeva;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*

**Computer-aided design of routes sink rawing.** Defined group of steels with the same type of deformation parameters. For each group of steels available options are defined by the diameter of breakdowns in sink rawing. Analyzed technology-drawn tubes. The technique and computer program for calculating routes sink rawing, which takes into account the types of lubricants, types of drawing dies and the maximum permissible absolute reduction in diameter.

**36. V. F. Balakin, I. A. Solov`eva, O. V. Sergeeva, K. S. Bilan;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*

**Investigation of the effect of different lubricants on the force with equal channel angular pressing samples of copper grade M2.** We investigated the blanks obtained by means of equal channel angular pressing (ECAP). In the extrusion process was carried out video evidence of efforts to fix the gauge deformation. According to our data we construct different depending on the type of effort pressing lubricant. Practical recommendations for the selection of oils during pressing, which provide the best indicators of surface with the least effort of pressing.

**37. V. F. Balakin, A. S. Golubitsky, O. V. Sergeeva, J. N. Nikolaenko;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*

**Investigation of the effect of different lubricants in ECAP on the surface quality, structure and properties of specimens of copper grade M2.** We investigated the blanks obtained by means of equal channel angular pressing (ECAP). Blanks for studying the structure, grain size was measured at different sites, as well as the distribution of microhardness in the longitudinal section of a workpiece in the axial zone and areas adjacent to the surface. According to our data we construct different depending on the microstructure and microhardness of the type of lubricant. Practical recommendations for the selection of oils during pressing, which provide the best indicators of surface with the least effort of pressing.

**38. M. V. Popov, V. F. Balakin, V. V. Perchanik, K. S. Bilan, I. Mamuzić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**New scheme of pilger rolling of tubes – a perspective way to obtain the required structure-sensitive properties.** The most perspective direction in improving of process of pilger rolling is considered. The main feature of new scheme is an installing in fixed stand two pairs of drive ring dies. That scheme lets increase length of summary deformation zone almost in two times and decrease diameter of rolls and engine power. Kinematic connection between the pairs of rolls promotes severe plastic deformation progress, getting submicrocristalline structure and as a result a significant change of structure-sensitive properties like corrosion resistance, radiation resistance etc.

**39. V. F. Balakin, J. N. Nikolaenko, I. A. Solov`eva, O. V. Sergeeva, M. Jurković;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**Computer designing of process production cold-deformed tubes.** One important area to improve the quality and accuracy of manufacturing of cold-deformed tubes is to develop new technological schemes that are resistant to random deviations of process parameters. Development of mathematical models, algorithms, and work programs for the analysis of the main technological operations of pipe production is an important stage of design. The analysis of production technologies multioperational cold-deformed tubes. Selected the maximum allowable deformation parameters, which provide stability and and reduce cyclical process, allow appreciation to reduce the consumption of metal.

**40. S. I. Pinchuk, V. F. Balakin, D. G. Tishkevich. I. Mamuzić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**The increasing of the corrosion resistance of the tubing.** In recent years there have been new ways to improve the quality of pipes due to the formation of ultra-fine grain structure, which alters the physical and mechanical properties. It is proposed in this article severe plastic deformation as one of the ways of forming such a structure to introduce in the technology of the tubing production.

**41. Y. K. Oginskyy, R. Križanić;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**Rolling and upsetting in the rolls with unequal diameter.** The method, proposed to determine the position of feed during rolling in the rolls with unequal diameter, is based on the principle of minimum work. Basing on the principle of minimum work, the total displaced volume from both rolls

shall be minimal, the feed meanwhile occupies the position of the least freedom. Basing on the clarification of the deformation and strength pattern in the rolling, establishing their relationship, it becomes possible to make refinements in methods of calculation of technological parameters.

**42. F. G. Hamidov, Z. G. Mamedov, S. R. Rakhmanov, I. Mamuzić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**Combined deformation and heat treatment of steel with a bainitic structure.**
**High temperature heat - mechanical bainit structure is had temperature as 1000-1050$^0$C in the regime of treatment, it is cooled by water as 450-500$^0$C press till 30% subject to deformation.** The cooling as drake is continued anger in the weather condition. Mikroscratch and inside tensions does not form with offered method in the process of treatment in the steel and mechanical properties of the steel improve.

**43. I. V. Markevich. V. U. Grigorenko, P. V. Drojja, R. Križanić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*

**Determination of the radius riding in the uneven distribution of normal contact stresses along the perimeter of the fire.** Problem of taking into account the nonuniformity of distribution of the normal contact stresses along the periphery of the pass had been dealt in the present paper in purpose of determining the natural rolling radius in the cross sections of the working cone.

**44. G. G. Shlomchack, T.I. Firsova, I.Yu. Sosnev;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*

**Rheological reasons for the formation of defects in rolling.** Methods of physical modeling (moire, optical polarization, etc.) investigated the flow patternof plastic and metal processing maloplastichnyh their pressure. Revealed a significant dependence of the behavior and character of the failure of ductile metals maloplastichnyh of their rheological properties. New technologies, which are based on observed phenomena, allow saving materials and energyin the processing of metals and plastic pressure to get products from maloplastichnyh metals without destroying them.

**45. K. Laber, S. Mróz, H. Dyja, P. Sygut***; Częstochowa University of Technology, Częstochowa, Poland*

**Analysis of the temperature change over the continuous ingot length on the parameters of wire rod rolling process.** The Forge2009® computer program was used in the continuous rolling mill. From the obtained results it has been found that a considerable decrease in band end temperature relative to the band beginning temperature takes place already in the first rolling stand. At the second stage of the study a modification of heating process was proposed, which consisted in heating the feedstock end up to an appropriately higher temperature, so that the band had a uniform temperature over its length during the rolling process.

**46. K. Sobczak, H. Dyja, A. Kawałek, M. Knapiński;** *Czestochowa University of Technology, Czestochowa, Poland*

**The analysis of the influence of changing types of shape grooves on behaviour of internal material discontinuities during rolling.** Issues concerning the influence of rolling processes on the progress of closing internal material discontinuities in continuous ingots during rolling in two types of shape grooves were discussed in the article. A numerical modelling of a rolling process of a 160 x 160 mm ingot made of the C45 steel was conducted by using the computer programme Forge 2008®. Temperature changes of the strand that was being deformed as well as shape changes of the holes simulating material discontinuities were analysed.

**47. P. Popovich, A. Dutka;** *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*

**Device for measuring the moment of torsion.** For testing of steel structures are deformed torsion developed a device for measuring the value of torque. Results of measurements are described analytically and energy geometry of the equipment. A proper graphic charts moments of tangential stresses, and given the mathematical dependence of data values used in assessing the performance hardware.

**48. A. Smolej, B. Skaza, B. Markoli, D. Klobčar, V. Dragojević*, E. Slaček*;** *University of Ljubljana, Ljubljana; *Impol, Aluminium Industry, Slovenska Bistrica, Slovenia*

**Microstructure and superplasticity of friction stir processed Al-Mg-Sc-Zr alloy.** The aim of the investigation was to determine the microstructure of the Al-4.5Mg alloy with a minor addition of Sc and Zr and to examine the superplasticity of the friction stir processed alloy. The superplasticity of the FSPed alloy was compared with the slightly modified AA5083 alloy with Sc that was prepared by a conventional hot and cold rolling. The FSPed Al-4.5Mg alloy with the combined addition of Sc and Zr has exhibited a good superplasticity at strain rates up to $1x10^{-1}s^{-1}$ with a maximum elongation of about 1500% at strain rate of $1x10^{-2}s^{-1}$ and at the temperature of 510°C.

**49. V. Szarková[1], J. Valíček[1], P. Hlaváček[1], M. Vlado[2], K. Rokosz[3], M. Harničárova[4], S. Hloch[4], I. Samardžić[5], D. Kozak[5], A. Wenglorzová[1], M. Luptak[2];** *[1]Technical University of Ostrava, Czech Republik, [2]Technical University of Košice, Slovakia, [3]Koszalin University of Technology, Poland, [4]Technical University of Košice/Prešov, Slovakia, [5]University of Osijek, Croatia*

**Influence of longitudinal cold rolling on the surface topography of low carbon structural steel.** The paper presents a method of surface evaluation of steel strips formed by longitudinal cold rolling using the rolling mill DUO 210 SVa. The experiments were performed on samples of low carbon structural steel in order to determine the impact of grain size of material with respect to technological parameters, particularly with respect to reduction and rolling force. Surface roughness of the steel strips was measured at three areas by an optical profilometer MicroProf FRT. Consequently, these three results were mutually compared.

**50. P. Beraxa, L. Domovcová, Ľ. Parilák***; ŽP VVC s.r.o., Podbrezová , Slovakia*

**Quality assessment of tool for cold-forming process, after application of PVD process.** One of the options for increasing tool life and wear resistance, is the use of tools surface treatment technology called as PVD (Physical Vapor Deposition) process. The paper introduces the possibilities of application of this process for straightening rolls used in operating conditions of Železiarne Podbrezová, a.s. Rolls are evaluated in terms of microstructure and microhardness of the rolls material and coating and the roughness of roll operating surface is measured after PVD process.

**51. Ľ. Parilák, M. Weiss***; ŽP VVC s.r.o. (Research and development centre), Podbrezová , Slovakia*

**Optimalization of controlled rolling process of hot rolled tubes.** In the Article, we observed special case of controlled rolling of hot rolled tubes in sizing mill of Železiarne Podbrezová JSC intended for cold drawing process. By rolling of seamless tubes in dual phase area and subsequent cooling, was created „bimodal" ferrite-perlite structure. We did analysis of forming properties of this structure. Hot rolled tubes with heterogeneous microstucture are not possible to use for cold drawing process without previous heat treatment. Analysis results followed to optimalisation of heating temperature, deformation, and finishing rolling temperature with following use for cold drawing production process.

**52. A. Gontarz, Z. Pater, K. Drozdowski;** *Lublin University of Technology, Poland*

**Hammer forging process of lever drop forging from AZ31 magnesium alloy.** The results of theoretical and experimental analysis of hammer forging process of lever drop forging from AZ31 magnesium alloy are presented in this paper. On the basis of the obtained results, the analysis of limiting phenomena, which could appear during the process, was made. Experimental tests in industrial conditions according to designed technology were carried out. Good quality of drop forgings were obtained. On the basis of conducted research, it was stated that hammer forging of lever drop forging from AZ31 magnesium alloy is possible.

**53. M. Suliga, R. Kruzel;** *Czestochowa University of Technology, Czestochowa, Poland*

**The mechanical-technological properties of high carbon steel wires drawn in conventional and hydrodynamic dies.** In the paper the influence of the hydrodynamic die on mechanical-technological properties has been assessed. The investigation of mechanical-technological properties has been carried out also. On the basis of numerical analyses wire drawing process, the effective strain of wires drawn in conventional and hydrodynamic dies has been determined.In the case of the wires drawn with hydrodynamic dies the increase of plasticity properties and technological properties have been noted. It has been shown that the increase of strength properties in wires drawn with conventional die is related to the occurrence in their bigger effective strain.

**54. R. Kruzel, M. Suliga;** *Czestochowa University of Technology, Czestochowa, Poland*
**The effect of multiple bending of wire on the residual stresses of high carbon steel wires.** In this paper the effect of the multiple bending of wire on residual stresses of high carbon steel wires has been assessed. It was found that the application of the multi-roller straightening machine in the banding wire process enables to reduce the residual stresses in the drawn wires. The residual stresses on the basis of stress-strain curve and metalographic investigations has been determined. It has been stated that the application of seven-rolls deformator gives the best effect of straightening.

**55. M. Terčelj, M. Fazarinc, G. Kugler, P. Cvahte*, P. Fajfar, I. Peruš;** *University of Ljubljana; *Impol, d.o.o, Slovenska Bistrica, Slovenia*
**Increasing of mechanical properties of extruded AA 6082 by optimization of chemical compositions and process parameters.In this investigation increasing of yield stress and ductility (elongation) simultaneously was achieved considering higher number of influential parameters.** Database of mechanical properties, process parameters and chemical compositions for hot extruded profiles was formed. A CAE neural network's individual as well as spatial analyses were performed to determine the influences of process parameters and alloying elements, e.g. Mg, Si, Mn, Fe, Cr and Cu, on mechanical properties.

**56. T. Večko Pirtovšek, I. Peruš, G. Kugler P. Fajfar, D. Bombač, M. Fazarinc, M. Terčelj;** *University of Ljubljana, Slovenia*
**Decreasing of edge cracking of AISI D2 tool steel during hot rolling.Aim of this investigation was to improve intrinsic hot workability of AISI D2 tool steel at industrial hot rolling of flat profiles with different aspect ratios.** Laboratory investigation comprises hot compression tests for assessment of soaking temperaturewhile in industrial conditions influence of profile aspect ratioon yield was studied. Analyse by CAE neural networks revealed thatchemical composition is very influential at edge cracking of rolled profiles. Its importance increases with increasing of aspect ratio of rolled profile.

**57. M. Terčelj, I. Peruš, A. Nagode, P. Fajfar, D. Bombač, M. Fazarinc, G. Kugler;** *University of Ljubljana, Slovenia*
**Varieties of degradation paths of nitrided microstructures at laboratory simulation of die wear in aluminium hot extrusion.** Time courses of degradation of the compound and diffusion layers of nitrided microstructures of AISI H10 tool steel were studied using laboratory simulations of the tribological conditions occurring in the hot extrusion of aluminium at a low and medium contact pressures. "Block on cylinder" test equipment was used for wear testing. In dependence of characteristics of nitrided microstructure and contact pressures different wear (degradation) paths were observed.

**58. D. Bombač, M. Terčelj, M. Fazarinc, P. Fajfar;** *University of Ljubljana, Slovenia*
**Hot compression and hot workability analysis of AISI T15 high speed steel.** Laboratory investigation of hot workability of AISI T15 high speed steel has been carried out and its improving was achieved. Hot compression tests in temperature range 1150 – 850ºC, strain rates range 0,001 – $6s^{-1}$ and applied strain up to 0,9 have been performed and microstructure of deformed specimen was analyzed. Optimal hot working conditions using processing maps were assessed. Activation energies for hot working for upper and lower temperature range were determined. Onsets of dynamical recrystallization (DRX) for applied deformation conditions on base of calculated strain hardening rate were determined.

**59. J. Tomczak, Z. Peter;** *Lublin University of Technology, Lublin, Poland*
**Analysis of metal forming process of a hollowed gear shaft.** This paper presents the results of numerical analysis of forming of a hollowed gear shaft forging, used in automotive industry. Next, the process of rotary compression for producing of axi-symmetrical hollowed forgings from pipe billet was proposed. During calculations, geometrical parameters of the obtained products were analyzed, distributions of strains and temperatures were determined. The proces force parameters were also given. In the result of conducted research works, it was stated that it is possible to form in a rotary way axi-symmetrical hollowed forgings.

**60. Z. Pater, J. Bartnicki, J. Kazanecki;** *The Lublin University of Technology, Lublin, AGH University of Science and Technology, Poland*
**3D FEM analysis of basic process parameters in rotary piercing mill.** In this paper 3D FEM analysis of process parameters and its influence in rotary piercing mill is presented. In this process material is formed by means of two skew rolls, two Diescher's discs and plug. In the result, progression of shapes, temperature and distributions of stress and strain were characterized. The numerical results of calculations were compared with results of stand test with use of 100Cr6 steel. The comparisons of numerical and experimental tests confirm good agreement betweeen obtained results.

**61. G. V. Klevtsov, R. Z. Valiev*, N. A. Klevtsova, M. V. Karavaeva*, A. V. Ganeev*, M. R. Kashapov;** *Orenburg State University, Orenburg, Russia; *Institute of Physics of Advanced Materials USTU, Ufa, Russia*
**Impact strength of steel 10 after equal channel angular pressing.** Influence of equal channel angular pressing (ECAP) on the impact strength (KCV) of carbon steel 10 (0,11%C) in the range of ductile-brittle transition is investigated. The average grain size of steel in the initial state was equal to 45 microns, and after ECAP - 300 nm. It is shown the interval of ductile-brittle transition of the steel 10 narrows after ECAP. And, after ECAP at 200 $^0$C, 4 passes, the brittleness transition temperature of steel has not changed. After ECAP at 400 $^0$C, 4 passes, the range of ductile-brittle transition shifts at 100 °C to lower temperatures. Following thermal treatment increasing impact toughness without changing strength properties is proposed.

**62. G. I. Raab;** *State Aviation Technical University, Ufa, Russia*
**Criteria for efficiency assessment of severe plastic deformation technique.** Severe plastic deformation (SPD) is characterized by large single deformations at temperatures below the temperature of recrystallization. The present work is devoted to search and justification of such criteria, related to the plastic zone and parameters of deformation zone in the course of processing of metallic materials: criterions – $A_{s_1}$ registering the scale factor; $\Delta A_{s_1}$ registering the intensity of impact; $K_{ref.ef}$, registering the refinement efficiency; $K_{gs}$, registering the efficiency of grain type structure formation.

**63. A. V. Shvychkova,V. N. Serebryany, S. V. Dobatkin,V. I. Kopylov*;** *A.A.Baikov Institute of Metallurgy and Materials Science, Moscow,Russia; *Physical-Technical Institute of National Academy of Science, Minsk, Belarus.*
**Anisotropic Deformation Behavior AZ41 Alloy after ECAP.** The purpose of study is to examine the causes of the anisotropy of the properties in three mutually perpendicular planes (X, Y and Z) of a magnesium alloy AZ41 after ECAP carried out for 4 passes at 250°C on route Bc. Considerable anisotropy of strength mechanical properties in the planes X and Z was found. In contrast, it is minimal in the Y plane. A marked difference in the microstructure and texture was not found in the all sample planes. Detected anisotropy of properties of the alloy after ECAP is associated with a different orientation of shear bands in different planes of the sample.

**64. V. V. Milyavskiy, S. V. Dobatkin*, A. S. Soldatov**, M. Mases**, E. I. Drozdova*, T. I. Borodina, O. P. Chernogorova*, G. E. Valino;** *Joint Institute for High Temperatures of RAS, Moscow; *A. A. Baikov Institute of Metallurgy and Materials Science, Moscow, Russia; **Lulea University of Technology, Lulea, Sweden*
**Aluminum - fullerene composites produced by severe plastic deformation technique.** Aluminum - fullerene $C_{60}$ composites were produced by high-pressure torsion (HPT) at room temperature under pressure of 4 GPa. Mass fraction of fullerene in the composites was 10 – 30 %. Fullerene molecules retained their cage structure after exposure to the extreme stress during HPT; the major fraction of the fullerene transformed into dimers coexisting with remaining monomers; in certain parts of the sample an admixture $C_{60}$ oligomers was detected.

**65. S. V. Dobatkin, O. V. Rybalchenko, M. N. Pankova*, K. A. Sharipova;** *A.A.Baikov Institute of Metallurgy and Material Science, Moscow; * I. P. Bardin Central Research Institute for Ferrous Metallurgy, Moscow, Russia*
**Structure and phase states of 0,08%C-18%Cr-10%Ni-Ti stainless steel after high-pressure torsion at T=20-500ºC.** After high pressure torsion (HPT) at room temperature of austenitic 0,08%C-18%Cr-10%Ni-0,5%Ti steel the average size of structural elements was 62 nm and martensitic transformations took place. HPT significantly increases the strength characteristics of 0,08%C-18%Cr-10%Ni-0,5%Ti steel: yield strength increases almost 6 times, and tensile strength - 3 times: YS = 1740 MPa was obtained after HPT at T = 300ºC, YS = 1640 MPa at EL = 10% was recorded at the temperature of deformation 500 °C.

**66. V. A. Ermishkin, N. A. Minina, A. I. Chernov, V. V. Roshchupkin, M. M. Lyakhovitskiy;** *Baikov Institute of Metallurgy and Material's Science, Russia*

**Photometric diagnostics of the structural evolution of alloy with the plastic deformation.** The samples of aluminum alloy were deformed at room temperature with the constant velocity of tension. In the process the surface of samples continuously was removed to the digital video camera and was studied by the photometric analysis of structural images. The degree of the structural damage of samples with the known values of effective stresses was determined. This dependence can be present in the form the superposition of the monotonically increasing parabolic curve, to which is superimposed alternating periodic curve with the gradually increasing amplitude. The carried out experiments made it possible to establish the critical value of the defectiveness of sample at the stage of its preexisting imperfection.

**67. Z. Keran, P. Piljek, M. Math;** *University of Zagreb, Zagreb, Croatia*

**Shear spinning: experimental, analytical and numerical analysis.** The paper gives introduction to shear spinning technology basis. Because of its simplicity and flexibility, this technology becomes a very serious competition to standard deep drawing technologies in a wide range of production processes. It is mostly concerning the production of axisymmetric sheet metal products. Using prearranged experimental data, an analytical and numerical analysis has been made. Numerical analysis was based on Finite Element Method, and MSC Marc Mentat program package was used. The results have been compared. Performed analysis showed very good matching with experimental data which offers a great help in development of new shear spinning processes.

**68. B. Grizelj, J. Cumin, I. Seuček*, N. Soškić*, B. Vujčić**, K. Knežević;** *University of Osijek, *University of Zagreb, Zagreb, **University of Applied Science in Slavonski Brod, Slavonski Brod, Croatia*

**Effect of spring-back in V-die bending of high strength steel sheet metal plates.** This article deals with the effects of technological parameters used in the v-die bending process, on the obtained product properties and dimensions. By variation of tool geometry, several cases of sheet meal bending process are observed through FEM simulations. Also by variation of different mechanical material properties, effects on product geometry are observed.

**69. S. V. Dobatkin, P. D. Odesskiy, G. I. Raab*, M. N. Pankova**, S. V. Shagalina;** *A.A.Baikov Institute of Metallurgy and Materials Science, Moscow, Russia; *Ufa State Aviation Technical University, Ufa, Russia; **I.P. Bardin Central Research Institute for Ferrous Metallurgy, Moscow, Russia*

**Structure of submicrocrystalline low carbon 0,19%C steel after equal channel angular pressing.** The ECA pressing of the 0,19%C steel at 400°C for 4, 8, and 12 passes at an angle of 120° between the channels led to the formation of the grain-subgrain structure with a ferrite structure element size of about 350 nm. Heating of the steel after ECA pressing to 400 and 450°C increases the fraction of high-angle boundaries, and the ferrite structure element size rises to 360–450 nm. The obtained grain-subgrain submicron-size structure provides a substantial strengthening (YS = 730 –790 MPa) at a sufficient plasticity (EL = 11,0–15,3%).

**70. T. Pepelnjak, V. Magoč*, B. Barišić†**;** *University of Ljubljana, Ljubljana, Slovenia, *University of Novi Sad, Novi Sad, Serbia, **University of Rijeka, Rijeka, Croatia*

**Analysis of shear hat test in digital environment.** Determination of flow curves of metals, which are indispensable for numerical simulations of forming processes, is often limited to tensile or compression tests. However in some cases the shear stress-strain behaviour of materials needs to be determined as well. In the paper digital analyses of shear-hat test at room temperature were performed for various steels, AlMg3 aluminium alloy and AZ80 magnesium alloy. Comparative analyses of process parameters and specimen geometry as a function of tool displacement were performed for better understanding of the testing procedure.

**71. Z. Pater, A. Tofil, J. Tomczak;** *Lublin University of Technology, Lublin, Poland*

**Steel balls forming by cross rolling with upsetting.** The paper describes a process of forming four balls with a diameter of 22 mm by means of cross rolling with upsetting. The paper also presents the tool used to form semi-finished balls. Owing to the application of the FEM, the course of the rolling process as well as temperature and strain distributions in the obtained balls could be presented. The rolling tests conducted in laboratory conditions at the Lublin University of Technology have proved that the balls produced with the developed rolling method meet the demands for grinding media used in ball mills.

**72. M. Stoić, B. Grizelj, J. Kopač**, A. Stoić, I. Samardžić*;** *University of Applied Sciences of Slavonski Brod; *Faculty of Mechanical Engineering of Slavonski Brod, Croatia, **University of Ljubljana, Slovenia*

**Control of dimensional accuracy in deep drawing process with more phases.** The process of deep drawing is realized in several operations which result in acumulatively greater elastic spring recovery. The final product was redesigned and two additional phases aimed to draw reinforcements were introducing. Test results confirm that deviation sap pear even after there design and as a consequence of the tool wear on functional area. Based on the identified discrepancies in the products and subsequent control of the tool, it was concluded that it is necessary to correct it with grinding.

**73. I. Alfirević, I. Skozrit;** *University of Zagreb, Zagreb, Croatia,*

**Some New Relations among the Elastic Constants in Orthotropic Materials.** Orthotropic materials have 3 mutually orthogonal planes of elastic symmetry. Although the most general anisotropic material has 21 independent elastic constants, the number of independent elastic constants in orthotropic materials are reduced to nine. These are: 3 principal moduli of elasticity, 3 principal shearing moduli of elasticity, 6 principal Poisson's ratios. However between Poisson's ratios and moduli of elasticity there are three additional relations. Two new groups of engineering elastic constants are introduced; 7 normal shearing coefficients and 3 coupled shearing moduli of elasticity . Among these elastic constants one cubic, 2 quadratic and 3 linear, invariants are established.

**74. Z. Muskalski, S. Wiewiórowska;** *Technical University of Częstochowa, Poland*

**The influence of drawing parameters on the properties high-manganese TWIP steel wires.** In the work on the way of experimental analysis the influence value of single reduction for multistage drawing process on mechanical properties of drawn wires was shown. In the aim of demonstration reasons the change of mechanical properties the computer simulation of drawing process with the use of computer program based on finite element method Drawing 2D was carried out. The wires drawn with small single reductions ($G_{p\%}$=11%) are characterized by higher value of plasticity reserve coefficient in ratio to wires drawn with large single reductions ($G_{p\%}$=26%). The decrease of tensile strength and yield strength after exceed the values of total reduction $G_{c\%}$=80% was observed which can be cased by "strain softening" process.

**75. S. Wiewiórowska, Z. Muskalski***; Technical University of Częstochowa, Poland*

**Analysis the influence of drawing process parameters on the amount of retained austenite in TRIP steel wires.** The theoretical analysis TRIP steel wire drawing process on the base of computer simulation was shown in the work. The drawing process was carried out with two variants : with small and large single reductions, for three speeds of drawing, equal:1,11; 0,23 i 0,005 m/s. The research allowed to elaboration the dependence between the amount of retained austenite, strain intensity and strain rate for drawn wires made from TRIP steel.

**76. L. Sochor, M. Balcar, J. Novák, L. Martínek, P. Fila, J. Svatoň, V. Turecký, P. Martínek*, P. Podaný, J. Bažan*****; ŽĎAS, Žďár nad Sázavou; * COMTES FHT a.s., Dobřany; ** VŠB TU Ostrava, Ostrava, Czech Republic*

**Production and heat treatment of duplex stainless steel forgings.** The production of duplex stainless steel in ZDAS Inc. includes primary and secondary metallurgic processes. For production of the basic liquid metal, the electric arc furnaces with capacities of 14 to 20 tons of a melt are used. The processing of liquid metal takes place in the secondary metallurgy equipment (LF, VD/VOD). For successful realization of heavy forgings made by

open-die forging technology it is necessary to observe the specific conditions of forming and heat treatment. The achieved microstructure of duplex stainless steel then shows a uniform proportion of ferritic and austenitic grains without undesirable inter-metallic phases.

**77. D. Letić, B. Davidović, I. Berković, B. Radulović***; University of Novi Sad, Technical High School, Kragujevac, Serbia*
**Development and implementation of computer methods at the analysis of the deformation of the beam body with the finite elements method (FEM).** This is a very substantial activity in which designer finds out possible deformations, rigidities (stifnesses) and stress states of the machine parts and fits after forming its virtual geometry, and later the real one as well. They are of the essential importance at the fast and accurate analysis of the possible elastic and plastic body deformation. In this case the point is the solid object of the device beam of an – agro – machine of relatvivelly more complex configuration.

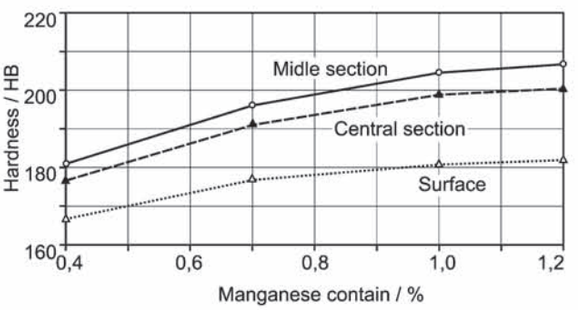
**78. D. Bombač, M. Terčelj, M. Fazarinc, P. Fajfar***; University of Ljubljana, Slovenia*
**Increasing of hot workability of 1.3302 high speed steel.** Laboratory investigation of hot workability of 1.3302 high speed steel was carried out and its improving was achieved. Hot compression tests for the determination of optimal soaking temperature as well as for the study of hot workability in temperature range 1150-850 °C, strain rates range 0,001-6 s-1 and applied strain up to 0,9 were performed. Microstructure of deformed specimen was analyzed. Apparent activation energies for hot working for upper and for lower temperature range were calculated. Onsets of dynamical recrystallization for applied deformation conditions on the basis of calculated strain hardening rate were determined. Extending of hot working temperature range at its lower limit, i.e. down 850 °C, by applying optimal soaking temperature was obtained.

**79. G. Shlomchak, I. Mamuzić*, I. Sosnev***; National Metallurgical Academy of Ukraine, Dnepropetrovski; *CMS, Croatia*
**Materials for modeling of the plastic forming processes of rheologically complex metals with low plasticity.** However, even to date many researchers continue to "model on lead" without any competent grounds of its use in the studying of a particular method of metals forming. At the same time it is often not even indicated brand of lead or its rheological characteristics, not to mention the absolute neglect of vasa vasorum of the experiment - the theory of similarity ... For studying in the laboratory environment the plastic forming processes of metals by methods of physical modeling, using the similarity theory, there were developed alloy-models of non-idealized real metals. Experimentally and theoretically was justified the usage of lead alloy - models for the studying of destruction processes. For the first time the experimental studies established that the cause of viscous destruction of the metals during rolling can be their rheological complexity.

# ADDITIONAL IMPORTANT WARNING TO AUTHORS FOR JOURNAL *METALURGIJA*

This is an "Abstract" from "Instructions to the authors" to serve as an additional important warning to authors/coauthors on how to prepare articles for publication in *Metalurgija* journal.

1. The papers must be prepared using the proper standard English language. Name and address of the professional / responsible translator (no authors) to be indicated at the end of the article as a Note.
2. Authors are obliged to **make format of an article personally by pages as it is going to be edited in the Metalurgija journal, 2 columns page A4. Max. length of an article up to 5 pages of the Journal; illustrations are included (figures and tables).** The text should be written in MS Word with letters Times New Roman, characters' size 12. Papers should be written in 3rd person, according to the legal standards and INDOK-regulations.
3. Authors are obliged to **write metrological correctly,** using appropriate terminology. The application of SIunits is obligatory. For all applied physical characteristics and factors it is necessary to enclose their list containing names and coherent SI-units.
4. The title and abstract **(max. 110 - 120 words)** and key words **(max. 5 words) should** be separately enclosed only "Key words" - italics.
5. **UDC (Universal decimal classification) is obligatory** for the paper.
6. Symbols of physical values should be written in capital and small italics and numerical values in normal letters.
7. Diagrams must be prepared using appropriable program package e.g. Corel Draw. The size of the symbols should be selected so that after the expected reduction of the figure (on 8 cm) each of the capital letters is 2 mm high, **model:**




8. The tables must be prepared similary:
   – Number of Tables - non bold
   – Description of Tables - bold
   – and **Model:**

Table 1 **Chemical composition / mas. %**

| Alloy | Dimensions of ribbons | | Chemical composition / mas. % | | |
|---|---|---|---|---|---|
| | Thickness / μm | Width / mm | Fe | Al | Cu |
| Al - Fe | 37 – 62 | 2,2 | 4,7 | 95,289 | - |
| Cu - Fe | 43 – 71 | 2,9 | 4,41 | - | 95,576 |

9. Generally the figures must be prepared similary:
   – Number of Figures - bold
   – Description of Figures - non bold
   – and **Model:**

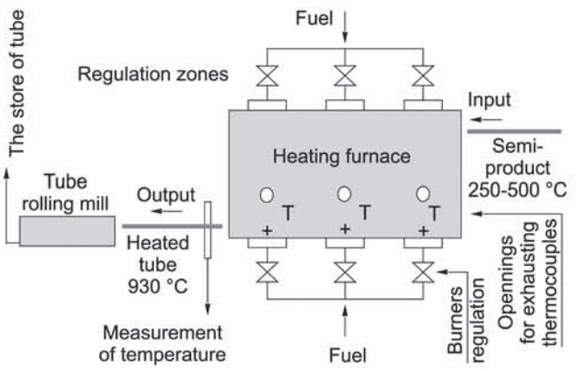



**Figure 1** Heating furnace...

10. References should be numerated according to the sequence of appearance in the paper and the number of each reference inserted into the text in appropriate position using square brackets. **the references must be cited according with the rules of Chemical Abstract** (see also "Instructions to the Authors" in journal Metalurgija) and they are of recent date. **Maxsimum 30% the Authors / Coauthors can quote personaly (one's own) the references**
11. Papers should be submitted in two print copies and one electronic version on CD, the author's address with first and the last name of all authors and e-mail should be included, to the address of Editorial Board:
    10000 Zagreb, Berislavićeva 6, Croatia.
12. Articles not prepared in acccordance with this Warning will not be officially accepted for further review and wil not be returned to their authors. The outcome of their submissions the authors can see on the Website of Croatian Metallurgical Society.

1. **G. Cukor, Z. Jurković, M. Sekulić*;** *University of Rijeka, Croatia; *University of Novi Sad, Serbia*
**Rotatable central composite design of experiments versus taguchi method in the optimization of turning.** This paper examines the influence of cutting parameters, namely cutting speed, feed and depth of cut on the tangential component of cutting force in the rough longitudinal turning operation. Two experimental plans, one based on the common rotatable central composite design and the other based on the Taguchi method with orthogonal arrays and signal-to-noise ratio, have been used to analyse impact of cutting parameters on the tangential component of cutting force and to find optimal level of the cutting parameters. The comparison of results obtained by given experimental plans was performed. Finally, the features, the merits and the limitations of the presented optimisation approaches were discussed.

2. **E. Kormaníková, I. Mamuzic*;** *TU of Košice, Slovakia; *CMS, Zagreb, Croatia*
**Optimization of laminates subjected to failure criterion.** The paper is aimed on laminate optimization subjected to maximum strain criterion. The optimization problem is based on the use of continuous design variables. The thicknesses of layers with the known orientation are used as design variables. The optimization problem with strain constraints are formulated to minimize the laminate weight. The design of the final thickness is rounded off to integer multiples of the commercially available layer thickness.

3. **M. Kostelac, N. Čular, J. Tepić*;** *Unversity of Zagreb, Croatia; *University of Novi Sad, Serbia*
**Justification of the application of tightening elements in the shaft- hub joint.** In addition to the basic requirement to be fulfilled by a joint – a reliable transfer of torque with or without axial and radial force – the joint has to have additional technical features (overload protection by slipping,, changeable rotational direction, axial and radial adjustability, centring accuracy, radial clearance, etc.) and has to meet economic requirements. An increasing number of practical hub-shaft joint applications using friction and tightening elements in particular, prove that the usage of aforementioned method is in expansion. This can be attributed to the development of innovative types of tightening elements with reduced manufacturing cost and production time.

4. **E. Kormaníková, I. Mamuzic*;** *TU of Košice, Slovakia; *CMS, Zagreb, Croatia*
**Shear deformation laminate theory used for sandwiches.** The shear deformation laminate theory is very useful for the calculation of the sandwich composites. Sandwich can be defined as a special laminate with three layers and therefore can be modeled using shear deformation laminate theory by neglecting of membrane and bending deformations in the core and the shear deformation in the facings.

5. **S. Legutko, P. Kluk, A. Stoić*;** *Poznan University of Technology, Poland; *University of Osijek, Croatia*
**Research of the surface roughness created during pull broaching process.** The paper characterizes the surface layer roughness formed in the process of pull broaching. The factors influencing the roughness of a workpiece subjected to pull broaching were analyzed. As a result of the measurements the basic roughness parameters as well as isometric images of the surface layer for different samples taken from production were obtained. 3D images were also obtained in the investigations of the surface layer of pull broached driving plate.

6. **J. Tepić, V. Todić, D. Lukić, M. Milošević, S. Borojević*;** *University of Novi Sad, Serbia; *University of Banja Luka, BIH*
**Development of the computer-aided process planning (CAPP) system for polymer injection molds manufacturing.** Beginning of production and selling of polymer products largely depends on mold manufacturing. The costs of mold manufacturing have significant share in the final price of a product. The best way to improve and rationalize polymer injection molds production process is by doing mold design automation and manufacturing process planning automation. This paper reviews development of a dedicated process planning system for manufacturing of the mold for injection molding, which integrates computer-aided design (CAD), computer-aided process planning (CAPP) and computer-aided manufacturing (CAM) technologies.

7. **W. Ptaszyński, A. Gessner, P. Frąckowiak, R. Staniek;** *Poznan University of Technology, Poland*
**Straightness measurement of large machine guideways.** This paper shows the guideway types of large machines and describes problems with their straightness measurement. A short description of straightness measurement methods and the results of investigation in straightness of 10 meter long guideways of a CNC machine by means of the XL-10 Renishaw interferometer are also presented.

8. **B. Sovilj, I. Sovilj-Nikić, D. Ješić*;** *University of Novi Sad, Serbia, *Tribotehnik, Rijeka, Croatia*
**The effect of specific relationship between material and coating on tribological and protective features of the product.** Today, parts and tools are increasingly made of composite materials. Realization of specific connection between basic material and coating is very important. The quality of coating on products, in terms of wear and resistance to destruction, has a large impact on productivity and reliability of production processes, in particular their life. In this paper, based on experimental investigations, the effect of specific relationship between the base material and coating on tribological and protective features of the product is analyzed.

9. **K. Brillová, M. Ohlídal*, J. Valíček**, S. Hloch**;** *Brno University of Technology, Czech Republic; *VŠB-Technicala University of Ostrava, Czech Republic; **TU Košice with a seat in Prešov, Slovakia*
**Evaluation of abrasive waterjet produced titan surfaces topography by spectral analysis techniques.** Experimental study of a titan grade 2 surface topography prepared by abrasive waterjet cutting is performed using methods of the spectral analysis. Topographic data are acquired by means of the optical profilometr MicroProf®FRT. Estimation of the areal power spectral density of the studied surface is carried out using the periodogram method combined with the Welch´s method. Attention is paid to a structure of the areal power spectral density, which is characterized by means of the angular power spectral density. This structure of the areal spectral density is linked to the fine texture of the surface studied.

10. **J. Valíček, S. Hloch, M. Kušnerová, M. Zeleňák, I. Samardžić*;** *TU Košice with a seat in Prešov, Slovakia; *University of Osijek, Slavonski Brod, Croatia*
**Influence of traverse speed on surface irregularities created by the abrasive waterjet.** The paper deals with the calculation of the optimal traverse speed for different types of materials, which is very important for predication, imaginings and dimensioning of technological factors and selection of the materials with the aim to increase of surface quality at abrasive waterjet cutting (AWJ) technology. The surface irregularities of the experimental used materials AISI 304, AISI 309 have been measured by non-contact shadow method. New empirically compiled equations of the influence of the traverse speed on tensometrical state of cut, deformation resistance of material and surface roughness *Ra* are at AWJ cutting available.

11. **U. Köklü***; TDumlupinar University, Simav-Kutahya, Turkey*
**Optimization of kerf and surface roughness of Al 7 475-T7 351 alloy machined with wedm process using the grey-based taguchi method.** In this study, the effects of cutting parameters on kerf and surface roughness were experimentally investigated in WEDM. Al 7 475-T7 351 alloy was selected as the work material to conduct experiments. An optimal parameter combination of the WEDM process was obtained by applying the grey relational analysis (GRA). Also, the analysis of variance (ANOVA) was carried out for finding out the contribution and the effects of machining parameters on the multiple performance characteristics (MPC).

12. **R. Staniek, A. Gessner, W. Ptaszyński, A. Myszkowski, O. Ciszak, A. Stoić*;** *Poznan University of Technology, Poland; *University of Osijek, Croatia*
**Stress and displacement analysis of a modern design lathe body by the finite element method (FEM).** The Finite element method (FEM) was used in this study for the analysis of the strain and stress of a turning machine body. The final design decisions were made on the basis of stress and displace-

ment field analysis of various design versions related to the structure of the considered machine tool. The results presented in this paper will be helpful for practical static and dynamic strength evaluation as well as for the appropriate design of machine tools using the FEM.

**13. B. Kosec, B. Karpe, A. Nagode, I. Budak*, M. Ličen****; *University of Ljubljana, Slovenia; *University of Novi Sad, Serbia; **Iskra Avtoelektrika, Gorica, Slovenia*

**Efficiency and quality of inductive heating and quenching of planetary shafts.** Presented work discusses a complex process of inductive heating and quenching of carbon steel planetary shafts for diesel engine starters. On the measurements base of temperature fields on the surface of the planetary shafts by thermographic camera and theoretical knowledge, a mathematical model for temperature conditions determination in the shaft during the entire process of heating and quenching was carried out. On the basis of developed mathematical model a computer program was developed, and used for analyses and induction hardening process optimization of planetary shafts.

**14. V. Todić, J. Tepić, M. Milošević, D. Lukić, M. Hadžistević**; *University of Novi Sad, Serbia*

**Design of casting blanks in CAPP system for parts of piston-cylinder assembly of internal combustion engines.** In order to successfully link systems of automated-design (or Computer Aided Design - CAD) with automated manufacturing systems (or Computer Aided Manufacturing – CAM), automation of manufacturing process planning is needed, i.e. CAPP (Computer-Aided Process Planning) systems can bridge a gap between design and manufacturing. In this paper is shown design of casting blanks in CAPP system for parts of piston-cylinder assembly of internal combustion engines in a manufacturing system.

**15. B. Gajdzik, T. Wieczorek, R. Wieszala***; *The Silesian University of Technology, Katowice, Poland*

**Identification of the exploatation dust in road dust.** The aim of this publication is to determine models of explore dust from vehicle brake systems and the presentation of measurement results of the exploitation dust, which is separate from road dust. The following methods and measuring devices were used: T-01M device, screen analysis, analysis of chemical composition with the use of a scanning microscope with Energy Dispersive x-ray Spectroscopy (EDS) analyser. The measurements for identifying this type of dust were conducted on marked sections of roads: motorway, city road and mountain road. The explored dust was distinguished in the following car systems: brakes, clutch plates, tyres and catalytic converters.

**16. M. Gostimirović, P. Kovač, B. Škorić, B. Savković, D. Ješić***; *University of Novi Sad, Serbia; *University of Banja Luka, BIH*

**Surface layer properties of the workpiece material in high performance grinding.** This paper focuses on the development of high temperatures in the cutting zone during high performance grinding. In order to identify the influence of grinding temperature on surface integrity, temperatures were measured in the workpiece surface layer under different machining conditions. Microstructure and microhardness of the workpiece surface layer, as well as the burned surfaces and microcracks phenomena were investigated. The conducted experimental investigations allow the surface layer properties of the workpiece material in high performance grinding to be defined.

**17. P. Frąckowiak, W. Ptaszyński, A. Stoić***; *Poznan University of Technology, Poland; *University of applied sciencies, Slavonski Brod, Croatia*

**New geometry and technology of face-gear forming with circle line of teeth on CNC milling machine.** Different types of geometric models of face-gear with circle line of teeth have been shown in the paper. Generation of a new geometrical of a face-gear is performed on CNC milling machine. The basic direction of the development geometrical of a face-gear and technology is in the search of new trends and methods focused on improving the quality of products, shortening the production cycles, their mechanizations, automation and implementation of a high-precision technology.

**18. D. Kovačević, I. Budak, A. Antić, M. Soković*, B. Kosec***; *University of Novi Sad, Serbia; *University of Ljubljana, Slovenia*

**Optimal finite elements method (FEM) model for the JIB structure of a waterway dredger.** This paper is presentation of the development of advanced approach for modeling and structural analysis of jib structure which is usually part of waterway bucket dredgers. Object of analysis is a jib structure which will be re-constructed for the excavation of grain material from a river bed. Main goal of paper is to proof benefits of enough sophisticated i.e. "optimal" FEM model for structural analysis of this type of structures in comparison with simple, but not adequate models. Proper stress state is emphasized as primary, but not only condition. It is necessary to reach serviceability and durability state, as well as affordable financial construction circumstances.

**19. S. Hloch, J. Valíček, M. Kušnerová, I. Samardžić*, D. Kozak***; *TU Košice, Slovakia; *University of Osijek, Croatia*

**Classification of technical materials according to classes machinability for hydroabrasive cutting.** This paper presents the major cutting knowledge, the opinion data and the results of actual theoretic parameters solutions and the current results, estimated by contemporary needs of hydro abrasive cutting technology. Here is a newly opened and discussed question of current data terminology disunity in the area of metrology topography surfaces of cutting walls created by abrasive waterjet.

**20. B. Gajdzik**; *The Silesian University of Technology, Katowice, Poland*

**The ecological value of metallurgical enterprise after privatization and restructuring.** The aim of the article was the presentation of the ecological effects achieved in the metallurgical company in Poland after privatization and overall, thorough restructuring. On the basis of the metallurgical company Ferrum SA (joint-stock company), the producer of the pipes, the road of the company towards the competitiveness is presented. The bases for the comparisons were various ecological aspects. Data from the environment reports of the metallurgical company Ferrum SA were used in order to conduct the analysis.

**21. R. Stefko, B. Slusarczyk*, S. Kot*, C. Kolmasiak***; *Technical University of Košice, Presov, Slovakia; *Czestochowa University of Technology, Poland*

**Transformation on steel products distribution in Poland and Slovakia.** Steel industry is one of the most globalized branch, globalization has had the influence on iron ore supply, steel production and distribution as well. In last years, steel products distribution process has changed significantly, because of rising competitiveness due to common world market influence and main global players actions. The paper presents changes in steel products distribution in Poland and Slovakia focusing on main steel producers activity in distribution as well as distributors response on new market situation.

**22. B. Gajdzik, W. Sroka***; *The Silesian University of Technology, Katowice; *Academy of Business in Dabrowa Gornicza, Poland*

**Analytic study of the capital restructuring processes in metallurgical enterprises around the world and in Poland.** The article presents the most common directions of changes in capital groups in the sector of metallurgy around the world and in Poland. The meaning of the capital consolidation was underlined on the global metallurgy market in order to gain competitive advantage through the increase of manufacturing capacity. The overview of the rating of the global steel producers in years 1989-2009 was conducted with this article in mind and it has shown the changes in the participation of particular capital groups in the world production of steel.

**23. J. Szymszal, B. Gajdzik, J. Piątkowski, J. Kliś***; *Silesian University of Technology; *Centrostal Górnośląski, Katowice, Poland*

**Optimisation of inventory management in foundry in terms of an economic order quantity.** Recording of inventory and constant monitoring have a huge impact on the cost level of enterprises operating in the metallurgical sector. The article presents methods to optimise the inventory management in terms of a size of orders. This applies to the assumed cost of storage, procurement, expenditure in time unit and unit prices calculated for a range of castings. As an optimisation tool, functions and modules supplied with the MS Excel spreadsheet have been used.

**24. I. Stanković, M. Perinić*, Z. Jurković*, S. Maričić*, V. Mandić****; *Engines & Cranes, Shipyard 3. Maj, Rijeka; University of Rijeka, Croatia; **University of Kragujevac, Kragujevac, Serbia*

**Usage of neural network for the prediction of surface roughness after the roller burnishing.** This article describes the usage of the neural network for the prediction of surface roughness after the roller burnishing. Since the observed problem is multidimensional with several input parameters and one output parameter and since nonlinearity and complexity of parameter correlation, there was used the backpropagation neural network algorithm.

Empirical and experimental values of input and output parameters were used as initial values for the learning of the neural network. Developed neural network model with its results can be used for easier implementation of further roller burnishing process plans.

**25. D. Česnik, M. Bizjak, B. Kosec, V. Bratuš***; *University of Ljubljana; *Hidria Institute for Materials, Slovenia*

**Distortion of ring type parts during fine-blanking.** Distortion control is one of the most important concerns of the metal processing industry, which also includes the fine-blanking technology. Fine-blanking of sheet metal involves metal flow and shearing, which result in complex deformation. Distortion occurs during the removal of parts from the tool due to the relaxation of internal stresses. Internal stresses that are generated during fine-blanking have an important effect on the shape and size of parts after fine-blanking. The distortion of ring type products during fine-blanking was analysed by using dimension measurements, microscopic observation and numerical simulation.

**26. B. Pandula, J. Kondela, K. Pachocka***; Technical University of Košice, Slovakia*

**Attenuation law of seismic waves in technical seismicity.** Blasting operations have positive and negative effects as well. Vibration intensity and seismic safety associated to the blasting operations are highly actual and challenging problem. The presented article describes the results of the analysis and the methodology of evaluation of objects` seismic safety during blasting operations by application of attenuation law of the seismic waves.

**27. R. Talar, A. Stoić***; *Poznan University of Technology, Poland; *University of Osijek, Croatia*

**Finish machining of hardened gears wheels using cubic boron nitride (CBN) inserts.** The paper presents some results of investigation of finish machining of hardened bearing surfaces of cylindrical gear wheels. Finish machining has been performed with wedges of defined geometry made of CBN. The presented investigation results are related mainly to the wear processes of the cutting wedges. Additional results of quality examination of finish machined gear wheels have been presented, too.

**28. A. Samolejová, R. Lenort, M. Lampa***; Technical University of Ostrava, Czech Republic*

**Specifics of metallurgical industry for implementation of lean principles.** The concept of continuous improvement is one of the types of non-technical, organizational innovation in a company. The ideal balance between innovating and effective financing is provided by the Lean principles. The basic principle of Lean is to eliminate the wastes and to increase the efficiency of production processes. The objective of this article is to define the basic specifics of metallurgical production, to analyze the classical sources of wastes (Ohno's seven wastes) from the point of view of the identified specifics and to propose the priorities for their elimination in metallurgical production.

**29. J. Tepić, V. Todić, I. Tanackov D. Lukić, G. Stojić, S. Sremac***; University of Novi Sad, Serbia*

**Modular system design for plastic euro pallets.** Although pallet, as a tool, yields significant and widely recognized economic effects in production and distribution systems, it is still not fully utilized, indicating that it needs to be defined and developed as a specific product. Euro pallet product was designed using PRO/ENGINEER software system CAD module, as one of the most popular CAx systems, yielding a pallet of novel modular design that meets all the operational requirements of the existing range. The chosen material ensures high pallet longevity and durability, in line with the concept of sustainable development.

**30. K. Janovská, Š. Vilamová, I. Vozňáková, A. Samolejová, E. Švecová, P. Besta***; VŠB-TU Ostrava, Czech Republic*

**Cost management in metallurgical production.** Price changes in the global raw material markets significantly influence the economic characteristics of Czech metallurgical companies as well. This article illustrates the utilization of changeable market situation when purchasing of raw materials influence on significant cost savings. The possible use of technical analysis methods to achieve potential cost savings in metallurgical companies is illustrated on the prices of imports of Ferro alloys - FeTi to the Czech Republic.

**31. V. Todić, J. Tepić, D. Lukić, M. Milošević, M. Kostelac***; *University of Novi Sad, Serbia; *University of Zagreb, Croatia*

**Design and economic justification of group blanks application.** Within the manufacturing process planning, blanks are either selected or designed, respectively forms of input material for the manufacture of products. Reviewed in this paper are three types of group blanks: group castings, group forgings manufactured by closed die forging and free forging, and group blanks manufactured by pressing melted metal in casts. The paper also presents requisites for design and evaluation of economic justification of group blanks application.

**32. J. Svetlík, P. Demeč***; Technical University of Košice, Slovakia*

**Mathematical modeling of machining by decomposition of lathe on modules.** The article deals with mathematical modeling of virtual machining. A specific lathe with specific parameters was selected as the machining tool. Computational model of the machine tool should be as simple as possible, but must be designed so that features all the factors affecting the accuracy of the working face. Generally, mathematical model of inaccuracies of machining is possible to use for analytical detection of inaccuracies in machining parts for a particular model machine tools.

**33. S. Vesković, M. Ivić, S. Milinković, J. Tepić*, G. Stojić***; *University of Belgrade; *University of Novi Sad, Serbia*

**Model for predicting the frequency of broken rails.** Planning of railway track maintenance cannot be done without an estimation of number of rails that will be replaced due to the broken rail incidents. There are many factors that influence broken rails and the most common are: rail age, annual gross tonnage, degree of curve and temperature in the time of breakage. The fuzzy logic model uses acquired data as input variables to predict the frequency of broken rails for the certain rail types on some Sections.

**34. P. Czech***; Silesian University of Technology, Faculty of Transport, Katowice, Poland*

**Diagnosis of industrial gearboxes condition by vibration and time-frequency, scale-frequency, frequency-frequency analysis.** In the article methods of vibroacoustic diagnostics of high-power toothed gears are described. It is shown below, that properly registered and processed acoustic signal or vibration signal may serve as an explicitly interpreted source of diagnostic symptoms. The presented analysis were based on vibration signals registered during the work of the gear of a rolling stand working in Katowice Steel Plant (presently one of the branches of Mittal Steel Poland JSC).

**35. E. Weiss, R. Weiss, J. Naščáková*, P. Červenka**, R. Turisová***; *TU Košice, Slovakia; *UE Bratislava, Faculty of Business Economics in Košice, Slovakia; **ČVUT Prague, Czech Republic*

**Valuation and comparison of return of investment for proposed use of solar systems in the Czech and Slovak Republic.** The paper deals with proposals for solar energy systems for various use, simple calculations of payback periods of solar systems financed with subsidy and without subsidy. Apart from climatic conditions, chemical composition the of the absorber and structural elements that are made of copper, respectively aluminum and Al-Mg alloy play an important role in assessing the payback period of the investment in solar panels.

**36. L. Mixtaj, J. Naščáková*, E. Weiss, R. Weiss, M. Zawada****; *TU Košice, Slovakia; *UE Bratislava, Faculty of Business Economics in Košice, Slovakia; **Faculty of Management, Czestochowa UT, Poland.*

**Evaluation of return on investment for proposed use of solar systems in Poland.** This paper focuses on analysis of costs and profits resulting from the application of solar installations in the process of heat generation for household requirements, by calculating the payback time, with taking into account prices of other energy carriers and the above mentioned subsidies. Collectors at present are manufactured solely from metals (copper, aluminium, Al-Mg alloys). The use of these materials is tied to considerable energy demand and the production technology is complex. This affects the economy of running a solar device.

**37. B. Gajdzik, K. Grzybowska***; *The Silesian University of Technology; *Poznan University of Technology, Poland*

**Example models of building trust in supply chains of metalurgical enterprises.** The article is an introduction to the notion of building trust in supply chains. In business world there are models based on trust of the companies which are connected with one another and such models are very popular.

Trust becomes the key link in the organisation of supply chains. It is one of the basic mechanisms of action co-ordination which provides the correctness of functioning in the whole chain. For the purpose of this publication example models of supply chains structures were constructed in which relationships are based on mutual trust with characteristics of the metallurgical sector taken into account.

**38. J. Dvořáček, R. Sousedíková, M. Řepka, M. Bartošíková, L. Domaracká*, P. Barták****; *VŠB-Technical University of Ostrava, Czech Republic; *Technical University of Košice, Slovakia; ** Kámen Ostroměř, Czech Republic*

**Choosing a method for predicting economic performance of companies.** This paper reports on the efforts to find a method for predicting economic results of companies. The input data files consist of 93 profitable companies and 93 bankrupt firms. From the total number of 93 firms in both categories, data of 72 firms served for establishing a classification criterion, and for the rest of 21 firms, a prognosis of their economic development was performed. The classification criterion for prognosticating the future economic development has been established by applications of discriminate analysis, logit analysis, and artificial neural network methods.

**39. I. Bostan, V.Grosu**; *"Stefan cel Mare" University, Suceava, Romania*

**The economic impact of prohibiting state aid for the romanian steel industry.** The total amount of State aid allowed in Romania has been of € 1,2 billion and was mainly awarded for financial restructuring and to a smaller extent for exemption from VAT and corporation tax. The EC has constantly monitored the Romanian steel industry and the way in which State aid has been granted by the Romanian government. As a consequence of the restructuring process– whit entry into force the EU Association Agreement was enforced – several obsolescent plants have been shut down because of physical and moral wear and tear, and the total number steelworkers has decreased significantly.

**40. V. Grosu, I. Bostan**; *"Stefan cel Mare"University, Suceava, Romania*

**The financial audit of companies operating in the metalworking industries.** In light of the effects of the economic-financial crisis and of the numerous changes occurring both on a European and a global level and altering the environment of the metalworking sector, the aim of the present paper is to focus on the specific alterations performed in the audit of the economic and financial activity and of the financial statements of each entity under consideration. Moreover, high quality audit is essential, especially in light of the numerous cases of fraud and corruption that have been documented in the past few years – occurrences we make reference to – and involving companies operating in this particular sector.

**41. K. Pałucha**; *Silesian University of Technology, Zabrze, Poland*

**Selected problems of development of the steel industry in Poland.** The article presents the background of the general condition of the Polish steel industry the basic problems associated with the functioning of enterprises in a competitive market.

**42. D. Letić, B. Radulović, I. Berković, E. Desnica, B. Davidović***; *University of Novi Sad; *Technical High School, Kragujevac, Serbia*

**The high – performance algorithm of the computer methods at the establishing of the states of stress of the brake mechanism by the finite element method (FEM).** Designing of the high – performance algorithms by the computer methods at the establishing of the states of stress of the brake mechanisms by the methods of the final elements is very substantial with fast and precise analysis of the state of stress and rigidity of the machine parts and the fits of machine parts affter forming its virtual, and later as well as real geometry. There are multiple reasons for it, and they include: economy, interchangeability and primarily its operating certainty, whose function is unavoidable especially with the parts as the brake mechanisms. To that effect are the results in the designing obtained by final elements analysis (FEA) or similar methods, very useful.

**43. C. Roman**; *"Stefan cel Mare" University, Suceava, Romania*

**The global crisis implications on steel production, Romania's case.** Iron and steel industry is an important sector of the real Romanian economy, knowing the fact that, generally, the metallurgy is a very important indicator of internal consumption. The most important companies in this sector are part of international groups (Arcelor Mittal, Mechel, TMK and Tenaris), which ensure an acceptable security standard regarding raw materials acquisitions, sales markets and treasury. However, the global crisis (2008-2010) has shown the Romanian metallurgy's vulnerability. Steel production has been reduced by almost a half, the global turnover of the Romanian iron and steel sector has dropped by more than 40% and the personnel was also reduced by a fifth.

**44. T. Pepelnjak, K. Kuzman, I. Kačmarčik*, M. Plančak***; *University of Ljubljana, Slovenia; *University of Novi Sad, Serbia*

**Recycling of AlMgSi1 aluminium chips by cold compression.** Current work elaborates possibilities for direct conversion of AlMgSi1 aluminium chips into solid billets by solid state recycling. Milling chips from an aluminium alloy were cold compressed in a closed cylindrical die by means of a 2,5 MN hydraulic press. Due to low initial relative density of the chips, several pre-compressions were needed. The influence of a compression regime due to various chip types were followed by load–stroke diagrams. Up to 97 % of density measured at extruded aluminium was attained for one type of chips. Results show that the shapes of the chips and their size (especially thickness) have a considerable influence on the final integrity of billets.

**45. D. Mates, M. Socoliuc***; *West University, Timisoara; *"Stefan cel Mare" University, Suceava, Romania*

**The development of the steel industry enhanced by the flows of foreign direct investment (FDI).** Despite the international economic crisis, the European Union has managed to maintain its important position in the world exports of metalwork manufactures, with slight imbalances recorded on its markets in 2010 and under circumstances of little importance for western European economies that have been actively competing with the Chinese economy. The present paper focuses on the role and the contribution of foreign direct investments (FDI) to the development and growth of this particular sector in the domestic economies of the EU.

**46. A. Morariu, I. Bostan**; *"Stefan cel Mare" University, Suceava, Romania*

**Trends in personnel and productivity associated with the steel industry in the Romanian economy.** The economic literature and statistical data available on the Romanian steel industry has revealed that the second option has often been the case in the past 10 years or so. Nevertheless, in order to reach the economic indicators of Westerns countries, the main Romanian steel plants should decrease the number of employees from 18 500 to 8 400. We argue that the accelerated production after the crisis would also entail increased productivity, but the lack of technological advancement and significant investments in competencies will not allow economic efficiency to exceed the average of EU developed member states.

**47. N. M. Kuznetsova, A. F. Kustodiev;** *NTU of Ukraine "KPI", Kiyv, Ukraine*

**Epitaxy Growth Mechanisms.** Examples are discussed to illustrate some of the main features of the details of the growth, and how they influence the overall structure of the deposits as growth proceeds. The aspects of the structure considered include the lattice spacings of the deposit, its physical form, and its imperfection content, especially misfit dislocations. Under some conditions, lattice tilting of the deposit occurs.

**48. K. M. Bratyna, P. I. Tertychnyi, F. K. Yaremenko;** *Lazer Science and Production Company, Vinnitsa, Ukraine*

**Real and Extended Volumes in Simultaneous Transformations.** The relationship between real and extended volumes is expanded to an indefinite number of simultaneous transformation processes. The assumption used in the present study is that the growth and nucleation of each product phase occurs randomly throughout the transforming region.

**49. V. A. Leonets, A. Lukaszewicz, L. M. Chaus, A. A. Leonets;** *G. S. Pisarenko Institute for Problems of Strength, Kyiv, Ukraine*

**Method Validation of the Adoption of Technical Solutions for Repair Parts, Components, Construction of Transport Vehicles.** Is possible through implementation running dynamic-strength tests with a given probability of obtaining reliable information about conditions repaired part or element of design, computer emulation of their work, as well as the calculation of reliability in the process cross-operational testing of probabilistic physical methods. Great economic benefit derived from the reduction in residence time of the vehicle on unscheduled maintenance, no need for a test bench refurbished units.

**50. V. A. Gladkih, A. I. Mikhalyov, N.V.Licaja, D. A. Lisiy, V. F. Lisenko;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**The inductive influence phase-to-phase on the sizeof the measured tension.** The method of adjustment to the measured error of instantaneous value of electrod tension is developed that takes into account the instantaneous values of currents nearby two power-off phases and one working phase, connected to the electric network, that allows automatically to determine the coefficients of inductive cooperation at every monophase including of stove.

**51. Y. V. Onasenko, I. V. Golub, O. C. Naumov;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine, R.N. Shevtsov, JSC "Velikoanadolsky Refractory Works", urban village Vladimirovka, Donetsk region, Ukraine.*
**Two-layer low cement castable for lining of rotary kilns/furnaces.** Two-layer low cement castable based on fireclay filler with differentiated properties of layers for lining rotary kilns/furnaces has been developed. The conditions of phase formation have been determined. The influence of the nature of microsilicasuspension on mechanical properties of low cement castable in the temperature range 110 – 1300ºC has been researched.

**52. A. J. Proydak;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Analysis of the thermodynamics of dissociation and recovery of calcium triphosphate carbon.** Data of brief analysis of the development of scientific approaches in retrospective and modern publications concerning thermochemistry and thermodynamics of calcium phosphate thermal dissociation and reduction with carbon oxide and solid carbon while pure phases and natural phosphate interact in the presence of silica and alumina are provided. The data have been used for thermodynamic modeling of ferrophosphorus melting process in terms of electric-arc furnaces using phosphorite from Ukrainian deposits.

**53. T. A. Sharabura, V. A. Pinchuk, N. Devčić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Ecological aspects of the thermal processing of water-coal fuel.** Influence of temperature on an exit of sulfur- and nitrogen-containing components in power gas by thermal processing of water-coal fuel is investigated and comparison of the maintenance of these components in power gas at various kinds of an oxidizer is presented. It is shown that use of coal in the form of water-coal fuel for the technological and power purposes allows improve essentially ecological indicators of thermal processing ways of coal.

**54. A. A. Zhurba, A. I. Mikhalyov, I. Vitez*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Fractal analysis of surfaces of Penrose.** A fractal dimension describes, as an object is filled by the space and is one of basic descriptions of fractal. The fractal distributing of surfaces of Penrose is shown by the presence of the special areas on distributing of fractal dimensions at the different sizes of cells of breaking («heavy tail») up, that underlines regularity of fractal surface in a range 1,75 – 1,77.

**55. Anatoliy M. Dolzhanskiy, O. S. Yermakova;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Regulatory support of prevailing torque type fasteners manufacturing in Ukraine.** Technical Committee of Standardization TC 136 "Fasteners" of the Ukraine state agency (its Secretariat - National Metallurgical Academy of Ukraine) has developed a number of documents, harmonized with international standards for prevailing torque type nuts of various kinds consistent with their potential producers. As result, this national economics sector efficiency increasing.

**56. A. M. Doldzhanskiy, O. A. Bondarenko, I. Mamuzić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Method of quality complex index maximizing for product and process.** It is proposed to present single quality indicators for the object (products, processes, systems), which form it's corresponding composite index, as functional with or without extremes depending on the level and significance of essential technical, technological and (or) the organizational factors. As a result, the search for rational values of the source of these factors is reduced to the multi-parameter optimization task.

**57. A. M. Dolzhanskiy, N. N. Mos'pan, D. Ćurćija;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Quality Evaluationof for Modeling of Virtual Experiment.** The method was realized for the qualimetry estimation of complex influence of dimensionless combinations of meaningful factors upon the degree of deformation by the alternating twisting, which determining the proper properties of steel wire at multiple drawing. Limitations of this method were defined: impossibility of its using for the analysis of alternating values of response function.

**58. T. V. Mikhaylovskaya, A. I. Mikhalyov;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Simulation and study of potential fields in the electron guns workspace, for developing their rational configurations.** Electron guns are widely used for of nanostructured coatings application by PVD-technology as a source of electron beam with a given kinetic energy and the configuration of which is directly used as the cleaning of substrates and for deposition of thin films. That is why the modeling of potential fields in the of the electron gun working space is an actual task that will allow to examine their characteristics, based on computer models, and thereby develop electron guns of high quality.

**59. M. A. Myronenko, A. V. Kramarenko, M. M. Gizenko***; National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Motivational factors in HR small metallurgical enterprises in the post-crisis period**
**In this paper an example case study addressed issues of motivation of employees of industrial enterprises.** In this paper were considered issues of motivation employee industry. The structure of the labor activity motivation of managers and experts of the enterprise were analyzed, and recommendations for its improvement were submitted.

**60. Yu. P. Synytsina, H. Yu. Shportko, I. A. Alyexeyenko;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine*
**Strategic management of metallurgical enterprise under market conditions.** Ensuring of development and successful operating of metallurgical enterprise under competitive market conditions is achieved by strategic management by such areas. Reduction of material cost – first of all energy use – in metal production. Restructuring of production based on introduction of new technologies and equipments. Active innovation investment policy within selective orientation of measures. Optimization of human resources potential of enterprises and implementation of new management techniques.

**61. Yu. P. Synytsina, H.Yu. Shportko, I.A. Alyexeyenko;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine.*
**Management of the strategy of enterprise during a crisis.** One of the controlling mechanisms of strategy of enterprise is corporate restructuring. Strategic restructuring is seeking to add value of the owned capital for shareholder, to keep corporate property and to meet the challenges of corporation in whole. Restructuring of corporations, which are in a grip of crisis, is concentrated on the solutions those are aimed at reorganization of insolvent enterprises or bankrupts on purpose to return them to operating state.

**62. U. V. Sivoplyas, M. Jurković*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Internal innovations as intangible project assets of industrial enterprises.** Consideration of internal project innovations (II) as intangible assets (IA) of the organization leads to increase of use of all available resources, the competitiveness level, security and new value both a project and an organization as a whole. II appear in the project due to the project team's knowledge of the who have timely change and affect the quality of the project. Therefore a rational development of knowledge management in project management at industrial enterprises is necessary.

**63. U. V. Sivoplyas, L. L. Karmazina, R. Križanić*;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Knowledge management in project management area at industrial enterprises.** One of the most influential factors on a project-oriented industrial enterprise, resulting in the introduction of changes to the knowledge system of the enterprise is the closest project environment - staff and stakeholders of the project. Therefore, the concept of application of knowledge in projects gives it possibilities of innovation development. But in order to intelligently and competently consider questions which are associated with it there is need to pick out the area of knowledge management in project management area by PMBOOK.

**64. J. G. Momot, N. Devčić;** *National metallurgical academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Cost management industry in crisis.** It is recommended to perform the following steps: the formation of the company's budget, integration (horizontal and vertical) analysis of the opportunities outsourcing expensive processes, new forms of payments to contractors (bills of exchange, barter), optimization of technological processes; revision assortment and pricing policies of the company, work receivables and payables; gain control functions of all kinds of costs, optimizing use of resources, selection of goods that yield the greatest profit of the company (ABC-analysis), optimization of cash flow, reduce labor costs and reorganize the personnel management system.

**65. V. M Akhundov, T. A. Skripochka;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**Modelling of the welded rubber hinge. Coaxial torsion.** In the real article we present some results of research of the coaxial twisting of rubber and metallic hinge from coercible elastic material.

**66. A. O. Sulim-Timovty, A. M. Dolzhanskiy;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine*
**System account of quality indexes at the project-oriented organization activity planning.** Analytical dependence of integral index constituent's development level for of the project-oriented organizations internal environment is definite on substantial influence factors. It allows quality optimizing and project command quantitative composition in organization.

**67. N. P. Rudenko, D. Ćurćija*;** *National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine; *CMS, Croatia*
**Mathematical model of acid etching.** Generalized problem of optimization of acid etching technology is formulated and mathematical formulation in the form of conditional task of mathematical programming is given. Empirical dependence equations of corrosion rate and scale removal time on etchant temperature and strength are given.

**68. M. Stashkiv;** *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
**Methods of Determination of SIF for the Thin-walled Elements.** This paper examines the engineering methods of determination of stress intensity factors (SIF) are considered for the elements of the opened type with cracks. These results for determination of SIF for cracks in crossrunner of the complicated configuration, allow more precisely to define a resource and promote reliability of constructions from the thin-walled elements of the opened type.

**69. T. Rybak, O. Tsion***; Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
**Equipment for simulate torsional loads.** For the simulation of loads, which are perceived torsional materials proposed to use equipment which includes a patented device to control the tangential stresses in the tested material, throttle to control loads, engine, clutch, auxiliary equipment. Using this equipment will significantly reduce the technical - economic costs for research, expand the type studied engineering designs, and the results to calculations the reliability of the site as a whole.

**70. V. Babiy;** *Ternopil National Ivan Pul'uj Technical University, Ternopil, Ukraine*
**Method of solving of shell theory limit tasks.** Analysis of contact task solving is carried out. Interrelation of the thin-wall body with the elastic and hard bodies is analyzed. As a result it was found that conditions of the real contact interrelation can not be defined within the shell theory. The choice of the cylinder shell elastic supports thickness is analyzed in the work. As a result approximate solving of the task is obtained. It is more accurate as compared with the generalized solving within the shell theory equations. In precise solving elasticity theory spatial equations are used.

**71. G. Brovč, F. Pavlovčič, D. Vončina, B. Kosec, S. Kobal*, M. Bizjak***; University of Ljubljana, Ljubljana, Slovenia; * Iskra Avtoelektrika, Šempeter pri Gorici, Slovenia*
**Characterization of starter motors swicth contact material based on the measurement of electrical parameters.** Switching of electric current in case of starter motors switches of internal combustion engines. Some features at the initial stage of switching electric motor engine are: bounced contacts, contact material evaporation, ionization of its molecules, formation of arcs and, consequently formation of welds. By measuring the parameters of these features that occur within a few ms and characterization of arcs, which depend on the nature of the contact material, the materials can be characterized precisely. The scope of the research is characterization of contact materials based on copper alloys and powders with subsequent oxidation.

**72. A. Smalcerz, R. Przyłucki;** *Silesian University of Technology, , Katowice, Poland*
**Electromagnetic field analysis of inductor – robot - work-piece system.** The paper presents an analysis of the influence of the industrial robot located nearby an induction heater on the electromagnetic field distribution. Experiment consists of numerical analysis and measurement verification. Altogether few variants which differed in: the presence (or absence) of the robot, the value of the heater power and work-piece parameters were considered. As a result the distributions of the electromagnetic field around the heater were obtained. Evaluation of the industrial robot location on magnetic field intensity was presented and discussed.

**73. P. Czech;** *Silesian University of Technology, Katowice, Poland*
**Application of multi layer perceptrons (MLP) – fast fourier transform (FFT) for detection of gearbox faults in power transmission system.** The paper presents the results of an experimental application of artificial neural network as a classifier of the degree of cracking of a tooth root and the degree of chipping tip of the tooth in a gear wheel. The neural classifier was based on the artificial neural network of MLP type (Multi Layer Perceptrons). The input data for the classifier was in a form of matrix composed of statistical measures, obtained from vibration signal and FFT analysis (Fast Fourier Transform).

**74. O. Ciszak, A. Myszkowski;** *Poznan University of Technology, Poznan, Poland*
**Modeling, simulation and assessment of an automatized upholstering workstation.** The paper deals with the aspects of computer-assisted modeling, simulation, and assessment of an automatized passenger seat upholstering workstation. It presents an overview of the developed models, simulation analyses, as well as an assessment of selected configuration variants following several patterns of the upholstering process. In its final part, the article addresses the results and ultimate conclusions concerning the simulative and experimental investigation of the prototype automatized upholstering workstation.

**75. A. Šalej, T. Rijavec, P. Fajfar;** *University of Ljubljana, Slovenia*
**Nitinol in textile.By using Nitinol in tekstile, it is possible to design and develop smart textiles and clothes with self-adapting functions for diverse fields of application.** The change of the shape of Nitinol-containing textiles is induced by an external source of heat, such as body temperature, environment temperature, hairdryer, or resistive heating of Nitinol with the electric current passing through the alloy. A yarn core, made from pre-programmed Nitinolfibers which are less than 100 μm thick, is wrapped with textile fibers. Because of low extensibility and high rigidity of Nitinol, it is difficult to bend the yarn to create loops which makes knitting a highly demanding process.

**76. N. L. Chekunova-Tomacheva, I. E Uskova;** *National University of Science and Technology "MISIS" (MISY), Moscow, Russia*
**Methodology of innovative orientated scientific development promotion into industry.** Technology centers transforms the technological innovations from universities and other research institutions or business enterprises to the surrounding area and encourage cooperation between these organizations to create technologic chains from the very beginning of the innovation till the creation of a new product. Potential benefits of innovation and technology centers in understanding of the needs and in creating opportunities for innovation are very high. They provide flexibility and ability to respond rapidly to market needs, which are of no less importance.

**77. I. E Uskova, N. L. Chekunova-Tomacheva National University of Science and Technology "MISIS", Moscow, Russia**
**Typical potentional investors for innovative oriented R&D.** For the correct selection combination "investor - innovation-oriented scientific development" the following things should be done: - Technical analysis, on the basis of which the most suitable for the innovation-oriented development scientific techniques and technologies are determined; - Commercial analysis including the retail market analysis of the products that can be made as a result

of innovation-oriented scientific development; – Institutional analysis. During investors selection in scientific research programs, methods based on a study of the financial - the state of the enterprise – investor may be used.

**78. J. Tušek, M. Hrženjak*, A. Skumavc, D. Klobčar;** *University of Ljubljana, Ljubljana, Slovenia; *TKC Laboratory and welding klinik d.o.o., Ljubljana, Slovenia*

**Permanent joint of electric cables, connectors and other electrical components.** The first part describes the basics of welding and brazing of electrical elements into permanent joint and also gives a review of the literature from this area. The emphasis of this research is on laser, resistance, ultrasonic and hybrid welding and brazing technologies. The cross-sections of the welded joints made under different process parameters were observed. The last part presents the findings, conclusion and directions for further studies. Optimal welding and brazing parameters were found in order to achieve the best properties of the joints of electric components.

**79. I. Alagić, D. Kozak*, K. Šimunović*;** *University of Zenica, Zenica, BIH, * University of Osijek, Slavonski Brod, Croatia*

**Analysis of gear oil pump flow capacity using design of experiment.** The investigation is realized under exactly established plan using statistical analysis of results with application of regression analysis. The theory of experimental design through the models of the first and second order was applied here to obtain a functional relationship between revolution speed, pressure, oil temperature, and gear normal pressure angle on the one side and flow capacity on the other side.

**80. I. Samardžić, A. Stoić, M. Duspara, M Stoić*, M. Bošnjaković*;** *University of Osijek, Slavonski Brod, *University of Applied Science in Slavonski Brod, Slavonski Brod, Croatia*

**Machining of the reparatory weldments on the duplex steels.** This paper identifies and explains the selection of the proper machining conditions for the reparatory weldments on duplex steels. The paper also provides guidance for proper common implementation of these two technologies. Investigation contains cutting tool life tests obtained for tools supplied by different manufacturer. Machining tests were performed on the lathe and turning process of duplex steel was observed.

**81. D. Kozak, P. Konjatić, J. Sertić, M. Kokanović, D. Damjanović, T. Baškarić;** *University of Osijek, Croatia*

**Experimental and numerical determining of bearing of water-tube boiler membrane wall for incineration power plant.** Large water-tube boilers which act within energy power stations are, usually, hung on steal construction or supported on distributor chambers. In case of *A.S.A. Incineration Zistersdorf* waste heat boiler, supports are placed on sideward membrane walls. After two years of boiler work, an analytical and numerical strength calculation of membrane wall in zone of two critical supports was done. In critical spots, the nondestructive testing was done. Determination of surface cracks was done by means of magnetic powder. Structure impress were analyzed according to VGB Richtlinie TW 507/2005. The condition of degradation of membrane wall pipes material due to exposure to creep was evaluated.

**82. R. Slavkovic, Z. Jugovic, D. Kozak*, A. Veg**, R. Radisa***, S. Dragicevic, M. Popovic;** *University of Kragujevac, Serbia, *University of Osijek, Croatia; **University of Belgrade, ***Lola Institute, Belgrade, Serbia*

**Simulation of the casting process - a powerfull tool for enchanced design of the cutting teeth in surface mining.** Among certain number of dedicated software packages the MAGMASoft is selected for availability reasons. Its effectiveness is proved with the simulation of moulding process of the cutting teeth for a bucket wheel excavator. Use of MAGMASoft enables a shortcut to a forceful and durable product, without internal cavities and microporosity. Properly simulated casting process reveals moulding faults, as well the points and the stages where the correction or improvement is needed. Such advancement of the moulding process is described in this paper.

**83. T. Baškarić, A. Šumanovac, D. Kozak, Ž. Ivandić, T. Ergić;** *University of Osijek, Croatia*

**Device for mechanical testing of fetal membranes (chorioamnion).** Premature rupture of fetal membranes alone is associated with 30 to 40 percent of all preterm births and is considered as one of the main obstetrical complications resulting preterm delivery. Factors that affect rupture of fetal membranes may be pathological, mechanical or biochemical. In order to understand the mechanical influences of fetal membrane rupture is necessary to examine the properties of the membrane. For the purpose of testing the mechanical properties of fetal membranes will be developed device suitable for such testing.

**84. V. Todić, M. Zeljković, J. Tepić, M. Milošević, D. Lukić;** *University of Novi Sad, Novi Sad, Serbia*

**Techno-economic method for evaluation and selection of flexible manufacturing systems (FMS).** To find best FMS solutions, experts use numerous multicriteria methods for evaluation and ranking, methods based on artificial intelligence, and multicriteria optimization methods. Presented in this paper is a developed techno-economic method for evaluation and selection of FMS based on productivity. The method is based on group technology (GT) process planning.

**85. B. Matić, J. Tepić, S. Sremac, V. Radonjanin, D. Matić, P. Jovanović;** *University of Novi Sad, Serbia*

**Development and evaluation of the model for the surface pavement temperature prediction.** This paper examines the existing models for predicting pavement temperatures and formulates a new one using a regression equation to predict the minimum and maximum pavement surface temperatures depending on the air temperature. Also, the paper presents a model for pavement temperature prediction according to the Superpave methodology and conducts the validation of the model for measured temperatures.

**86. K. Janovská, Š. Vilamová, P. Besta, A. Samolejová, I. Vozňáková;** *Faculty of Metallurgy and Materials Engineering, VŠB – Technical University of Ostrava, Ostrava, Czech Republic*

**Determination of complex energy consumption of metallurgical production on the base of mathematical modelling of interdisciplinary linkages.** The article suggests the possibility of using methods of structural analysis to the determination of the complex energy demands in metallurgical production, which would include both the energy demands of direct inputs of energy media and the energy demands of previous metallurgical stages and the energy demands of purchased materials and services.

**87. B. Gajdzik, A. Wyciślik;** *The Silesian University of Technology, Katowice, Poland*

**Assessment of environmental aspects in a metallurgical enterprise.** The publication characterises the quantity and quality methods applied in the assessment of the environmental aspects. The method of cumulated environmental loads is particularly interesting, where the network of process connections within an enterprise and between it and the surrounding (the co-operation of the enterprise with the suppliers of resources and materials, the networks of energy resources and distributors of products or other contributors in the chain of added value. The paper finishes with an example presenting the methodological assessment of the environmental aspects in the metallurgical enterprise.

**88. B. Gajdzik;** *The Silesian University of Technology, Faculty of Materials Science and Metallurgy, Katowice, Poland*

**Comprehensive classification of environmental aspects in a manufacturing.** This paper presents a comprehensive approach to classification of environmental aspects with a broad set of criteria which may be useful in a manufacturing enterprise in defining the relevant aspects. Additionally, the publication presents the list of key environmental aspects for metallurgical enterprise. According to standard ISO 14001:2004 process of environmental aspects identification should be planned. The paper finishes with a scheme presenting the place of the environmental aspects identification procedure in the system of environmental management.

**89. K. Grzybowska, B. Gajdzik;** *Poznan University of Technology, Poznan, The Silesian University of Technology, Katowice, Poland*

**Optymisation of equipment setup processes in enterprises.** Fast equipment setup in a machine on production line is the key precondition to increase the flexibility of the production. Methodology of SMED (Single Minute Exchange of Die) is an example which allows reducing the time of setup

practically to the minimum. The article presents the theoretical bases and required rules as well as case study conducted in one of chosen enterprises. This paper also answers the question if SMED methodology is applicable in metallurgical sector, presenting the example of shortening the time between the production of various metallurgical products manufactured in the machine for continuous casting of steel.

**90. M. Zacharov, R. Farkašovsk;** *Technical University of Košice, Košice, Slovakia*
**Analysis of the rocks exposed to high temperatures for purposes of the thermic hole sinking.** The aim of the artice was to excavate a hole by the process of melting and mechanical destroying (crack formation) into the rocks. The rock material was exposed to the temperatures of 1700 – 1800 °C in the atmospheric conditions. Further petrographic analyses, mainly microscopic investigation of the rocks were made (activity 4.1). Also formation and radius of the cracks in different rock types were observed. The penetration of the melt into the cracks and its reach in cracks during high temperatures was characterized (activity 4.4).

**91. K. Jelšovská, B. Pandula;** *Technical University of Košice, Košice, Slovakia*
**NMR study of polymer liquid crystals.** In our studies two samples of the nematic polymer liquid crystals LCP A – 123 and LCP A – 137 based on the aromatic polyesters we used. The aim of this paper is the study of the possible structural heterogeneity, i.e. to identify different structural phases, to detect any structural changes, phase transitions and relaxation transitions by broad – line $^1$H NMR and $^1$H spin – lattice relaxation time. The measurements were carried out within a temperature range from –100°C to +150°C. Two areas have been detected that correspond to different motion in polymer group. If in these materials leads to phase transitions, then they will be implemented at higher temperatures than 200°C, which was realized in our experimental conditions.

**92. A. Csikósová, M. Antošová, A. Seňová, K. Čulková;** *Technical University of Košice, Košice, Slovakia*
**Impacts of the economical crisis to the steel industry in Slovakia.** Contribution deals with the evaluation of reasons and impacts of rising and existing of economical crisis to the steel industry and with measurements for elimination of crisis reaches and maintenance of competitiveness of U.S.Steel Košice at the steel market. From the industrial perspective we can see demand for building and car industry, equipments and packing or tinned plates. Such types of investments presents „drive motor"for future growth of the company. Less independence on the distributors will enable company to draw to the demand of final consumer and to develop relationships that are necessary for creation of long term strategic partnership.

**93. A. Csikósová, M. Antošová, A.Seňová;** *Technical University of Košice, Košice, Slovakia*
**Benchmarking of steel plants in Europe.** More and more bigger attention is giving in the steel industry to the modern management methods of market research and comparison with the competition. In last years benchmarking had became the spotlight as an effective tool for business improvement. The goal of contribution is benchmarking of the chosen companies in selecting areas of the entrepreneurship that are used in the suggestion of references for the increasing of control effectiveness in U.S.Steel Košice, ltd. with determination of the new courses for the development of steel companies .

**94. L. Mihalová;** *TU Košice, Košice, Slovakia*
**The teplica karst spring hydrogeological evaluation; Jasov, Slovakia.** The analysis based on statistical processing of regime observations at the Teplica spring provides integral view on regime-creating agents influence to the groundwater regime of the partial hydrogeological structure the spring drains. The analysis mentioned is based on statistical processing of regime observation of Teplica well, an integral view of particular regime-creating conditions influence to the regime of ground water hydrogeological structure of area drained by this well is given.

**95. L. Mihalová;** *TU Košice, Košice, Slovakia*
**Determining characteristics of hydraulic parameters.** The paper focuses on relation of permeability and lithology or Paleogene formations explanation. A functional relation of a mean permeability to lithology is not definite. Even though sandstone- and conglomerates- dominated Borové Fm. expresses a higher permeability, the difference to the pelitic Huty Fm. is not as clear as expected. Results then correlate with chemistry of grondwaters, for fluids associated with formations of weak permeability manifest the Na prevalence over the Ca-HCO3 associated component.

**96. S. Jacko;** *Technical University of Kosice, Slovakia*
**Geological and geothermal conditions in the southeastern part of the Central Carpathian Paleogene Basin (CCPB) in the Eastern Slovakia.** CCPB is the largest Paleogene basin in the Central Western Carpathians (CWC) rimming simultaneously the western margin of the East Slovakian Neogene basin fill. The general chemical composition of geothermal waters in CCPB shows highly natrium – chloride type containing a minor portion to absence of a natrium – hydrogen carbonate component. Total mineralization varies from 27 to 32 g/l. The mentioned attributes incl. other geochemical factors (i.e. $HCO_3$/Cl, Na/K and relatively low content of biogenic elements), indicates a geochemical closure of the hydrogeological structure.

**97. G. Amza, D. Dobrota;** *University of Bucharest, «Constantin Brancusi» University of Targu Jiu, Romania*
**Risk estimation of air pollution produced by a welded constructions company.** The study refers to the air pollution produced by a welded constructions company that achieves a production of 1000 t of products/month. Air quality monitoring was conducted in the area of influence of the welded construction company that is 200 m radius around the company and the monitoring period was May to September, 2008-2011. Air quality monitoring was performed in seven different monitoring stations denoted by A, B, C, D, E, F, G. For air quality monitoring we have measured the concentrations of various pollutants ($NH_3$, $NO_2$, $SO_2$, CO, $H_2CO$, HCl, phenols), and for each hazard the hazard ratio was calculated.

**98. B. Gajdzik***; Silesian University of Technology Katovice, Poland*
**Diagnosis of employee engagement in metallurgical enterprise.** In the theoretical part of the publication an overview of the definitions of employee engagement was conducted together with the analysis of the methods and techniques which influence the professional activity of the employees in the metallurgical enterprise. **The practical part discusses the results of diagnosis of engagement in steelworks.**

**99. C. Lazăr, C. Roman, I. Bostan***; "Ovidius" University, Constanta, "Stefan cel Mare" University, Suceava, Romania*
**Efficiency quantification in technological contexts aiming at consumption minimization and maximizing industrial production.** Through this work we intend to point out some fundamental aspects regarding the calculation of efficiency for factors used in industrial systems (productive ones), using mathematical functions (production functions). For this, we approach technology as a triplet - $\tau$=(N,K;Y), were N represents the labor factor, K the capital stock and Y the result obtained by using the two factors. Then, considering the production function as being y=x(x1,…,xn) (the results of an activity based on the production factors used for obtaining certain goods), we show how to determine the average yield of each production factor (N,K;Y). We refer to two consecutive moments in the evolution of the production volume, made obvious by indices 0 and 1.

**100. Z. Kaláb, B. Pandula, M. Stolárik, J. Kondela***; Institute of Geonics, Ostrava, Cech Republik, Technical University of Košice, Slovakia*
**Examples of law of seismic wave attenuation tunnelling and underground space technology.** This paper summarized results from several experimental seismological measurements in different tunnels in Czech Republic and Slovakia. General graph of obtained maximum vibration velocities depending on so callled reduced distance was compiled.

**101. Lenort R., Klepek R., Samolejová A.***; Technical University of Ostrava, Czech Republic*
**A New Concept for Heavy Machinery Production Planning and Control.** The paper introduces a new concept for planning and control of complicated heavy machinery production which is based on the principle of „production paths". The proposed concept significantly reduces difficulties of heavy machinery production planning and control, it cuts semifinished products stock and improves the material flow continuousness, the balance and utilisation of production resources as well as the whole production process. The implementation of the production planning and control concept applying the production paths and its benefits are demonstrated on the forged pieces machining.