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RESEARCHES ON OBTAINING THIN FILMS OF STAINLESS STEEL FROM INOXIDABLE STEEL BY PHYSICAL VAPOR DEPOSITION MAGNETRON ASSISTED

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ABSTRACT

The experimental researches carried out in this paper aimed at obtaining thin films of stainless steel and their characterization in terms of structural, optical and electrical properties. The films were made using a PVD spraying system consisting of a vacuum chamber with a capacity of 2 liters, a plane magnetron with ferrite magnets (φ40x22x9) neodymium (φ15x8), a vacuum pump with sliding blades, a DC source of 100 to 600 volts. The atmosphere used for the maintenance of plasma during deposition was rarefied argon in a pressure range of $3 \cdot 10^{-2}$ - $8 \cdot 10^{-3}$ *mbar. The argon flow rate used was 100* cm^3/min*. The support material consisted of glass plates of 76x25x1 mm dimensions and copper plates of 80x20x1 mm. It has been noticed that the properties of the deposited films are influenced by the parameters used. It has been found that when increasing the deposition time, the surface resistance and transparency decrease.*

KEYWORDS: d.c. magnetron, electrical and optical properties, stainless steel deposition

1. Introduction

Thin films have become a major research area with applications in electronic, optical, magnetic, biochemical, protective, sensing or catalyzing devices. Nanometric dimensional control allows very good flexibility in adjusting thin film properties and adapting both the properties and behavior of the devices containing them.

There are several methods of thin films deposition, the PVD method being the most widely used. Choosing one of them depends on: the requirements for the thin layer properties, the maximum temperature the substrate can withstand, the compatibility of the process with the processes applied to the substrate before and after deposition, and finally the production costs, the efficiency and the large-scale manufacture of the products.

The control of the deposition of thin films from the vapor phase involves a thermodynamic and kinetic control of the phase transition (evaporation - condensation), nucleation of the crystalline phase to condensation of molecules on the surface of the substrate, growth of nuclei or film grains, and activation of processes such as diffusion and desorption of molecules.

The production of thin films from austenitic stainless steel is the basis of applications in the microelectronic, micromechanical, food, chemical, petrochemical, energy and medical industries requiring materials resistant to corrosion, abrasion, friction, oxidation at high temperatures as well as in making decorative pieces.

The terrestrial, naval, aerial, space transportation means also includes components made of stainless-steel coated materials of good mechanical strength as well as resistance to aggressive environments and atmospheres.

The unlimited resistance to erosion of austenitic stainless steels has been noted, compared to the poor corrosion resistance of copper where the corrosion products are fragile and easy to shear [1, 2].

Resistance to high temperature oxidation and corrosion in different environments, correlated with mechanical and physical properties, are primary elements, stimulating the creation of new films of stainless steel.

The research carried out in this paper has as general objective the setting up of a technology for obtaining thin films of austenitic stainless steel X10CrNi 18-8 and their characterization.

2. Experimental Conditions

A circular austenitic stainless-steel plate with a diameter of 46.5 mm and a thickness of 1 mm was used as the target for the films.

The support material consisted of glass plates of 76x25x1 mm and copper plates of 80x20x1 mm.

The films were made using a PVD sputtering system consisting of a vacuum chamber with a capacity of 2 liters, a planar magnetron with ferrite magnets (φ40x22x9) neodymium (φ15x8), a vacuum pump with slides blades, a DC source of source of 100 to 600 volts.

The installation allows varying the magnetron substrate deposition distance between 25 and 90 mm, and the substrate temperature can be monitored with a chromel - aluminum thermocouple.

The atmosphere used for plasma maintenance during deposition was thinned argon in a pressure range of between $3 \cdot 10^{-2}$ - $8 \cdot 10^{-3}$ mbar. The argon flow rate used was 100 cm^3/min.

Fig. 1 illustrates the device used for the experimental researches.

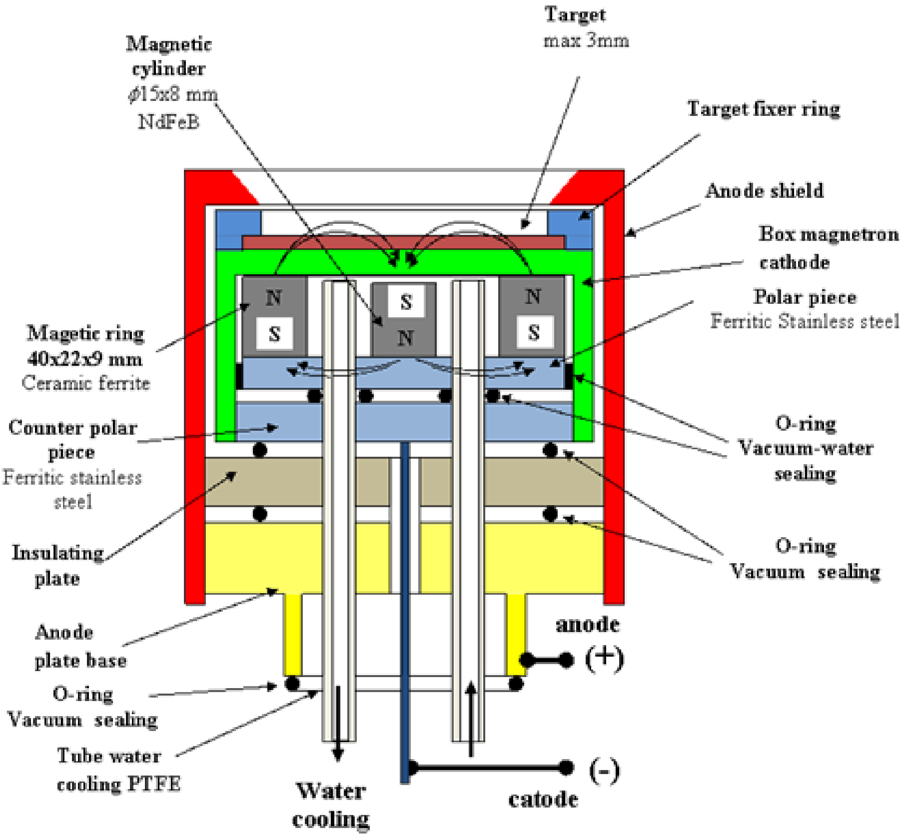


Fig. 1. *Magnetron scheme*

The microscopic analysis of the obtained films was performed using a Neophot 2 optical microscope with the acquisition of computerized data.

Transparency of films was determined using an electronic device that uses a light source and a photoreceptor. The light after passing through the film is measured with the photoreceptor and an amplifier and the result is displayed by means of an analogue device.

The electrical properties (resistivity) of the films were determined using the four-point collinear probe method using a laboratory device. As a principle, this is to inject the current through two external points and measure the voltage at two internal points.

With thin films, resistivity is calculated by the relation:

$$\rho = \frac{\pi \cdot t}{\ln 2}\left(\frac{U}{I}\right)$$

where: t – layer thickness, U – measured voltage, I – applied current.

$\frac{\rho}{t} = \frac{\pi}{\ln 2}\left(\frac{U}{I}\right)$ - surface resistance of the film.

The stages of obtaining the deposits were:

a. preparation of substrate surface

b. film deposition by DC magnetron sputtering process

a. Preparation of substrate surface

This step consisted of washing the glass plates (size 76x25x1 mm) with a special detergent, washing them with water, then with distilled water, ultrasonic cleaning with ethanol and then drying with compressed air.

b. Film deposition by DC magnetron sputtering process.

To obtain the films, a circular austenitic stainless-steel plate was used as target, the chemical composition of which, revealed by spectral analysis, is shown in Table 1.

A series of regimes shown in Table 2 were used to obtain the films.

Table 1. *Chemical composition of the austenitic stainless steel X10CrNi 18-8 used as target*

Chemical composition [%]										
Mo	**C**	**Si**	**Mn**	**S**	**P**	**Cr**	**Ni**	**Al**	**V**	**Ti**
0.30	0.046	0.28	1.34	0.005	0.004	21.45	7.58	0.01	0.07	0.05

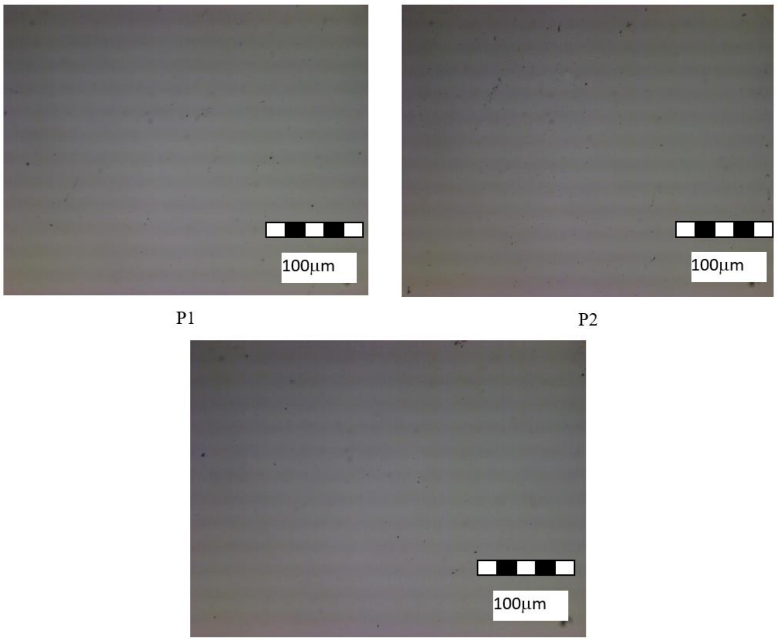
Table 2. *Working regimes used in film deposition*

Sample code	**Voltage [V]**	**Current [mA]**	**Pressure [mbar]**	**Substrate temperature [°C]**	**Target – substrate distance [mm]**	**Deposition time [min]**
P1	550	55	2.5×10^{-2}	35	66	10
P2	540	55	2.5×10^{-2}	35	66	20
P3	545	55	2.5×10^{-2}	34	66	40
P4	550	55	2.5×10^{-2}	34	66	40
P5	550	55	2.5×10^{-2}	34	66	20

3. Experimental results

The optic microscopy analysis revealed that the films obtained did not show cracks, were homogeneous and adherent as shown in Fig. 1.

The analysis of the electron microscope revealed the structure of the deposited film and its chemical composition by the EDS method, Fig. 2 and 3.



P1

P2

P3

Fig. 1. *Image of the films deposited under different regimes*

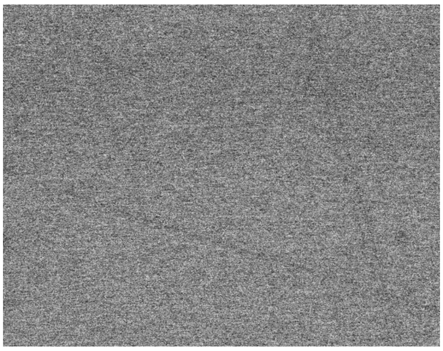
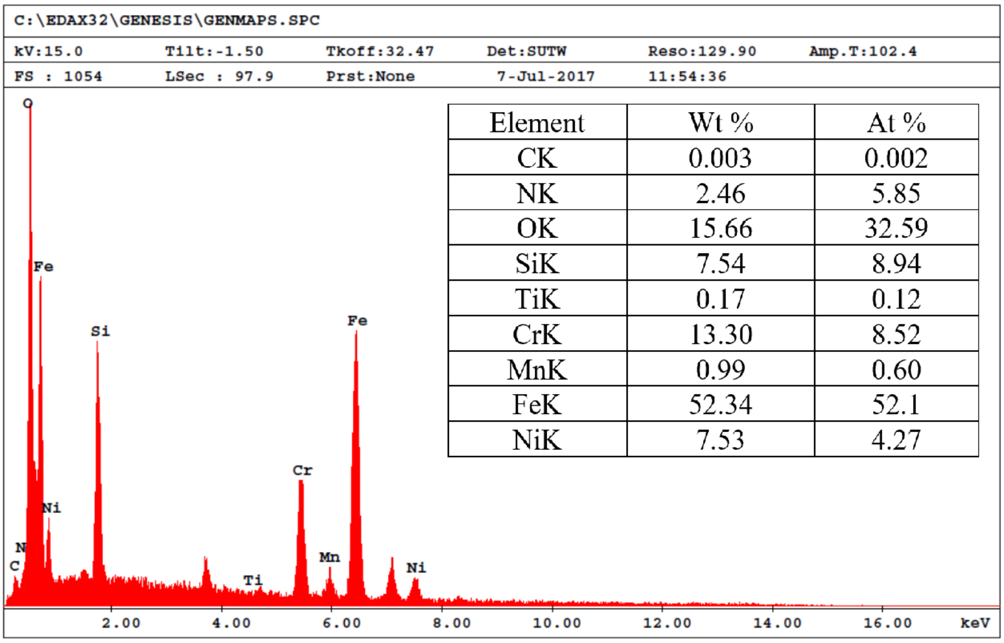


Fig. 2. *SEM image of the austenitic stainless-steel film*



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C:\EDAX32\GENESIS\GENMAPS.SPC
kV:15.0        Tilt:-1.50     Tkoff:32.47    Det:SUTW       Reso:129.90    Amp.T:102.4
FS : 1054      LSec : 97.9    Prst:None        7-Jul-2017   11:54:36
```

Element	Wt %	At %
CK	0.003	0.002
NK	2.46	5.85
OK	15.66	32.59
SiK	7.54	8.94
TiK	0.17	0.12
CrK	13.30	8.52
MnK	0.99	0.60
FeK	52.34	52.1
NiK	7.53	4.27

Fig. 3. *EDS analysis of the austenitic stainless-steel film*

The results of the transparency and electrical resistance measurements for samples P1, P2, P3 are shown in Table 3. The P4 and P5 samples were deposited on the support with copper base.

Analyzing Table 3, it can be observed that when increasing the deposition time, surface resistance and transparency decrease. This behavior is due partly to the increase in the thickness of the deposited film and, partly, to its oxidation. These aspects can also be seen on the graphs in Figures 4 and 5.

Table 3. *Determining transparency and electrical properties of films*

Sample cod	**Film transparency**	**Film surface resistance [Ω]**
P1	0.281	404.9
P2	$68*10^{-4}$	214.5
P3	$12*10^{-5}$	190.9

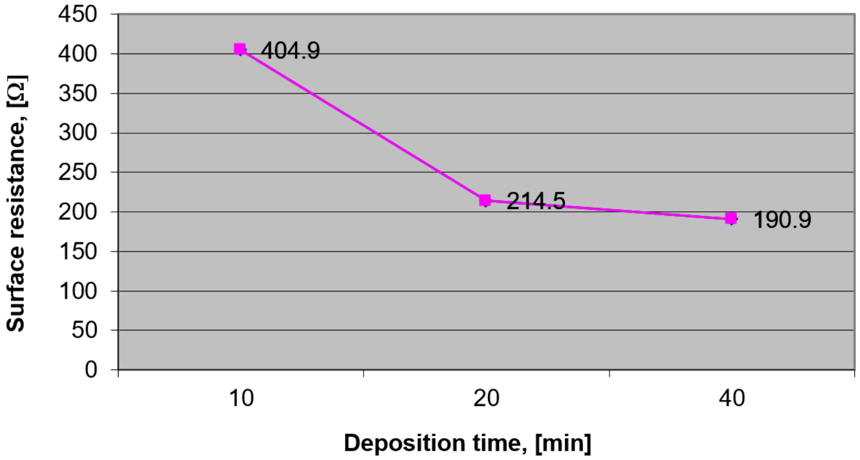

Fig. 4. *The influence of the deposition time on the surface resistance of the film deposited*

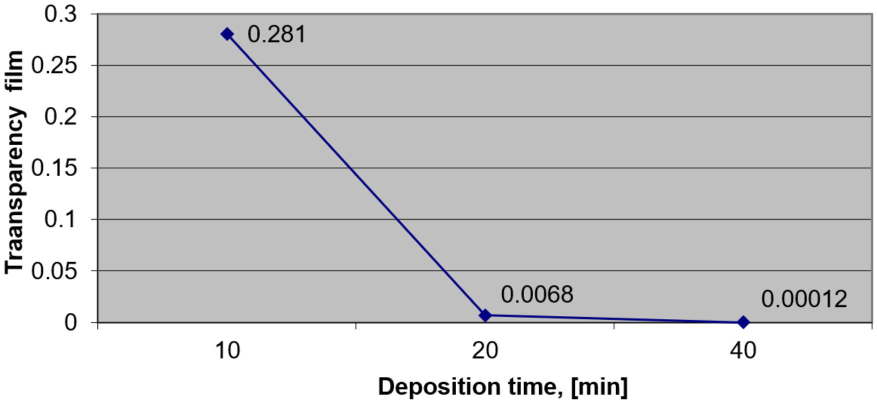

Fig. 5. *The influence of the deposition time on the transparency of the film deposited*

3. Conclusions

The experimental researches lead to the following conclusions:

- films deposited by DC magnetron sputtering process have highlighted an economical and simple way to synthesize several austenitic stainless-steel films.

- the films were obtained using as an atmosphere for the maintenance of plasma the rarefied argon in a pressure range between $3\cdot10^{-2}$ - $8\cdot10^{-3}$ mbar; the argon flow rate used was 100 cm^3/min.

- the structures and properties of the deposited films obtained depend on the parameters used.

- the microscopic analysis reveals that the films obtained do not show cracks, are uniform and adherent with mirror surface.

- when increasing the deposition time, the surface resistance and the transparency decrease the values obtained being in the range 404.9 – 190.9 Ω and 0.281 – $12\cdot10^{-5}$ respectively (this behaviour is due on the one hand to an increased deposited film thickness, and on the other hand to oxidation their).

- the EDS analysis revealed the presence of alloying elements specific to austenitic stainless steel (Cr, Ni, Mn) which implies the achievement of the proposed objective.

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USE OF ECOLOGICAL PARADIGM IN MATERIAL DEGRADATION ENGINEERING

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ABSTRACT

The necessity to move from the conventional technical-technological paradigms to the ecological paradigm is perfectly justified. The degradation of materials is defined as a negative phenomenon, whose study should be extended as a new scientific branch, called material degradation engineering. The two types of life cycles of materials (products) are: the entropic cycle and the antientropic cycle (negentropic).

The three arguments conditioning the ecological paradigm to be analysed are:

- the law of unity of opposites;

- the impurification with inclusions is a technological dirtying process, included into the industrial ecology;

- the degradation adversely influences the capacity of durable material.

The paper work is structured in five chapters based mainly on chapters II, III and IV, as fallows: II. The need to use new knowledge paradigms in the material degradation engineering, III. Classification of the degradation processes, IV. Complex degradation in continuous casting plants (c.c.p.)

KEYWORDS: sustainable materials, ecological paradigm, degradation

1. Introduction

The process of finding modalities to maximize the performance in metalworking engineering must be currently designed and operationalized on the coordinates of two modern concepts (models) of evolution:

- global knowledge;
- durable and sustainable development of the society [1].

In a context like the one above, it becomes necessary for the metalworking engineer to investigate the interconditioning and interactions existing in the convergence zones of the following three systems:

- the social system – S.S. (the quality of life in relation to the socio-cultural needs);

- the natural-ecological system - N.E.S. (the quality of environment in relation to the prevention of environmental pollution);

- the technological system - T.S. (in connection with the qualitative maximization of the technological parameters of manufacturing and use of metal materials) [2].

The material degradation is the major process (phenomenon, event) that causes the material quality alteration throughout its lifecycle (l.c.). Degradation is a multisystem (inter- or intra-) process because: [3, 4]

- It directly determines the durability of materials and products, i.e. their social utility (S.S.);

- It influences the process of primary material transformation into secondary material (waste or residue), which are polluting substances (N.E.S.);

- It can have a negative effect on the quality of material manufacturing processes and the durability of the components used in the industrial equipment and plants (T.S.) [5].

The final quality of the manufactured materials mostly depends on the mechanism and kinetics of the processes within the outline of thermotechnological plants. In such a context, the material engineer is interested in:

- the degradation of metal melts caused by the impurification with inclusions, which can be: [6]
  - endogenous, generated by their own metallurgical phenomena;

– exogenous, generated by the interactions between the metallurgical melts and the construction components of the plant, such as the refractory lining made of ceramic materials;

- the degradation of plant components caused by the destructive interactions between the metallurgical melts and the equipment material.

The importance of knowing the degradation of materials derives also from the fact that it can penetrate the entire life cycle (Table 1).

Table1. *Succession of possible material degradation processes over the lifecycle (l.c.) phases*

Possible degradation during the designing activity	Possible degradation when providing resources	Possible degradation during the manufacture of metal materials		Possible degradation when using the materials	Possible degradation in the relationship with the environment
		Melting, casting and solidification	Solid metal processing		

On the other hand, it was found that the specialized interest in degradation occupies a very small area. Thus, we can deduct from the literature that: [7-10, 11]

∗ Currently, most research topics focus on improving the use performance and *less* on studying the degradation phenomena;

∗ Even when the degradation is investigated, the degradation in the use phase of the material is mostly considered.

Based on the above, the authors believe to be important be launch a new scientific sub-branch on the knowledge market.

The material degradation engineering studies the quality deterioration in the field of technological processes and materials, caused by the intersystem destructive interactions (even inter-phasically) developed throughout an anti-entropic life cycle.

There are two types of life cycles (l. c.): [5]

− the circular-linear cycle, whose simplified representation is shown in Figure 1; it is an entropic cycle, because the secondary materials disposal into the environment increases its entropy deposit;

− the circular-active cycle, whose representation is shown in Figure 2; it is a negentropic (anti-entropic) cycle, because the reintegration of secondary materials contributes to the preservation of the environmental negentropy deposit.

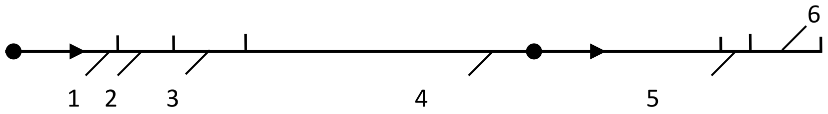

Fig. 1. *Schematisation of the life cycle of a metal product:*
1 - designing of the mechanical product; 2 - resource qualitative processing; 3 - product manufacture; 4 - use; 5 - removal from use; 6 - disposal of secondary materials (residues) into the environment.

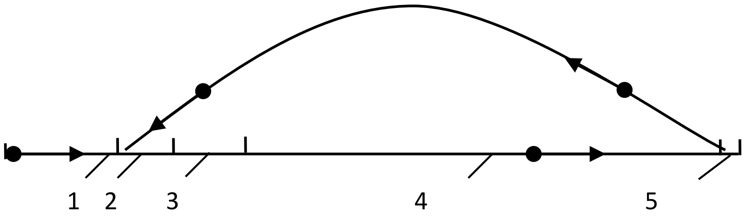

Fig. 2. *The phases of circular-active life cycles:*
1 - material designing; 2 - providing resources; 3 - manufacture; 4 - use; 5 - removal from use; 6 - 3R reintegration.

2. The need to use new knowledge paradigms in the material degradation engineering

In the field of defining, characterizing and designing of new ways of evolution in the field of materials, there is a need for a qualitative leap on a level of knowledge superior to the existing one. In the field of material knowledge, it becomes necessary to resort to new paradigm and methodology elements. More specifically, this means moving from the technical-technological paradigms to a new form of paradigm [12].

The ecological paradigm used in this paper as a vector of in-depth knowledge is considered to be a special paradigm, which is understood as a constellation of beliefs, values and methods within which the members of a community ask questions and give answers. In such a context, the event is investigated, identified, characterized and made available on methodological principles, methods and tools that highlight the priority importance of N.E.S. as a core system. More specifically, this means that the technological processes and the resulting materials are going through an anti-entropic life cycle (providing resources → manufacture → use → secondary material reintegration by using 3R technologies → disposal of residues [4].

The application of ecological paradigm to material engineering is based on three fundamental arguments [13, 14].

a) the law of unity of opposites acts dialectically in case of material manufacture and use. By applying this law, it can be stated that, in reality, the quality of a material life cycle is the result of two opposite events, as occurrence mechanism, and, in particular, as effect on the social sustainability of the material. The two events are generally considered to be:

∗ the efficient use, as a positive effect on the material durability; the maximization of this parameter requires the optimization of the use properties (also called technological properties or technical-functional properties);

∗ the degradation, having a negative effect on the durability of materials; the minimization of the effect of this event means optimizing the degradation properties (e.g. the minimization of the negative effect of corrosion claims the maximization of corrosion resistance).

The conflict between the efficient use and degradation can be optimized based on the lifecycle duration maximization, influencing the use and degradation parameters. There are a number of different situations concerning the causes acting upon them:

➢ material internal causes, aimed at preventing by reducing the factors that favour the degradation, i.e.:

– maximizing the use properties;

– maximizing the specific anti-degradation properties.

➢ material external causes, concerning the prevention or reduction of the intensity of the interactions between the material and environment, i.e.: [15-17]

– the manufacturing technological environment represented by the technological plants for steel-making – casting – rolling;

– the technological environment of material use;

– the environment.

➢ Conditions of reintegration through 3R technologies (recirculation, recycling, regeneration);

➢ Environmentally friendly storage of polluting residues.

b) Impurification of metal melts with inclusions can and must be analysed in the light of ecological paradigm. This assertion is supported by:

– Etymology, through the Latin origin (poluo - poluere), the term to pollute means to get dirty, to defile, and pollution can be interpreted as dirtying, a special form of impurification;

– The generation of inclusions in the melted steel is currently characterized as a dirtying phenomenon, which adversely affects the quality of material. [7]; we can speak about the technological pollution of the steel with inclusions;

– A similar situation is encountered in case of technological pollution of steel with tramp elements (Cu, Sn, Pb), caused by their transfer from scrap into the melt in the electric arc furnace.

c) The degradation adversely affects the function of durable material of the metal materials

The durable material – D.M. (sustainable material – S.M.) is the material that carries out simultaneously the functions of advanced material, efficient material, eco-material and socio-material, fulfilling in this way the rigours imposed by the three systems [14].

The advanced material, according to the ecological paradigm, is the material that goes through a full negentropic life cycle.

According to the technical-technological paradigm, the advanced material is the material that meets the rigours imposed by the advanced (top) industries. Based on this paradigm, the nuclear materials, for example, are advanced materials. According to the ecological paradigm, this function is not fulfilled because the material does not go through a negentropic life cycle, the nuclear waste being just disposed and not re-used.

The efficient material, according to the ecological paradigm, is the material which, going through an anti-entropic life cycle, ensures a maximum degree of recovery to the primary substance (intrinsic substance or native substance).

The primary substance is a necessary notion, because the cost-benefit analysis provides costs only for extraction, preparation, transport and handling, but not for the intrinsic value of the raw materials given by the content in the useful substance (e.g. the value of the main petroleum hydrocarbon) [18].

According to the technical-technological paradigm, the efficient material is the material whose use features reach maximum values. Judging by this paradigm, the nuclear materials are efficient materials. According to the ecological paradigm, this function is not fulfilled, since the nuclear residues, which still contain the primary substance, are not re-used.

3. Classification of the degradation processes

The authors believe there are several categories of degradation [13, 8], as follows:

a) depending on the life cycle phase, there are:

a.1) technological degradation caused by the degradation of processes occurring during the material manufacture; it can be also called process degradation or early degradation, because the degradation begins from the zero point of the life cycle.

a.2) use degradation.

b) depending on the determinants, there are:

b.1) objective degradation, caused by certain processes that cannot be avoided, but only reduced; in this category fall such examples:

– degradation caused by the metal melts impurification with inclusions and degradation caused by the destruction of ceramics by the melted steel - refractory ceramic lining interactions;

– metal corrosion in the environment or in the working environments, which exercise destructive actions [17].

b.2) subjective degradation, caused by the dysfunctions between the measures adopted in process designing and management (imposed specifications) and the actual operational conditions.

c) The complex degradation is the degradation involving multiple technical materials. It is the case of technological plants where the metallurgical melt interacts destructively with the construction components of the plant, resulting in the degradation of both phases.

4. Complex degradation in continuous casting plants (C.C.P.)

The processes occurring in the C.C.P. are the result of interactions between two main materials: molten steel and ceramic material of the refractory lining of the construction components:

The mechanism of degradation of the two materials consists of the phenomena described below, taking into account the notations shown in Figure 4.

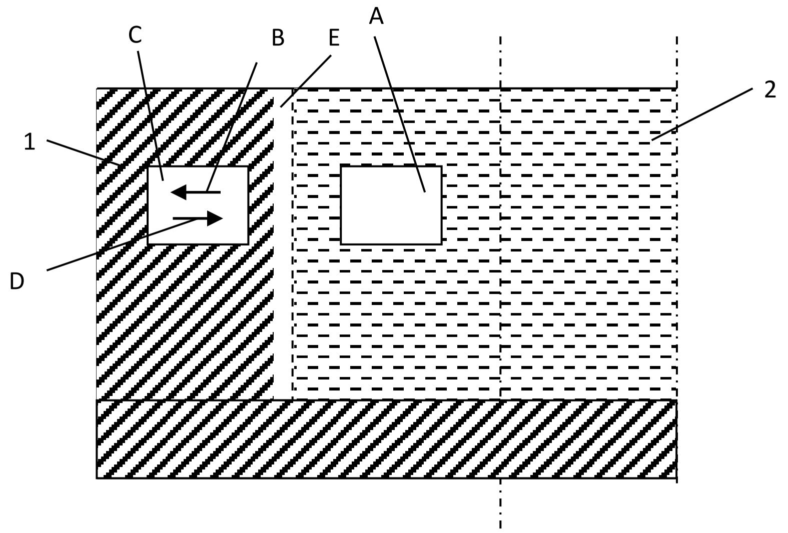

Fig. 4. *Schematization of metallurgical melt - ceramic material interaction processes.*
1 - ceramic material; 2 - melted steel

A) The interaction space is the area where the endogenous inclusions generation processes occur.

B) This is the area where exogenous inclusions generation processes occur. The phenomenon of ceramic material degradation begins here.

C) This is the area of penetration and physical-chemical interaction between the melt and the ceramic material. It is the actual process of ceramic material degradation.

D) This is the evacuation area of inclusions from the ceramic material of the refractory lining.

E) This is the area of possible adherence of the degradation interaction products. The metallurgical engineer is interested in two situations:

– deposits on the tundish refractory lining, a phenomenon leading to the formation of a pseudo-wear layer with degraded properties;

– deposits on the surface of the immersion tubes, which cause the clogging of the tubes, a phenomenon that adversely influences the steel casting properties [19, 20].

Three sub processes are occurring:

a) processes of adhesion to the melt - ceramic material interface. They are physical-chemical processes based mainly on wetting phenomena, which in turn dependent on the phase and interphase tensions. To study them, it is necessary to know the activation energy of the adhesion phenomena, $E_{a.a}$. They also depend on the shape (globular or polygonal cluster), as well as on the roughness of the inclusion surface, assessed through the roughness factor, r, [21, 16]. The latter influences the correlation:

$$\cos\theta_{s.r} = r\theta_{s.l} \qquad (4.1)$$

where: $\theta_{s.r}$ is the interphase wetting angle of the rough surface, and $\theta_{s.l}$ is the interphase wetting angle of the smooth surface.

b) down flow processes. They are determined by the casting speed v_t, i.e. by the kinetic energy of the jet, $E_{c.j}$. In this case, the inclusions dissipate in the melt mass, where they are embedded by solidification.

c) processes for breaking the already-formed adhesion crust. In this case, the inclusion conglomerates dissipate in the mass of the melt, where they are embedded by solidification. $E_{c.j}$ plays a predominant role in this situation, too. Two situations can be met, depending on the values of the two energies [22].

- If $E_{a.a} > E_{c.j}$, the inclusions adhere to the ceramic lining and may cause unfavourable events (degradation of the wear layer of the lining or clogging of the tubes).
- If $E_{a.a} < E_{c.j}$, the inclusions decant into the melt, being driven by the flow. In this case, the inclusions dissipated inside the melt mass affect adversely the properties of the steel, determining the phenomenon of qualitative degradation of the material. Given that:

$$E_{c.j} = \frac{1}{2} m_i \cdot v_t^2 \qquad (4.2)$$

and:

$$E_{a.a} = f(\alpha_{s-g};\ \alpha_{s-l};\ \alpha_{i-g};\ \alpha_{i-l};\ p_{top}) \qquad (4.3)$$

where α represents the interphase tensions among the non-metallic inclusion, gas (from lining or as gaseous inclusion) and solid (ceramic material), and p_{top} is the melt pressure in the technological equipment, we deduce that the generation of inclusions and, implicitly, the phenomena of plant performance determination and steel degradation depend on two categories of factors:

– technological casting parameters;

– intrinsic characteristics of the materials involved in the phenomena.

5. Conclusions

❖ The study of material degradation should become a widespread and diverse area of knowledge called material degradation engineering.

❖ The complex degradation is an example of convergence between two branches (metal material engineering and ceramic material engineering).

❖ The ecological paradigm is becoming more important than the conventional paradigms, as it considers certain principles that take into account the importance of N.E.S. in interaction with the other systems.

❖ The ecological paradigm is based on three fundamental arguments:

- the law of unity of opposites;
- the impurification with inclusions is a technological dirtying process, included into the industrial ecology.

The degradation adversely influences the capacity of durable material.

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DEGRADATION OF CERAMIC MATERIALS IN THERMOTECHNICAL PLANTS

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ABSTRACT

It is demonstrated that the degradation of materials is currently a poorly studied scientific area. We propose a definition of degradation and a classification of the types of degradation. It is investigated, using a technical model, the destructive interactions between the ceramic materials of the tundish refractory lining, in a continuous steel casting plant. We hereby present the experimental results regarding:

- the importance of the steel penetration depth in the refractory ceramic mass;
- the assessment of mineralogical degradation;
- the analysis of chemical degradation.

It is shown that the results of laboratory - pilot scale research can be extended to the industrial level.

KEYWORDS: materials, degradation, continuous casting, ceramic - liquid steel interaction

1. Introduction

The research on the ways to maximize the performance in metalworking engineering must be currently designed and operationalized on the coordinates of two modern evolution concepts (models):

- global knowledge;
- durable and sustainable development of the society.

In such a context, it becomes necessary for the metalworking engineer to investigate the inter-conditioning and interactions existing in the convergence areas of the three systems:

- the social system - S.S. (the quality of life in relation to the socio-cultural needs);
- the natural-ecological system - N.E.S. (the quality of environment in relation to the prevention of environmental pollution);
- the technological system - T.S. in connection with the qualitative maximization of the technological parameters of manufacturing and use of metal materials.

The material degradation is the major process (phenomenon, event) that causes the material quality alteration throughout its lifecycle (l.c.). Degradation is a multisystem (inter- or intra-) process because:

- it directly determines the durability of materials and products, i.e. their social utility;
- it influences the process of primary material transformation into secondary material (waste or residue), which are polluting substances;
- it can have a negative effect on the quality of material manufacturing processes and the durability of the components used in the industrial equipment and plants [3, 4].

The importance of knowing the degradation of materials derives from the fact that it penetrates the whole life cycle, i.e. the entire flow [design of material] [transformation of material into pollutant residue] (Fig. 1).

Possible degradation during the designing activity	Possible degradation when providing resources	Possible degradation during the manufacture of metal materials		Possible degradation when using the materials	Possible degradation in the relationship with the environment
		Melting, casting and solidification	Solid metal processing		

***Fig. 1.** Succession of possible material degradation processes over the lifecycle phases*

The final quality of metal material is clearly influenced by the quality of the melting, casting and solidification processes [1, 2]. From the phenomena to be investigated in this case, a significant role is played by the steel quality degradation at continuous casting (C.T.) in continuous casting plants (C.C.P.), resulting from two processes-phenomena which are very important for the ferrous materials engineering [3, 4]:

- degradation of metal bathes caused by impurities;

- degradation of the ceramic materials used for building the C.C.P., caused by the melted steel - ceramic destructive interactions (it is about the ceramic materials that make up the refractory lining of the tundish, an important component of the C.C.P.).

The authors believe that there are several categories of degradation [10], as follows:

a) depending on the lifecycle phase:

a.1.) technological degradation caused by the degradation of processes during the material manufacture; this one may be called process degradation;

a.2.) use degradation

b) depending on the determinant causes:

b.1.) objective degradation caused by some processes that cannot be avoided, but only reduced; in this category fall such examples:

- degradation caused by the metal melts impurification with inclusions and degradation caused by the destruction of ceramics by the melted steel - refractory ceramic lining interactions;

- metal corrosion in the environment or in the working environments, which exercise destructive actions [11].

b.2) subjective degradation, caused by dysfunctions between the measures adopted in designing and process management (imposed specifications) and the actual operationalization conditions [5, 7].

2. Purpose of research. Studied materials. Research methodology elements

2.1. Purpose of research

In general, research can target the extensive area of degradation knowledge, i.e. the area of double interest for degradation, which is the sphere of phenomena occurring between:

The area of metallurgical melts (area of major interest for the metallurgical technology of steelmaking-casting-solidification), where the endogenous inclusions generation processes occur.

The area of the ceramic materials of the plant lining (area of interest for the manufacturer of ceramic materials), which is analyzed from two points of view:

- the ceramic material as participant in generating exogenous inclusions based on physical-chemical interactions with the metallurgical melts;

- the ceramic material as component subject to internal degradation caused by the corrosive interactions with the metallurgical melts.

2.2. Studied materials

The degradation interactions are developing along two material vectors:

- the melted steel, and
- the ceramic material of the refractory lining.

a) steel grades

Three steel grades have been studies (Table 1).

b) studied ceramic mixtures

The ceramic mixtures (C.M.) were prepared using materials whose compositions are shown in Table 2.

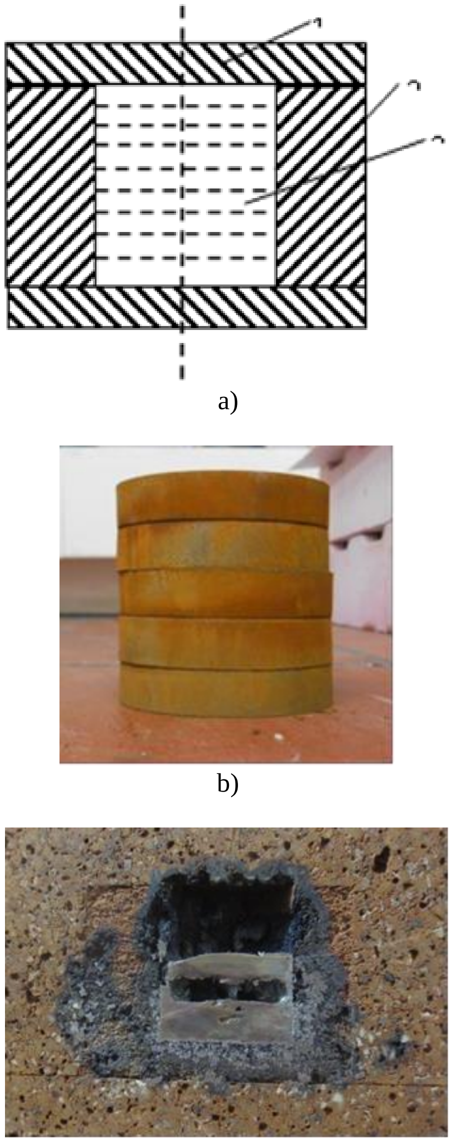
***Table 2.** C.M. compositions*

Designation	Symbol	Composition				
		MgO %	CaO %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %
Pure magnesia	M.C.M.	93.4	3.1	2.9	0.5	0.1
Low silica magnesia	L.S.M.C.M.	80.8	2	14.4	2.6	0.1
Medium silica	M.S.M.C.M.	66.0	1	26.7	5.1	0.6
Lime magnesia	L.M.C.M.	80.4	14	1	4	0.6

2.3. Research methodology elements

The Physical-Technological Investigation Model is a pilot plant for studying the ceramic - liquid steel interaction processes.

In fact, it is a crucible made according to the general scheme shown in Figure 2.2.



a)

b)

c)

Fig. 2. *Elements of designing and modelling: a) Sketch of the crucible: 1 - cover; 2 - crucible body (refractory lining made of ceramic mixture - C.M.); 3 - Steel under investigation. b) Steel discs. c) Sample cut for analyses*

The experimentation technology

- the crucible is filled with discs of the steel to be studied;

- the crucible returns to the oven to heat and melt the steel at 1600 °C for 10 hours;

- the assembly is left for two days for cooling and solidification;

- the area (sample) to be studied is cut out.

The research equipment

In the research, two analytical methods of investigation were used:

- mineralogical investigations (reflected light microscope and SEM scanning electron microscope) and

- chemical analysis (X-ray fluorescence spectrometer).

The research situations (E1...E12) resulted from the combination in various variants of the two materials marked with special symbols (Tables 1 and 2).

The grid of research situations with the experiment numbers (E) are shown in Table 3.

Table 3. *Symbolization of experimental cases*

	M.C. M.	L.S.M. C.M.	M.S.M. C.M.	L.M.C. M.
L.C.S.	E 1	E 2	E 3	E 4
V.L. C.S.	E 5	E 6	E 7	E 8
B.S.	E 9	E 10	E 11	E 12

The parameters used for assessing the degradation were:

- penetration depth of steel in the ceramic material mass, ap [mm];

- mineralogical degradation, assessed by mineralogical transformations of ceramic components;

- chemical degradation, assessed by the chemical composition changes.

The cooling rate, v_r, of the melted steel in the ceramic mass and its influence on the degradation could not be established experimentally for objective reasons, which is why the authors used assessments based on the thermophysical properties of the ceramic materials. They started from this idea since the cooling rate of the melt is dependent on the thermal diffusivity coefficient "a" [m/s] of the ceramic material:

$$v_r = f(a) \tag{1}$$

In turn, the coefficient "a" is given by the equation:

$$a = \lambda / c \cdot \rho \tag{2}$$

Where "λ" is the thermal conductivity coefficient [w/m·degree], "c" is the specific heat [J/kg·degree], and "ρ" is the density [kg/m^3].

The values that have been used are shown in Table 4.

Table 4. *Thermophysical properties*

Material	λ [w/m·gr d.]	c [J/kg·gr d.]	P [kg/m^3]	a·10^3 [m^2/s]
MgO (A.C.M.)	5.02	1.35	2750	1.4
CaO	3.3	1.06	2400	1.25
SiO$_2$	1.68	1.05	2000	0.8
L.S.M.C.M.				1.28
M.S.M.C.M				1.20
L.M.C.M				1.37

3. Experimental results. Data processing

The degraded area condition (microscopic appearance) of the ceramic material led to results similar to the ones shown as examples in Figure 3.

The mineralogical structure of the degraded layer revealed a number of complexes, but mainly magnesio-wüstite (Fig. 4-6).

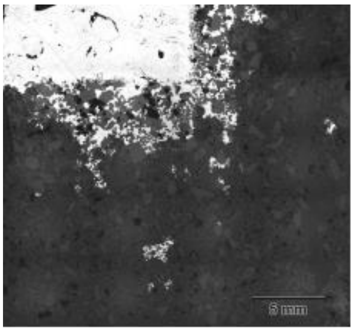


Fig. 3. *Appearance resulted after the E11 experiment: 1 - steel; 2 - penetrated ceramic material*

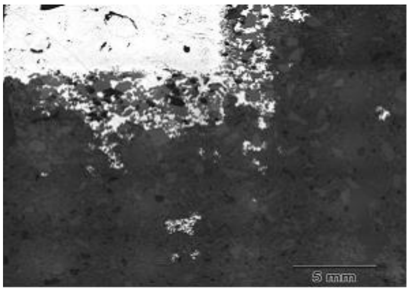


Fig. 4. *Result of research for highlighting the multi-oxide inclusions*

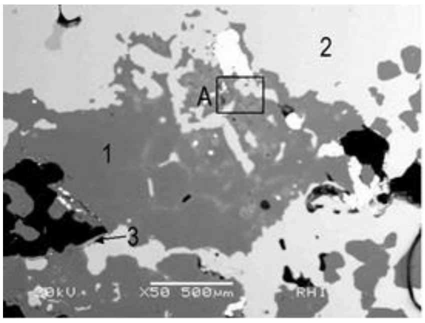


Fig. 5. *Detail of Figure 4: 1 - magnesio-wüstite; 2 - iron; 3 - FeO*

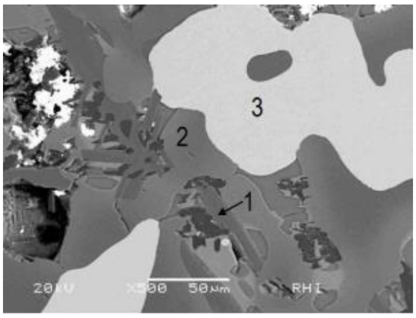


Fig. 6. *Detail of Figure 5: 1 - multi-oxide; 2 - magnesio-wüstite; 3 - iron*

The steel penetration depth, a p, [mm], in the ceramic mixture depends on the steel nature and the ceramic mixture nature (Table 5 and Figure 7).

Table 5. *Penetration depth values, a_p [mm]*

	L.C.S.	V.L.C.S.	B.S.
M.C.M.	7.5	5.5	4.0
L.S.M.C.M.	9.0	8.5	6.0
M.S.M.C.M.	11.0	9.5	7.0
L.M.C.M.	6.5	4.5	3.5

The degradation degree of C.M. has been assessed using the degradation degree of MgO, gd.Mg [%]:

$$g_{d.MgO} = \frac{(MgO)_i - (MgO)_d}{(MgO)_i} \cdot 100 \quad (3)$$

In the above relationship, (MgO)$_i$ is (MgO) in initial condition, and (MgO)$_d$ are the distances (d1 – d4) from the contact interface.

The changes in chemical composition are caused by the processes:

- reaction;
- diffusion of FeO in MgO with the formation of the magnesio-wüstite compound (Mg, FeO).

The processes mentioned above are in line with the theory of steel processes. [6, 9, 12] The concrete explanation is given in Figure 8.

The experiments were carried out in case of interaction between C.M. and L.C.S. (E2).

The tabular and graphical data processing is presented in Table 6 and Figure 9.

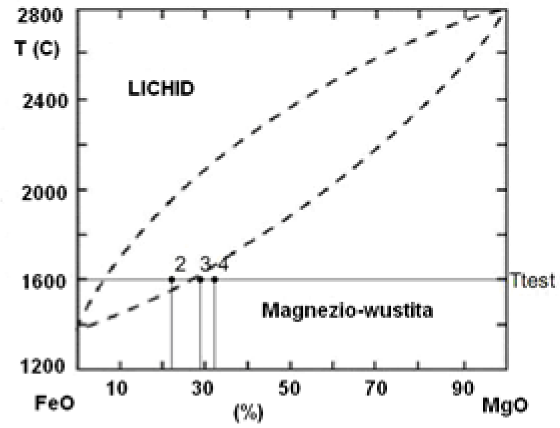


Fig. 8. *Fragment of the FeO-MgO phase diagram [6, 9, 12]:1 – liquid steel at 1600 °C: 2 - magnesia with solid-liquid wüstite; 3 and 4 - magnesia with solid wüstite at 1600 °C*

Table 6. *Results of chemical analyses*

Distance [mm]	Composition		Phases	$g_{d.MgO}$ [%]
	MgO	Fe_2O_3(x)		
$d_1 = 0$	-	100	Metal iron	-
d_2 = 2 mm	22.4	77.6	Magnesia and wüstite	77.6
d_3 = 3 mm	29.2	70.8	Magnesia and wüstite	70.8
d_4 = 4 mm	32.4	67.6	Magnesia and wüstite	67.6

x – Total iron, calculated as Fe_2O_3

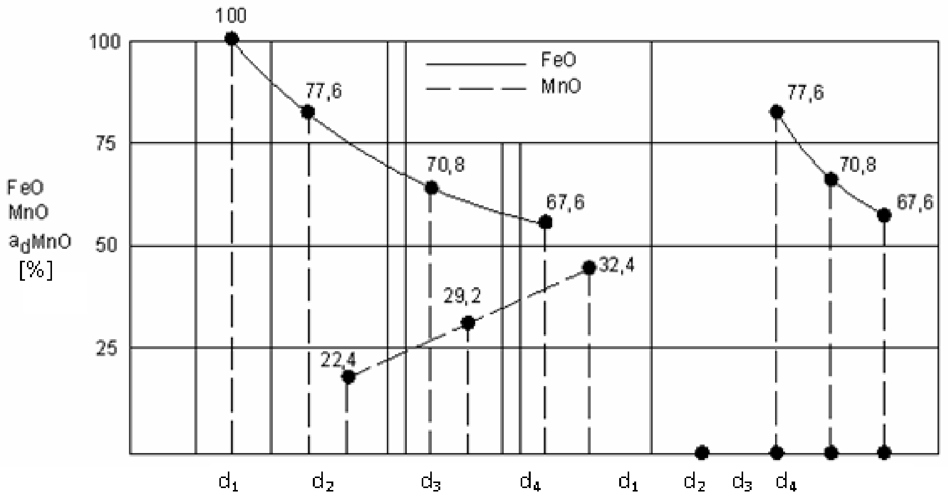


Fig. 9. *Dynamics of chemical and mineralogical transformations*

4. Interpretation of results. Conclusions

The following explanations were found for the influence of ap:

- the depth of penetration is influenced by the fluidity of steel (carbon content variation) and the purity of steel (case of bubbled steel);

- the depth of penetration is influenced by the possible reactions occurring inside the C.M. Therefore, at L.S.M.C.M. it is possible to be generated low-temperature melting constituents:

$$MgO + SiO_2 \rightarrow (MgO \cdot SiO_2)$$

- the depth of penetration is influenced by the ceramic mixture compaction degree. Such a case must be regarded as a subjective deviation from the mixture preparation conformity;

- another reason to be considered is the refractoriness of mixtures, knowing that the melting temperatures of MgO and CaO are higher than that of SiO.;

- it is noted that the degradation of C.M., assessed by ap, can be also influenced by the thermophysical properties of the C.M.;

- the paper points out that the research on material degradation must become a scientifically important segment of materials engineering.

In this respect, the following justifications can be brought forward, knowing that:

- currently, most research topics focus on improving the use performance and less on the degradation phenomena;

- even when the degradation is investigated, the scientists mostly consider the material degradation in the use phase rather than in the primary phases (production and casting);

- this paper demonstrates that the degradation occurs throughout the entire lifecycle of the material;

- the results of pilot-scale research can be extended at the industrial level.

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CREATING INTEGRATED SYSTEM BETWEEN LIFECYCLE QUALITY MANAGEMENT AND FINITE ELEMENT ANALYSIS TO IMPROVE TYPICAL TURBINE BLADE DESIGN AS A CASE STUDY

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ABSTRACT

This article proposes a process to integrate efficiently the Finite Element Analysis in the Quality Life-Cycle Management in order to use the simulation engineering in analyzing and improving the design of one industrial part. In addition, a new flowchart has been created to enter the data resulted from Numerical Analysis using ANSYS code in QLM process for a typical turbine blade (as a case study) to show the practical steps of design validation in digital method. This paper prepares the base to simulate a complex industrial assembly in integrated FEA-QLM process as a future work.

KEYWORDS: Finite Element Analysis, Simulation, Digital Manufacturing, Life-cycle Quality, Management

1. Introduction

Quality assurance and efficient management are basic titles for any successful industry in our days, furthermore using computer simulation and Numerical analysis should the keys to obtain these goals in global market. There is a big challenge nowadays to integrate the simulation engineering in management process and we are trying in this paper to promote an integrated process which combines the FEA results and data in QLM process using a simple case study to show the practical steps in order to optimize the design and create a valuable database for production management. New approach in Quality management can be seen now by using simulation to improve life-cycle quality for any type of products, which leads us more and more toward hybrid industry and automation design [1]. In addition, the FEA-QLM flowchart, which has been created, helps the engineer to control all quality-oriented activities.

2. Quality Lifecycle Management (QLM)

2.1. QLM definition

Quality lifecycle management is multidimensional process which provides solutions to manage all aspects in product quality and reliability; however, this process has to start early in product development and design and continuously be applied in following levels like products, validation, quality assurance etc.

Quality lifecycle management (QLM) promotes information about quality process and assures product’s reliability using methods that are fully integrated into the product development lifecycle and highly visible to all personnel with a stake in product quality [2].

Quality management must connect all activities related to quality in one procedure, easy to follow and control, from design level to cost planning and risk estimation. Figure 1 shows the QLM continues cycle which work to improve activity in the production line [3].

As we see in Fig. 1 QLM will accompany the designer and manager in each step during the production, so the lifecycle of the product will be controlled step by step to minimize the errors and assure that we will have production driven by quality. Indeed, we need criteria for every step, for example designers will have criteria to which part needs more support and improvement, test engineers have criteria to define which character must be tested, manufacturers have to know which aspect will be controlled in production line, and service section will have a clear plan to do maintenance and repairing respecting to product performance and properties [3].

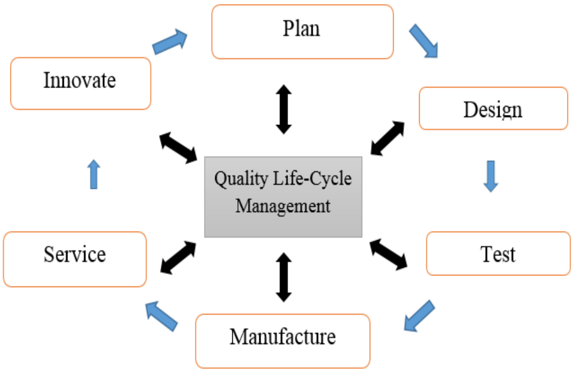


Fig. 1. *QLM process*

2.2. QLM Challenges

Achieving quality in production process will meet many challenges because there is no ideal environment or system for quality management; however, QLM is designed to overcome these challenges during the lifecycle of the product if it is applied in right way. Basic challenges in production process are as following:

1 - quality of each specific product must be defined by the producer, because every product has special purpose with quality concept, conditions and criteria.

2 - the need of gathering, organizing, documenting and promoting quality information for all the production levels and providing the ability to access to this information for all responsible staff.

3 - enroll quality rules in the management system and production process to have integrated procedure of quality [4].

3. An Overview of Numerical Analysis

Numerical Analysis is the method to use numerical approximation for equations in a mathematical analysis. Numerical calculation creates a great chance to use simulation engineering for all kinds of engineering projects using the high power of computers in our days. This analysis concentrates on obtaining approximate solutions for our problem with an acceptable margin of errors [5].

The main idea of numerical analysis is to study the physical model of our problem and obtain a suitable mathematical model that describes the problem and can control the variables and push forward for solution. Mathematical model means use approximate functions to change differential equations to integral algebraic ones, so we can use the power of computers to solve the new matrix of equations.

Based on computational discretization methods to divide geometry and enter boundary conditions we can discuss three basic methods for numerical analysis:

1 - Finite Element Method (FEM).
2 - Finite Volume Method (FVM).
3 - Finite Difference Method (FDM).

3.1. FEM

FEM is a computational method to divide the geometry (CAD model) into small finite-sized elements in simplest possible shape, the name of this network of elements is Mesh and we call the contacts points between elements Nodes. In this method dependent values are stored at the elements and nodes.

3.2. FEM basics

This method is the most difficult to apply however it has the best accuracy especially in complex CAD models, because of that we will concentrate on this method and its basics and applications.

For applying FEM for engineering model, we need first to specific the physical governing equations which control the model, then to obtain mathematical model we need to change PDE to integral equations using approximate functions (linear, nonlinear, quadratic polynomial); [See 3]. Using this function and creating the Mesh which contains elements and nodes with specific number of Degree of Freedom (DOF^s) lead us to end up with a large sparse matrix equations system that can be solved by power calculation of computers [5].

3.3. FEA Industrial Applications

Nowadays engineers can use FEA to simulate almost all engineering problems and analysis (structural analysis, heat transfer, flux and fluid dynamics, electromagnetic, etc.).

In machine manufacturing field we can mainly distinguish three basics applications:

1 - design optimization.
2 - test quality and reliability for mechanical parts.
3 - improve manufacturing Process for mechanical assembly [5, 6].

4. Integrated FEA and QLM system

4.1. FEA-QLM Flowchart

In this paper a new efficient system is designed to integrate FEA process in QL - Management and got benefits from both to improve the quality.

It is true that the basic step in any quality procedure is to collect data and analyze them in best possible way, so this system relays on gathering data from both FEA and QLM processes and create an effective data-base which helps the designers and managers to push over the product's quality and reliability forward in lower cost and time.

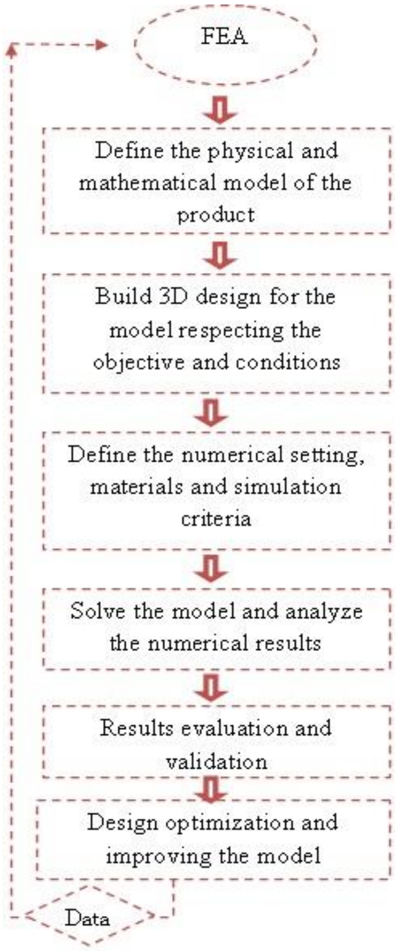


***Fig. 2.** FEA flowchart*

Fig. 2 shows FEA process, which we can use for every simulation we want, and this process creates a valuable source of data for the designer engineer. However, in Fig. 3 we can see the flow chart which has been created in this paper to show an integrated system between FEA process and QLM flowchart. [5, 7]. As we notice from Fig. 3, the FEA will enter the QLM process in design level and will provide a source of numerical results, which will be return to the process in Test level.

4.2. FEA-QLM cycle

FEA provides very good source of data to the designer about the product's behavior under many scenarios of loading and working, furthermore helps them to analyze data and evaluate the results. In engineering projects testing the prototype models for any products needs a big budget and time, while by using numerical analysis and simulation, the designer can create a virtual environment very similar to reality and test the product in many cases of service [8].

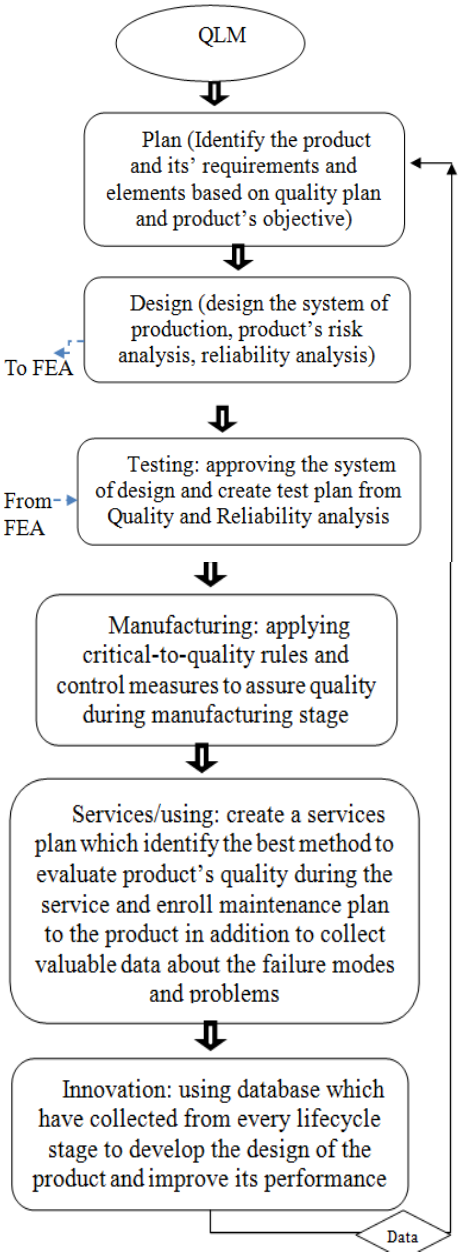


***Fig. 3.** FEA-QLM integrated flowchart-insert the FEA database in Design and Testing levels during the Quality Life-cycle Management*

By integrating FEA and QLM together we can create a new Data-cycle process which is very efficient in any quality management system. Fig. 4

displays the Data-Cycle which collects data from both real environment and virtual environment.

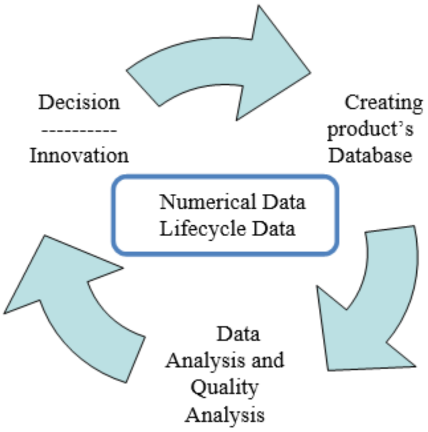


Fig. 4. *FEM-QLM Data cycle*

By using numerical data from simulation and lifecycle data from quality management, the designer has very clear view about the product and its (reliability, behavior, maintenance cases, failure modes, crack and deformation), so optimizing the design and apply innovation in next generations-designs will be easier and absolutely cost-time effective. Indeed, this system needs high level of cooperation between managers and designers to achieve the best results.

5. Case Study

As a model for case study, we used a design for turbine-Blade model. The blade is a major important component for gas or steam turbines which makes up the turbine section and extracting energy from the high temperature, high pressure gas is produced by the combustor.

The model of blade completely [9] effected on turbine efficiency and productivity. Blade design, test and manufacture are accurate and complicated stage because this part will work under structural stresses, thermal stresses and dynamical stresses.

The margin of error or failure has to be very small, that's why we used FEA-QLM process to control the blade's design and optimize the model of course based on work conditions and uses [10, 11].

The case is really huge and has many details that is why we take in consideration the parametric design of the blade and structural analysis using FEA. Fig. 5 shows blade's geometry and the basic parameters of its design.

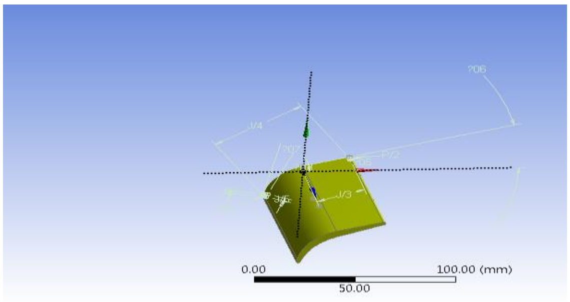


Fig. 5. *Blade geometry and design parameters using ANSYS-academic software*

The model has many design parameters like chord, span length, stagger, head angel (alpha 1, alpha 2) like we see in Fig. 6 which shows also the reaction of the blade cross section and flow pattern in operating conditions [12].

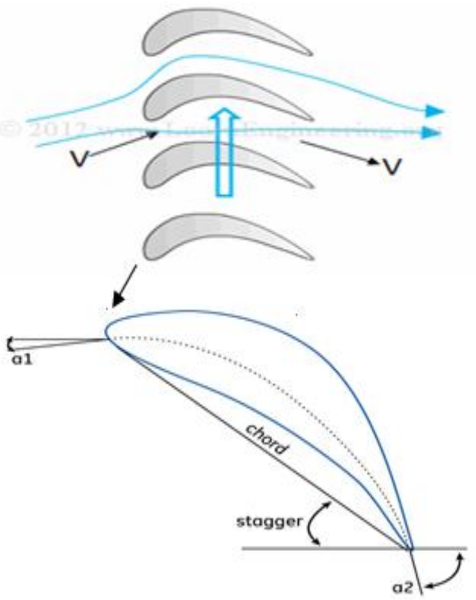


Fig. 6. *Design's parameters of turbine's blade and a typical reaction turbine rotor cross section and flow pattern- the figure from: (http://www.learnengineering.org/2013/02/ working-of-steam-turbine.html)*

5.1. Turbine's Blade-Analyzing

To apply FEA-QLM system on Blade's model, all mentioned steps above should be followed step by step.

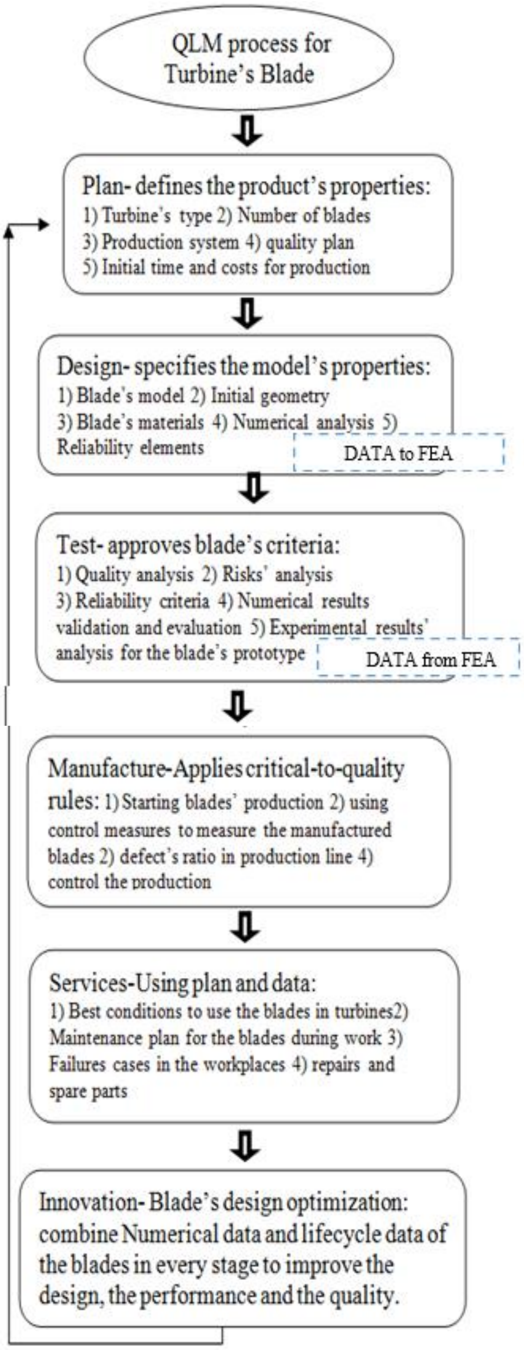


Fig. 7. *QLM-Blade process*

5.2. Results and Discussion

Fig. 7 show FEM-QLM integrated system to analyze and improve the design of our Turbine’s Blade and the materials and operating conditions have written based on industrial case applied in factory [11].

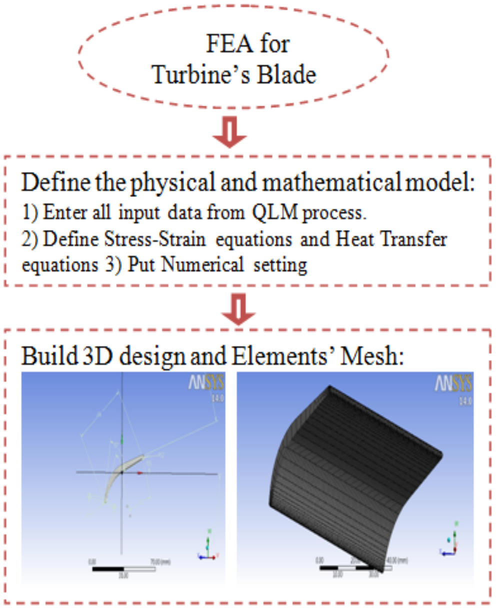


Fig. 8. *First step in FEA process- Create the CAD model and the elements’ network (Mesh)*

The internal FEA process will be displayed separately to show the simulation steps which have been made on ANSYS-Structural code and how we can adapt the Numerical solution.

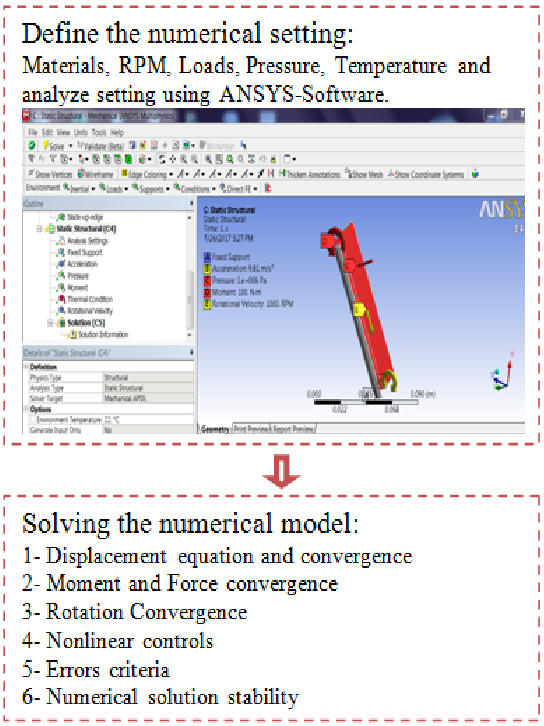


Fig. 9. *Second step in FEA-Define Numerical setting and Boundary conditions in ANSYS-Structural environment*

Fig. 8 shows the first step in the process, which contains creating the CAD model and input data from QLM process.

The second step will define the Numerical setting for our model as we see in Fig. 9, indeed this step is very sensitive and important because it will lead the solution and control the accuracy of the results, so should be done very carefully.

ANSYS-Structural code has a flexible environment, which allows the designer to adapt the setting and choose the loads affecting on the blade. For turbine blade model two calculations should be done, one is the structural analysis, which is the case study for this paper and the other will be the CFD (Computational Fluid Dynamic) [13, 14] flow analysis, which will be the future work.

The Third step is submitting the numerical solution for the model, according to that a personal computer station I5-4GB RAM has been used and the solution was repeated 2 times for assuring the convergence, however the convergence limit was adapted at 0.0001.

Under three different loading cases, deformation, strain and stresses have been resulted; so, the designer can estimate the behavior of the blade under each operating condition. The loading cases are shown in Table 1.

Fig. 10 displays the total deformation in the blade's body under the loading case No. 1.

Table. 1 *Loading cases which applied on the blade in Numerical solution*

Loading case Number	RPM for Blade	Operating Temperature	Loading force on Blade
No. 1	2500	60 °C	35 N
No. 2	2800	70 °C	50 N
No. 3	3000	75 °C	60 N

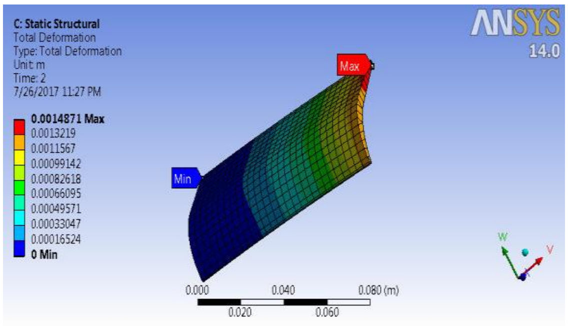


Fig. 10. *Total deformation on the Blade under Loading case No. 1*

The strain distribution on the blade is an important parameter to estimate, so we can identify the areas with high strain (red color) and areas with low strain (blue color) like as Fig. 11 shows.

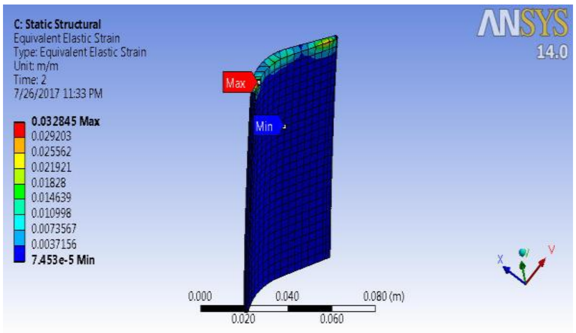


Fig. 11. *Strain contour on the blade's body under Loading case No. 1*

To analyze the structural behavior of the model, we have to estimate the stress created on the blade's body, especially the maximum shear stress, maximum normal stress and equivalent stress. In Fig. 12 the max shear stress can be noticed and Fig. 13 shows the maximum principal stress distribution on the body displayed (high stress values in red color and low ones in blue color). To summarize the results for loading Cases, Table. 2 displays the changes in results because of changing the loading case. Fourth step in FEA process consists in applying a parametric study [15] on the model in order to optimize the design of the blade in order to find the most effective and efficient one, and send this information to QLM process which can (depending on this data) identify the best design to be made as a prototype in the laboratory to perform an exponential test.

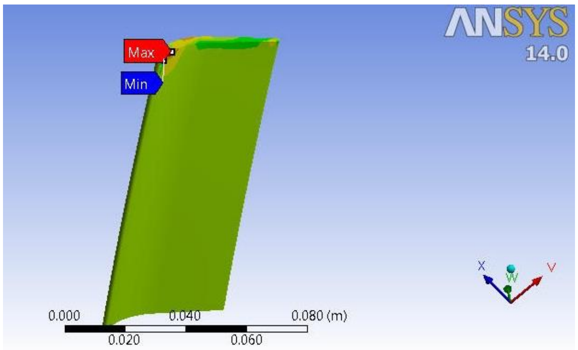


Fig. 12. *Max shear stress under Loading case No. 1*

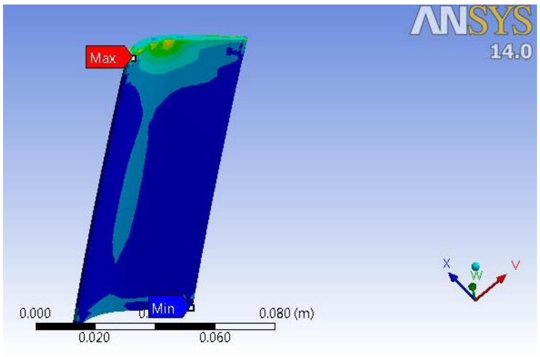


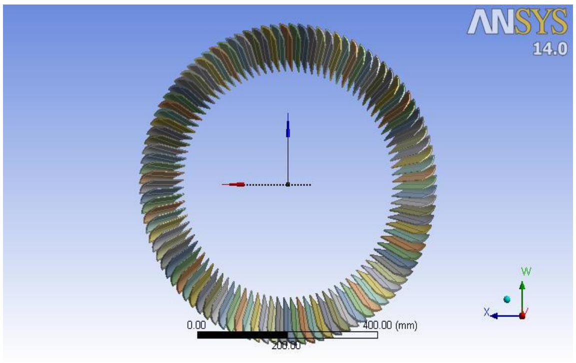
Fig. 13. *Max principal stress distribution on the blade under the loading case No. 1*

Table. 2. *The main results of FEA under three loading cases for blade's model*

Loading case number	Max total deformation, mm	Max shear stress, MPa	Max principal stress, MPa
No. 1	0.0014	63.2	86.5
No. 2	0.00152	67.3	86.7
No. 3	0.0017	70.04	90.6

The designer engineer can use the ANSYS code to perform this parametric study by creating many design points and calculate the max deformation, strain and stress for every point directly. This function is very efficient to analyze all possible loading cases for the model and can provide fast and direct results for parameters which are chosen by the designer.

The last step for FEA process will be results validation by comparing our result with experimental data, however this step will be available after assembling the blade in a complete turbine model as shown in Fig. 14 and performing the CFD flow simulation. This step will be the subject of future work to develop the FEA-QLM integrated process and combine the CFD simulation in it.



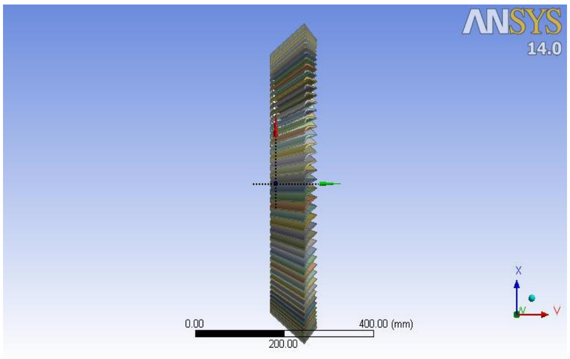


Fig. 14. *assembling the blades in one combination mechanism to perform the CFD calculation as a future work*

6. Conclusion

- FEA helps the designer and manufacture to analyze every Quality parameter during the life-cycle management.

- FEA gives the designer the possibility to test the part under many loading cases and estimating the resulted stresses, strains, deformations, fractions.

- Simulation engineering can show the relationships between all designed parameters (RPM, forces, materials, temperature) in direct and non-direct ways.

- We can reduce the time and costs to achieve the best possible design for our industrial part by doing the design optimization step during the FEA process.

- Results validation is very important step to assure the Numerical results and it will be the subject for future work by completing the CFD simulation and estimate error's sources.

- The QLM-FEA integrated system gives the designer and the manufacturer ability to control every step of part's production, during designing, manufacturing, managing and maintaining levels.

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PREDICTING OF REMAINING EUTECTIC CARBIDE CONTENT IN W1.4855 STEEL AS FUNCTION OF CARBON CONTENT AND HEAT TREATMENT PARAMETERS

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ABSTRACT

The relationship between the carbon content of W1.4855 steel, and the parameters of heat treatment of solution quenching (maintaining time and maintaining temperature) is investigated. The obtained experimental data are used to perform a statistical processing, resulting in a regression equation, useful for predicting the remaining eutectic carbide content in W1.4855 steel as function of carbon content and heat treatment parameters.

KEYWORDS*:* refractory steel, carbide, carbon content, solution quenching, maintaining time, temperature

1. Introduction

Austenitic refractory steels are widely used in the heat treatment industry to produce components that operate at temperatures in the range of 540 °C-1200 °C. Depending on their field of use, they fall into two broad categories. The first consists of components that work inside the furnaces and are subjected to high mechanical and/or thermal shocks (trays, fixtures, conveyor chains and belts, quenching fixtures). The second category consists of components that operate outside the furnace and are subject to less mechanical and thermal shocks (support beams, hearth plates, combustion tubes, radiant tubes, burners, thermowells, roller and skid rails, conveyor rolls, walking beams, retorts, muffles, recuperators, fans).

Because of the carbon content, most of these components are made from cast steel. In order to homogenize the structure and uniformly distribute the carbides, the cast components are subjected to a heat treatment of solution quenching. Their behavior in exploitation is in direct correlation with the structure, respectively with the content of carbides remaining after heat treatment. The analysis of the influence of the chemical composition on the carbide content of cast steel revealed that the most influential element is carbon [1, 2]. The smallest deviations in the sense of exceeding the prescribed limit of this element may have disastrous effects on the behavior of the material in use as it generates a higher volume of carbons that predominantly distributes to the grain boundary. This effect is even more pronounced as the chromium content of steel is higher, steel W1.4855 being a good example in this respect. Correction of such a situation is possible by heat treatment of solution quenching in the conditions of prolonging the maintaining time at high temperature or use of a higher maintaining temperature, for the purpose of dissolving carbides. However, this solution it is not always efficient to be applied due to too high manufacturing costs.

For this reason, establishing a complex relationship of dependence between the carbon content of steel, and the parameters of heat treatment of solution quenching (maintaining time and maintaining temperature) can be particularly useful for optimizing the whole process to improve their exploitation behavior.

2. Experimental method

The experimental investigations aimed to qualify the effects of the content variation in the carbon content of the steel obtained in W1.4855 (EN 10295-2002) analysis, austenitic stainless steel within the limits imposed by the mark and the thermal and temporal quality parameters for the solution of the proportion of the eutectic carbides remaining in the matrix. The analysis of the steel position in the Schaeffler structural diagram, considering the equivalent content of chromium and nickel respectively by the percentage of the general effects of the alpha- and gamma-phases, leads to the conclusion that regardless of the way of combining the proportion of the chemical elements of the steel within the required concentration limits brand, it remains in the austenitic field. The carbides appearing in the casted steel are inter-dendrite chromium carbides. The experimental researches aimed at explaining the effect of changing the chemical composition of steel on the proportion of carbide in casted state have highlighted that the variation of niobium concentration within the prescribed limits does not significantly influence the proportion of carbide in the cast. The effect of the proportion of this element is proved during subsequent heat transformation heat treatment or welding transformations through the appearance of very fine NbC carbide precipitations. Since Nb gold has a higher alliance than Cr than C, it prevents the formation of chromium carbides and thereby the austenitic build-up during long-term heating. In addition to the stabilizing role, niobium carbides also provide an increase in matrix breaking strength.

Earlier research in the field of carbides content in this casted steel confirm the current influence of carbon on increasing their proportion in steel, clearly superior to that associated with chromium and manganese alloying elements [1].

$$\%Carbide = 2.512 + 24.12\%C + 0.154\%Cr - 0.093\%Mn - 0.074\%Fe \qquad (1)$$

This justifies the choice of carbon content as the variable of interest in the study of the proportion of carbide remaining after the steel solution is required.

The other parameters of interest for the statistical processing, namely the temperature at which the heating and the maintenance in order to dissolve the carbide and the isothermal maintenance time were chosen in conjunction with the information required by the standard with the start-up temperature of the grain intensive growth for such a steel.

3. Experimental work

Starting from the standardized composition of W1.4855, %, the C% was varied between 0.1 and 0.19% keeping the other relative ones constant. As a measure of the effect on the structure, the percentage of eutectic carbides was used four alloys, chemical composition variants according to Table 1. All the specimens were manufactured at UTTIS industries SRL.

Elaboration of the alloys was carried out in an induction furnace with a 250 kg crucible. Y-samples were done in molds made of sodium silicate casting (96% quartz sand, 6% sodium silicate) and coated with zirconium paint.

Table 1. *The chemical composition for the group with variable content of Carbon*

Chemical composition	Sample No.		
	1	2	3
C	0.10894	0.29032	0.49064
Mn	0.76099	0.75832	0.74687
Si	1.03863	1.06435	1.09160
P	0.03976	0.03397	0.03652
S	0.02264	0.01956	0.02263
Ni	24.10008	24.29665	24.36708
Cr	25.58822	25.18587	24.82062
Cu	0.14994	0.16418	0.13577
Mo	0.10307	0.10554	0.11070
V	0.05465	0.05743	0.04933
Ti	0.00050	0.00050	0.00050
Al	0.01963	0.09040	0.15017
Nb	0.00200	0.00200	0.00200
W	0.01300	0.01300	0.01300
Sn	0.00315	0.00359	0.00317
Co	0.14160	0.15711	0.12845
B	0.00105	0.00108	0.00105
Ca	0.00048	0.00037	0.00028
FE %	47.8173	47.7781	47.6758

The experimental analysis was made in the UTTIS laboratory and involved the following steps: - analysis of the chemical composition of cast samples - chemical composition investigations were performed using the optical emission spectrometer ARL QUANTRIS which is a compact, stationary spectrometer for metals analysis, based on the latest high-end CCD (Charge Coupled Device) technology.

Heat treatment of samples - Heat treatment was done in a forced-roaster furnace with a maximum heating limit of 1200 °C. The experimental program implied the variation of two parameters: the isothermal maintenance temperature at 950 and 1100 °C and maintenance time at this temperature, between 1 and 8 hours.

- Cutting and preparing metallographic samples - both electrolyte and mechanical polishing were used to accomplish the critical surface preparation.

- Performing the structural analysis of the analyzed samples and interpreting the data - the structural analysis was made with an Olympus microscope, according with the ASTM B487 standard, by using Scentis Software version 1.2 for Windows and interpreting the data.

- Statistical data processing and determination of the correlation equation between the carbon content, temperature and maintaining time at the heating temperature.

4. Experimental results

The obtained results are presented in Tables 2 and 3 and represented graphically in the Figures 1, 2 and 3.

Table 2. *Carbide content of alloys with different carbon content for 0 to 8 hours maintaining time at 1100 °C and water cooling*

Isothermal maintenance temperature	**Carbide content, %**		
	Alloy with 0.10% C	Alloy with 0.29% C	Alloy with 0.49% C
As casted	4.7	12.52	16.92
1 hour	2.15	10.75	13.09
4 hours	1.59	8.7	10.77
8 hours	0.71	5.77	8.9

Table 3. *Carbide content of alloys with different carbon content for 0 to 8 hours maintaining time at 950 °C and water cooling*

Isothermal maintenance temperature	**Carbide content, %**		
	Alloy with 0.10% C	Alloy with 0.29% C	Alloy with 0.49% C
As casted	4.7	12.52	16.92
1 hour	3.46	11.52	14.16
4 hours	2.49	9.61	12.34
8 hours	1.78	8.32	10.32

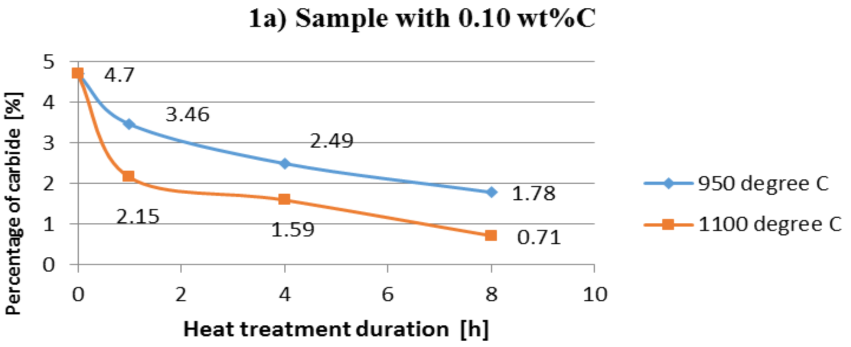

Fig. 1. *The relation between the temperature and maintaining time and the carbide content of steel with 0.10 % C*

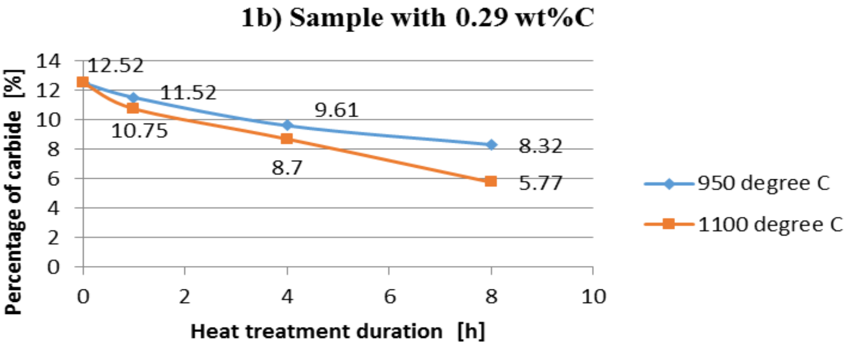

Fig. 2. *The relation between the temperature and maintaining time and the carbide content of steel with 0.29 % C*

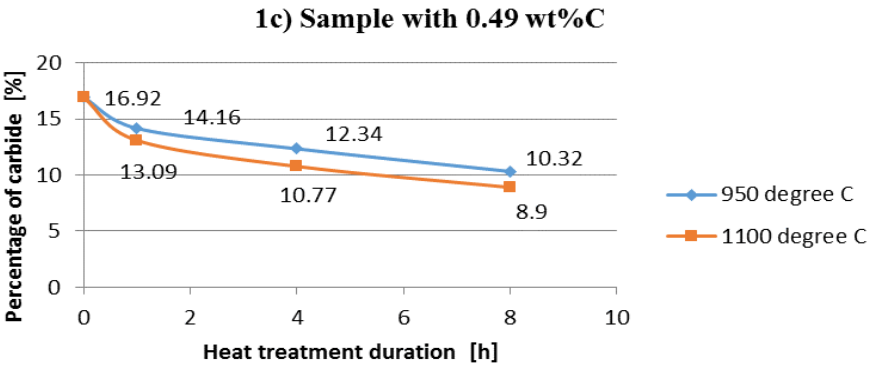

Fig. 3. *The relation between the temperature and maintaining time and the Carbide content of steels with 0.49% C*

***Table 4**. Correspondence between factor values expressed in natural units and in coded units*

Factor	(%C)		The temperature of treatment, TPS		Isothermal maintenance time		%Carbide
	Natural units Z1 in %	Coded values X1	Natural units Z2 in %	Coded values X2	Natural units Z3 in %	Coded values X3	Natural units Y, in %
Basic level Δ_{Z_0}	Z0=0.29	$\frac{0.29-0.29}{0.19}=0$	Z0=1025	$\frac{1025-1025}{75}=0$	Z0=4	$\frac{4-4}{3}=0$	-
Variation interval ΔZ_i	ΔZ=0.19	-	ΔZ=75	-	ΔZ=3	-	-
Higher level $Z_{io}+\Delta Z_i$	Z0+ ΔZ= 0.48	$\frac{0.48-0.29}{0.19}=+1$	Z0+ΔZ= 1100	$\frac{1100-1025}{75}=+1$	Z0+ΔZ= 7	$\frac{7-4}{3}=+1$	-
lower level $Z_{io}-\Delta Z_i$	Z0-ΔZ= 0.1	$\frac{0.1-0.29}{0.19}=-1$	Z0-ΔZ= 950	$\frac{950-1025}{75}=-1$	Z0-ΔZ= 1	$\frac{1-4}{3}=-1$	-
	INDEPENDENT VARIABLES						DEPENDENT VARIABLES

***Table 5.** Matrix of central orthogonal composite programming for 3 independent variables (K = 3)*

No.	X0	Factors						X1X2	X1X3	X2X3	Y
		X1	X2	X3	X1’	X2’	X3’				
1	+1	+1 0.48	-1 950	-1 1	+0.27	+0.27	+0.27	-1	-1	+1	14
2	+1	-1 0.1	+1 1100	-1 1	+0.27	+0.27	+0.27	-1	+1	-1	2.15
3	+1	-1 0.1	-1 950	+1 7	+0.27	+0.27	+0.27	+1	-1	-1	1.8
4	+1	-1 0.1	+1 1100	+1 7	+0.27	+0.27	+0.27	-1	-1	+1	0.8
5	+1	+1 0.48	-1 950	+1 7	+0.27	+0.27	+0.27	-1	+1	-1	10.1
6	+1	+1 0.48	+1 1100	-1 1	+0.27	+0.27	+0.27	+1	-1	-1	13
7	+1	+1 0.48	+1 1100	+1 7	+0.27	+0.27	+0.27	+1	+1	+1	9.1

8	+1	-1 0.1	-1 950	-1 1	+0.27	+0.27	+0.27	+1	+1	+1	3.46
9	+1	+α=+1.215 0.52	0 1025	0 4	+0.746	-0.73	-0.73	0	0	0	11.8
10	+1	-α=-1.215 0.59	0 1025	0 4	+0.746	-0.73	-0.73	0	0	0	1.2
11	+1	0 0.29	+α=+1.215 1116.1	0 4	-0.73	+0.746	-0.73	0	0	0	8.4
12	+1	0 0.29	-α=-1.215 933.4	0 4	-0.73	+0.746	-0.73	0	0	0	9.9
13	+1	0 0.29	0 1025	+α=+1.215 7.64	-0.73	-0.73	+0.746	0	0	0	7.2
14	+1	0 0.29	0 1025	-α=-1.215 0.355	-0.73	-0.73	+0.746	0	0	0	11.8
15	+1	0 0.29	0 1025	0 4	-0.73	-0.73	-0.73	0	0	0	9

5. Statistical data processing and determination of the correlation equation between the carbon content, temperature and maintaining time at the heating temperature

In order to quantify the variation effects of the parameters of interest (stainless steels carbon content, temperature and isothermal maintenance temperature at the temperature of dissolving the carbide), a method of programming opted for the second orthogonal composite experiment. Statistical methods are used in all stages of the experiment, before developing it. The use of statistical methods in this way aims at establishing the number and conditions of the experiments needed to generate the data obtained after the end of the experimental cycle and the elaboration of the strategies for carrying out new experiments.

This way of dealing with the problem is called the active experiment, and it involves programming the experiment [3].

The correspondence between the values of the factors - independent variables-expressed in natural units and respectively in the coded units is mentioned in Table 4, and the actual matrix of the programming containing the actual conditions in which it will be experimentally performed in Table 5.

The relationship between the natural value (Zi) and the coded (X_i) of a dependent variable is:

$$X_i = \frac{z_i - z_{i0}}{\Delta Z_i} \qquad (2)$$

Calculation the caloric coefficient of regression bo and bi, bij, bii;

The regression equation will have the following general form:

$$\tilde{y} = b'_0 + \sum_{i=o}^{k} b_i x_i + \sum_{\substack{i=1,\\ j=1\\ i\neq j}}^{k} b_j x_i x_j + \sum_{i=1}^{k} b_{ii}\left(x_i^2 - \bar{x}_i{}^2\right) \qquad (3)$$

If the matrix is orthogonal, the coefficients of the regression equation will be determined by the relations:

$$b'_0 = \frac{\sum_{n=1}^{N} x_{0n} y_n}{\sum_{n=1}^{N} x_{0n}^2} \qquad (4)$$

$$b_i = \frac{\sum_{n=1}^{N} x_{in} y_n}{\sum_{n=1}^{N} x_{in}^2} \qquad (5)$$

$$b_{ij} = \frac{\sum_{n=1}^{N} x_{in} x_{jn} y_n}{\sum_{n=1}^{N} (x_{in} x_{jn})^2} \qquad (6)$$

$$b_{ii} = \frac{\sum_{n=1}^{N} x'_{in} y_n}{\sum_{n=1}^{N} (x'_{in})^2} \qquad (7)$$

The transition equation (1) at its usual form most commonly used, respectively of a polynomial of the second order:

$$\tilde{y} = b_o + \sum_{i=1}^{k} b_i x_i + \sum_{\substack{i=1\\ j=1\\ i\neq j}}^{k} b_{ij} x_i x_j + \sum_{i=1}^{k} b_{ii} x_i^2 \qquad (8)$$

It can be done by explaining the coefficient value b'_0:

$$b_0 = b'_0 - \sum_{i=1}^{k} b_{ii} \bar{x}_i^2 \qquad (9)$$

with dispersion: $S_{b_o}^2 = S_{b'_o}^2 + \sum_{i=1}^{k} (\bar{x}_i^2)^2 - S_{b_{ii}}^2$ (10)

Calculation dispersions of the regression equation coefficients;

$$S'_{b_o} = \frac{S_0^2}{\sum_{n=1}^{N} x_{0_n}^2} \qquad (11)$$

$$S_{b_i}^2 = \frac{S_0^2}{\sum_{n=1}^{N} x_{i_n}^2} \qquad (12)$$

$$S_{b_{ij}}^2 = \frac{S_0^2}{\sum_{n=1}^{N} (x_{i_n} y_{j_n})^2} \qquad (13)$$

$$S^2_{b_{ii}} = \frac{S^2_0}{\sum_{n=1}^{N}\left(x'_{i_n}\right)^2} \tag{14}$$

where: (S^2_0) representing the dispersion of experiments reproducibility (experimental error).

S^2_0 was determined from the results of four experiments performed in identical conditions corresponding to the basic levels of the independent parameters (x_1=0.29%C; x_2=1025 °C; x_3=4h).

The results; $S^2_0 = \frac{\sum_{n=1}^{4}(y_n - \bar{y})^2}{\sigma_1} = \frac{1.29}{3} = 0.43$

Where $\sigma_1 = n - 1$ in which σ_1 = Number of free degrees and n = number of parallel experiments.

Calculate the confidence interval (Δbi, Δbij, Δbii) in which coefficients were estimated Δbi;

$$|\Delta b_1| = |\Delta b_2| = |\Delta b_3| = S_{b_i} \cdot t_{\alpha,N} \tag{15}$$

where:
$$S_{b_i} = \pm\sqrt{S^2_{b_i}}; \tag{16}$$

$t_{\alpha,N}$ - Tabulated criterion value;
α – Level of Significance Student.

$$\Delta b_{ij} = \pm\sqrt{S^2_{b_{ij}}} \cdot t_{\alpha,N} \tag{17}$$

$$\Delta b_{ii} = \pm\sqrt{S^2_{b_{ii}}} \cdot t_{\alpha,N} \tag{18}$$

Statistical verification of coefficients:

A coefficient is considered statistically determined (so with significant statistical influence), if and only if its absolute value is greater than or equal to its calculated confidence interval.

Verifying the hypothesis consistency of the adopted model:

An adopted model is considered to be consistent, so it expresses with good approximation the process / phenomenon realized if the calculated value of the Fischer criterion is lower than the table, so the condition of concordance can be written:

$$F_{calc} = \frac{S^2_{conc}}{S^2_0} = \frac{1}{S^2_0} \cdot \frac{\sum_{n=1}^{N}\left(y_{n_{calc}} - y_{n_{exp}}\right)^2}{\sigma_1} < F_{tabel_{\alpha,\sigma_1,\sigma_2}} \tag{19}$$

Where $\sigma_1 = N - k$ in which:
S^2_0 - Dispersion of Experiment Reproducibility.
σ_1 - Number of free degrees.
N - number of experiments (N=15).
K - the number of determined statistical coefficients of the regression equation, including the free term.
α- the level of significance (α = 0.05) which indicates that the probability with which the equation expresses the influences taken in the analysis is 95.

Concretely, going through the algorithm steps led to the following results:

The coefficient values of regression are:
$b'_0 = 7.514$, $b_1 = +4.91$, $b_2 = -0.56$, $b_3 = -1.49$, $b_{12} = +0.038$,, $b_{13} = -0.598$, $b_{23} = +0.038$, $b_{11} = -2.33$, $b_{22} = -0.196$, $b_{33} = +0.04$

The calculated values of the coefficients of the regression equation (for $S^2_0 = 0.43$) are:
$S^2_{b_i} = 0.0396 \rightarrow S_{b_i} = \pm 0.198$
$S^2_{b_{ij}} = 0.053 \rightarrow S_{b_{ij}} = \pm 0.23$
$S^2_{b_{ii}} = 0.098 \rightarrow S_{b_{ii}} = \pm 0.39$
$S_{b'_0} = 0.0286 \rightarrow S^2_{b_0} = S^2_{b'_0} + (\bar{x}^2_1)^2 \cdot S^2_{b'_n} = 0.0808$
$\rightarrow S_{b_0} = \pm 0.898$

The confidence intervals values for coefficients of regression equation:

$$|\Delta b_i| \rightarrow |\Delta b_1| = |\Delta b_2| = |\Delta b_3| = 0.42$$

Comparing the calculated values of coefficients b_1, b_2, b_3 with their confidence interval are found to be statistically significant.

$$|\Delta b_{ij}| \rightarrow |\Delta b_{12}| = |\Delta b_{13}| = |\Delta b_{23}| = 0.42$$

By comparing the calculated values of the coefficients b_{12}, b_{13}, b_{23} with their confidence interval it is found that only the coefficient b13 has a higher value than the confidence interval, so it is statistically significant.

$$|\Delta b_{ii}| \rightarrow |\Delta b_{11}| = |\Delta b_{22}| = |\Delta b_{33}| = 0.66$$

By comparing the calculated values of coefficients b_{12}, b_{13}, b_{23} with their confidence interval it is found that only the coefficient b11 fulfills the condition of statistical significance. Concerning the free term b_0 = 9.33, this value is higher than the confidence interval.

$|\Delta b_0| = S_{b_0} \cdot t_{\alpha,N} = 0.898 \cdot 2.131 = 1.995$, so, it is also statistically determinant.

Followed by the particular formation of equation (8) will be:

$$y = 9.33 + 4.9x_1 - 0.56x_2 - 1.49x_3 - 0.598x_1x_3 - 2.33x_1^2 \tag{20}$$

in which:

- x_1, x_2, x_3 are the encoded forms of interdependent variations (Table 6 discussed);
- y is the natural value of the dependent parameter (%carbides) in the steel.

Verification the conformity of the adopted model

Table 6. *Calculating the dispersion produced by the regression equation,* S^2_{conc}

No.	y_{exp}	y_{calc}	$(y_{exp} - y_{calc})^2$	$\sigma_1 = N - k'$
1	14	14.548	0.3	15-6=9
2	2.15	2.432	0.179	
3	1.8	1.768	0.001	
4	0.8	0.648	0.023	
5	10.1	10.372	0.074	
6	13	13.428	0.183	
7	9.1	9.252	0.023	
8	3.46	3.552	0.0084	

9	11.8	11.843	0.00185	
10	0.2	0	0.04	
11	8.4	8.649	0.062	
12	9.9	10.01	0.012	
13	7.2	7.519	0.101	
14	11.8	11.14	0.43	
15	9	9.33	0.109	
$\sum_{1}^{15}(y_{exp} - y_{calc})^2 = 1.447$				

$$S_{conc}^2 = \frac{\sum_1^{15}(y_{exp} - y_{calc})^2}{\sigma_1 = N - k'} = \frac{1.447}{9} = 0.16$$

$F_{calc} = 0.37$

$F_{tab_{0.05,9,3}} = 8.8$ (table value)

Because $F_{calc} < F_{tab}$ hypothesis about the conformance of the model is checked and the regression equation (18) expresses with an extremely high probability of water influences that show the parameters independent of the analysis taken on the proportion of eutectic carbides remaining after applying the solution. Introducing the expression in the equation (20) between the coded or natural values of the independent parameters can obtain a regression equation in which the variables are in their natural form:

$$\%\mathbf{Carbide} = 4.85 - 64.54(\%C)^2 + 67.42(\%C) - 7.46 \cdot 10^{-3}T_{cal} - 0.19t_{m_{iz}} - 1.05(\%C)t_{m_{iz}} \quad (21)$$

6. Conclusions

The particular forms determined for the regression equations allow the choice of the thermal processing conditions so that the proportion of the remaining eutectic carbide is predictable. The equation analysis clearly shows the following:

- The influence of carbon concentration on the proportion of steel eutectic carbide is extremely strong both in casting state as well as after applying the heat treatment.

- The best effect to dissolve the carbide it is maintaining time of the temperature than increasing the temperature – the statement must be controlled within the range of variance chosen for the two parameters, $T \in [950°C \ldots 1100°C]$, $t \in [1 \ldots 7\ h]$.

Thus, if the varying of treatment temperature between 950-1100 °C obtain lower proportion of carbide around 10%, a variation of the isothermal maintenance time within the chosen range, between 1 and 7, causes a decrease in the proportion of eutectic carbide by approx. 30%, (calculated value for the solution inlet temperature of 1100 °C and the initial carbon concentration of 0.48%).

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RESEARCH ON THE INFLUENCE OF CHEMICAL COMPOSITION AND STRUCTURAL CONDITION ON THE PROPERTIES OF HIGH-RESISTANCE NAVAL STEEL FLAT ROLLED PRODUCTS

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ABSTRACT

The performance achieved in the manufacture of large ships and components of special characteristics requires the use of quality metallic materials with physico-chemical and mechanical characteristics able to satisfy the quality conditions specified in the product standards for a safety operation.

The category of flat rolled products widely used in naval industry includes the high-strength sheet steel whose characteristics depend on the correlation of the chemical composition with the thermal and / or the thermo-mechanical processing in order to obtain the prescriptions imposed by the naval regulations.

The paper presents some of the experimental results obtained by a laboratory scale research program for the study of the influence of the thermal and / or thermomechanical treatment parameters on the use characteristics of the high-strength naval steel sheet while ensuring the constancy of these characteristics in the manufacturing. The evaluation of the physical-mechanical properties and the interpretation of the experimental results obtained have as reference similar properties obtained from conventional thermal processing or even from the state of rolling as the state of the product delivery.

KEYWORDS: steel, rolled, heavy plates, temperature, structures, mechanical properties, heat treatments, thermomechanically rolled, naval industry

1. Introduction

In time, the manufacturing technology of naval thick plates had to demonstrate its performance at the highest level throughout the technological flow, starting with the production of steel and continuing with casting, rolling and subsequent heat treatments which define the delivery condition in compliance with standards. At the same time, the assurance of constancy in manufacturing required the correlation of factors regarding the chemical composition, structure and use characteristics. The fulfilment of this requirement was possible by the development of new steel brands and the application of modern metallurgical processing technologies and procedures. The steel sheet for the shipbuilding industry can be delivered according to the ship's standards and regulations [1-8] in the state/condition of: rolled by heat treatment of normalization, thermal quenching / recovery, or thermomechanical treatment. Researches on the processing methods have demonstrated the effectiveness but also the diversity of thermal and thermo-mechanical treatment technologies for the production of flat rolled products with the most varied requirements in the field of shipbuilding [9, 10]. The transition from classical thermal treatments to thermo-mechanical treatments presents a number of advantages, of which important are those concerning the elimination of certain operations in the manufacturing technology and the reduction of energy and material consumptions. Among the thermomechanical processing technologies with applicability on an industrial scale, controlled rolling has been imposed.

The rolling/ lamination regime combined with controlled cooling or direct hardening from lamination represented the first studies in the field of thermomechanical treatments performed in order to establish a way to control the microstructure in the hot rolling process.

The introduction of special accelerated-cooling equipment systems has allowed the thermo-mechanical treatment technologies to be diversified through the development of increasingly complex combinations such as normalized rolling/lamination-the final deformation takes place within a temperature range resulting in a material with a structural condition equivalent to that obtained after normalization- or thermo-mechanical rolling where the final deformation takes place within a temperature range resulting in a structural condition and mechanical characteristics which cannot be achieved or kept by heat treatments only. Regardless of the processing mode though, it has been demonstrated that the obtaining of high mechanical characteristics is ensured only by the proper choice of the steel brand (chemical composition) and by strict compliance with the technological parameters specific to the metallurgical processing.

The beneficial effects of lowering the carbon content to improve weldability and microalloying with different elements should be exploited and combined with the benefits of an unconventional approach to the heat treatment process. Thus, in spite of the conservative positions to be found in the practice of thermal treatments, there are more and more research results that recommend incomplete austenitization for the normalization treatment of the naval plates or for the hardening of structural steels and the heat-affected zone in the welded joints, with some Ni- Mo or Ni-Mo-V low carbon steels [9-11]; by reducing the heat treatment temperature, the products of such steels have achieved increased values of both resistance and plasticity indices.

In USA for instance, use is made of biphasic alloys with Mn, V, Al with inter-critical thermal treatment, while in Russia, complex inter-critical controlled lamination tests were performed on metal structural steels and the results show values of strength ($R_{p0,2} > 500$; $R_m > 600$ MPa) associated with values of extremely high plasticity properties and with a level of ductility almost twice as high as with normalized steel [9].

Deepening and systematizing the results of researches in this field is also the objective pursued in the development of experimental research, the results of which are partially presented in this paperwork.

Laboratory experiments will be able to draw a new orientation in the practice of heat treatments applied to naval steel products resulting in the development of technologically and economically optimal technologies.

2. Materials and experimental conditions

The experimental researches were carried out in the Micropilot Plant Laboratories and the Laboratory of Thermal Treatments and Surface Engineering of the Faculty of Engineering at “Dunarea de Jos” University of Galati. Samples of A36, D36 and E36 steel grades are taken from plates of 12,5; 15,5 and 30mm thickness which come from different batches of slabs manufactured at the A.M. Steel Works of Galati.

Table 1 shows the chemical composition of naval steels and Table 2 presents the mechanical properties of the naval plate steels in compliance with the naval standards.

Table 1. *The chemical composition of high-strength steel for the ship hulls as per standards [1, 2]*

	A32	D32	E32	**A36**	**D36**	**E36**	A40	D40	E40
Elements%	Calmed and fine grain steel						Calmed and fine grain steel		
Steel production conditions deoxidation	Calm steel and manufactured with fine grain								
Delivery State	According to Table 3								
C_{max}	0.18						0.18		
Mn	0.90–1.16						0.90–1.60		
Si, max	0.50						0.50		
P, max	0.040						0.04		
Cu, max	0.35						0.35		
Co, max	0.20						0.20		
Ni, max	0.40						0.40		
Mo, max	0.08						0.08		
Al_{sol}, min	0.015						0.015		
Mo	0.02–0.05						0.02–0.05		
V	0.05–0.10						0.05–0.10		
Ti, max	0.02						0.02		

***Table 2.** Mechanical characteristics of high-strength steel for the ship hulls as per standards [1, 2]*

Steel grade	**Breaking Strength Rm**	**Yielding point Rc**	**Breaking Elongation *A5 ($L_0=5.65S_0$)**	**Impact bending test on Charpy specimens with V-notched longitudinal (L) and transverse (T) Breaking Energy (J) min**					
A36 D36 E36	[N/mm^2]	[N/mm^2] min	[%] min	KV_L t ≤ 50 mm	KV_T t ≤ 50 mm	KV_L 50 < t ≤ 70 m	KV_T 50 < t ≤70 mm	KV_L 70 < t ≤ 100 mm	KV_T 70 < t ≤ 100 mm
	490-630	**355**	**21**	**34**	**24**	**41**	**27**	**50**	**34**

**) For tensile tests on flat specimens of thickness (t) equal to that of the plate, of 25 mm width and 200 mm calibrated length, the breaking elongation should correspond to the minimum values given in Table 2 bis*

***Table 2 bis.** Minimum values for breaking elongation **A5** [2]*

Thickness t, (mm)	≤5	>5≥10	>10≤15	>15≤20	>20≤25	>25≤30	>30≤40	>40≤50
Breaking elongation %	**13**	**15**	**16**	**17**	**18**	**19**	**20**	**21**

Remark:

To ensure that every single class of steel has a single strain value regardless of the product thickness, a rule specific to shipbuilding design - it is necessary to compensate by appropriate technological solutions the metallurgical effects resulting from the change of the cooling rates after rolling or heat treatment depending on the thickness of the product.

Since the chemical composition is the main factor of influence on the material characteristics to ensure a satisfactory level of weldability, naval regulations prescribe for each grade of steel the maximum allowed values for carbon and manganese contents and the calculation of the equivalent carbon, leaving the manufacturer's freedom to regulate the chemical composition of the steel within these limits, depending on the product thickness. In order to execute the highly–stressed welded joints as required in the marine drilling platforms, the competent authority in the field such as the Romanian Naval Register (RNR) has introduced a new quality of products with guarantees of plasticity characteristics in the thickness direction as presented in Table 3 [3], and the state of delivery of the steels is mentioned in the quality certificate; certain categories of steels may be delivered in a rolled condition provided that satisfactory results are consistently obtained with shock bending tests.

Replacement of the normalization of the laminate semi-finished product with controlled temperature lamination or thermomechanical processing is acceptable only with the consent of the competent naval authority.

The chemical composition of the plates from which the samples were extracted is shown in Table 4, as compared to the product standard indications. They are steels additionally deoxidized with aluminium and of fine granulation, grading score 10.

***Table 3**. Delivery state of the highly resistant steels [1, 2]*

Category	**Elements of granulation finishing**	**Thickness t (mm)**	**Delivery state/condition**
A32; **A36**; A40	Nb,V	≤12.5 >12.5	No (N), CR, or TM is regulated
A32; **A36;** A40	Al or Al+Ti	20<t≤35 >35	No (N), CR, or TM is regulated
D32; **D36;** D40	Nb,V	≤12.5 >12.5	No (N), CR, or TM is regulated
D32; **D36;** D40	Al or Al+Ti	20< t ≤25	No (N), CR, or TM is regulated
E32; **E36;** E40	Any	All	N, TM, (QT)

Table 4. *The chemical composition of the plates from which the samples were extracted*

batch	**Chemical elements [%]**													
	Steel	**C**	**Si**	**P**	**S**	**Al**	**Cu**	**Cr**	**Ni**	**Mo**	**Ti**	**Mn**	**V**	**Nb**	**B**
S1	**A36-1**	0.169	0.197	0.015	0.005	0.041	0.014	0.035	0.013	0.002	0.001	1.550	0.003	0.003	0.0002
S2	**A36-2**	0.169	0.212	0.020	0.006	0.045	0.013	0.032	0.076	0.001	0.002	1.528	0.006	0.002	0.0003
S1	**E36-1**	0.168	0.240	0.014	0.005	0.040	0.016	0.027	0.025	0.002	0.014	1.420	0.001	0.030	-
S2	**E36-2**	0.149	0.270	0.015	0.008	0.049	0.016	0.035	0.026	0.003	0.017	1.390	0.001	0.030	-

Analysing the chemical composition of the experimental batches, the following observations can be made:

- the carbon content of the batch varies within the range of 0.15-0.17 and is within the limits prescribed by the standard (max. 0.18);
- the silicon content ranges from 0.20-0.27 to 0.10-0.50 as prescribed in the norm and is estimated to be relatively constant in the batch concerned;
- the manganese content is within the range of: 1.39-1.55 and is within the limits prescribed by the standard (0.90-1.60);
- the aluminium content complies with the minimum allowed content and is approximately constant in the experimental batch composition, at around 0.40%;
- the same observations are also valid for the copper element;
- the chromium content in the range of 0.27 – 0.35% exceeds the maximum prescribed limit (0.20%) for all experimental batches;
- the nickel content is lower than that prescribed by the norm (0.20-0.40) for the two experimental batches of A36 quality;
- the molybdenum content comlies with the prescribed content (does not exceed 0.08% for any of the four batches);
- the content of titanium which is not regulated in the norm increases significantly with the E36 grade compared to A36 one;
- the vanadium content of the batch is significantly lower (0.001-0.006) than the prescribed one (0.05-0.10);
- the content of niobium increases significantly in E36 grade batches (0.03) being within the norm requirements (0.02-0.05) vs. A36 where the values are below the prescribed standard (0.002-0.003).

Boron is only found in the composition of A36 steel grade at very low values (thousandths of a percent).

In conclusion, it can be appreciated that for, the experimental batches, there are compositional deviations from the prescriptions of the naval norm. With some chemical elements such as nickel, niobium (values below those specified), chromium (values over the maximum normed content for all experimental batches), vanadium (values significantly lower than the prescribed ones). On the other hand, it can be seen that the effect of decreasing titanium and niobium content in the A36 batches compared to E36 ones may be counteracted by the presence of boron.

The samples were subjected to thermic and thermomechanical regimes using the existing aggregates and machines in the laboratories of the Faculty of Engineering (electric furnaces, mini rolling mills, hardness meters, metallographic sample preparation machine, metallographic microscope). The experimental regimes of thermal and thermomechanical processing on laboratory scale include the following variants:

I. regimes 2, 3, 4: complete austenitization* (supercritical heating at 880 °C) followed by cooling in different environments (air, oven, oil); II. regimes 5-10: complete austenitization (supercritical heating) followed by plastic deformation (10%, 30%, 40%) and cooling in different environments (air, water); III. regimes 11, 12: incomplete austenitization* (intercritical heating) followed by plastic deformation with a degree of deformation of 30% and air cooling.

Fig. 1. *Electric furnace used in experimental regimes of thermal processing on laboratory scale*

3. Experimental results and discussion

In Table 5 the experimental regimes are described by the characteristic technological parameters. After the application of the processing regimes, standard specimens have been made which have been put to a tensile/traction test under the terms of the hip plates specific rules.

The values obtained for the s mechanical properties of resistance (Rm, $R_{p0,2}$), plasticity (A5) and tenacity (energy absorbed, KV, determined on V- crest specimens) of the experimentally processed samples in the variants described above were compared with those obtained on the samples in the structural state provided by the classic rolling at different rolling end temperatures ($t_{e.r.}$).

Table 5. *Heat processing regime*

Nr Crt	**Regime**	**Heating temperature t [°C]**	**Degree of plastic deformation ε [%]**	**Cooling media**
0	Rolled $T^{**}_{e.r.}$=850 °C	-	-	-
1	Rolled $T^{**}_{e.r}$ =810 °C	-	-	-
2	**C**	880 °C	-	furnace
3	**D**		-	air
4	**E**		-	oil
5	**F**		10%	air
6	**G**		30%	
7	**H**		40%	
8	**I**		10%	water
9	**J**		30%	
10	**K**		40%	
11	**L**	880 °C/760 °C+ deformation	30%	water
12	**M**	760 °C + plastic deformation		

(*) Critical batch points from which samples were experimentally processed were calculated and the results are: A_{C1}*= 709 °C;* A_{C3}*= 813 °C*
(**) end rolling temperature

Figures 2-5 presents the values of the mechanical properties of resistance (Rm, Rc), plasticity (A5) and tenacity (energy absorbed, KV) of the experimentally processed samples.

The results obtained under variant I, regimes 2, 3 and 4 confirm that the cooling medium, which determines an optimal set of physical-mechanical properties of strength and plasticity is the air. Very slow cooling (30-50 °C/h) compromises the mechanical properties of resistance (e.g. the limit admissible value for mechanical tensile strength and values below the permissible limit of yielding/flowing), while rapid cooling in *oil* leads to very low values of the breaking elongation (values far below the prescribed ones.

This conclusion was used in the variants II and III, in the high temperature thermo-mechanical treatment regimes (with supercritical heating) and intercritical thermomechanical treatments (with heating in the intercritical range of the steels studied).

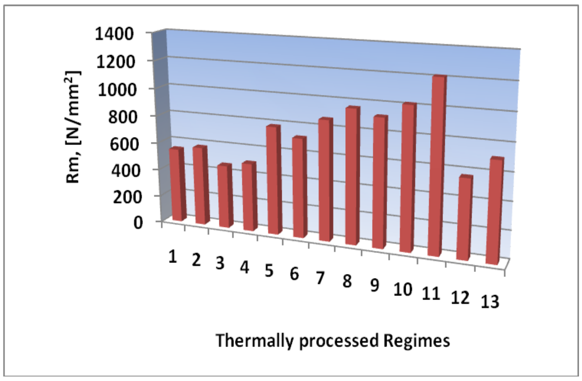

Fig. 2*. Variation of mechanical resistance values at breaking according to experimental processing regimes*

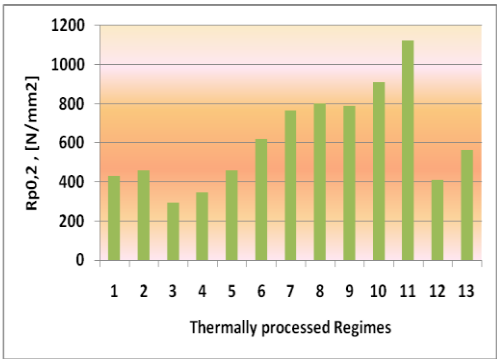

Fig. 3. *Variation of the yield point ($R_{p0,2}$) values according to experimental processing regimes*

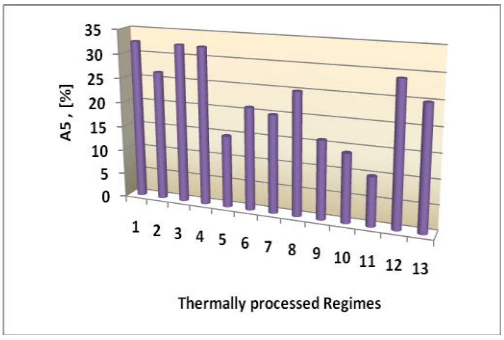

Fig. 4. *Variation of the elongation at break (A_5) values, according to the experimental processing regime*

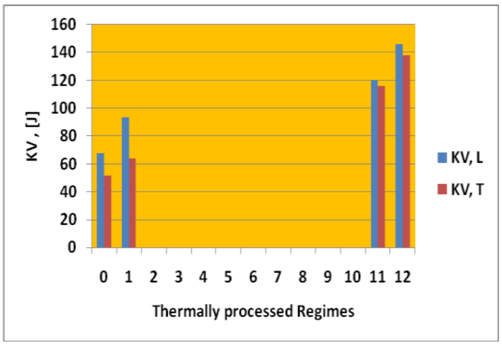

Fig. 5. *Variation of the of the energy absorbed (KV) values according to the experimental processing regime*

4. Microstructural aspects

Figures 6-10 show some microstructural aspects of thermally and thermomechanically processed samples in different variants and experimental regimes (A36 –S1-2).

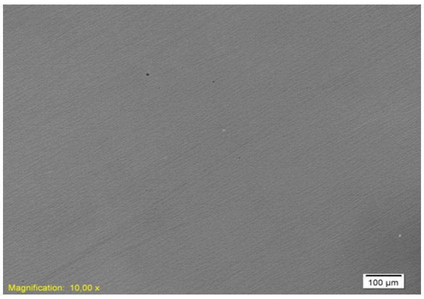

Fig. 6. *Purity of scoring material max.0,5 (laminated state, X100)*

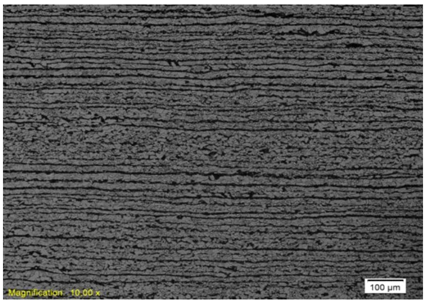

Fig. 7. *Ferrite-perlite structure in score ranges-strings 4-5; Grade size 9.5 (nital attack 3% X100)*

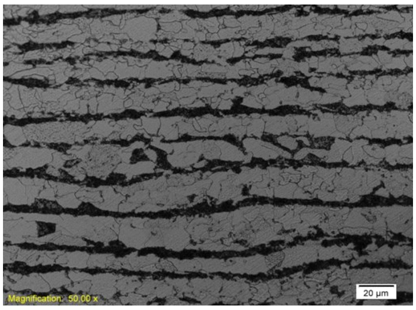

Fig. 8. *Perlite distributed in strings and oriented in the direction of deformation (nital attack 3% X500)*

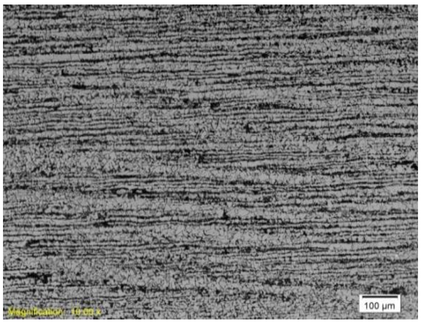

Fig. 9. *Thermally processed samples (variant I, regime1), X100*

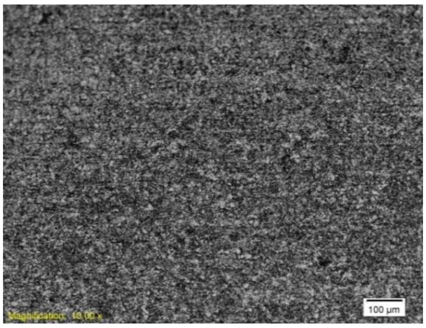

Fig. 10. *Thermally processed samples (variant I, regime 3), X100*

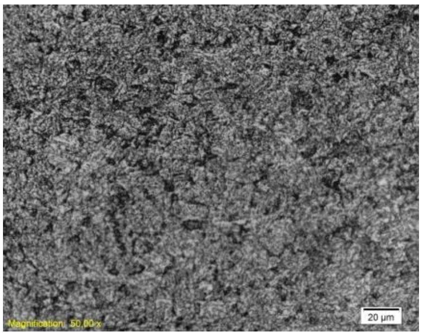

Fig. 11. *Thermomechanically processed samples according to regime 5*

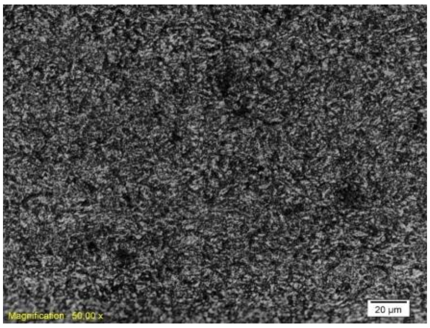

Fig.12. *Thermomechanically processed samples according to regime 6*

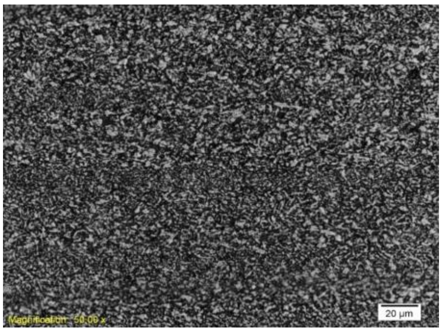

Fig. 13. *Thermomechanically processed samples according to regime 7*

5. Conclusions

The paper presents some results obtained in the study of the influence of thermal treatments, experimental variants applied in order to establish the optimal technological parameters (e.g. heating temperature, cooling medium) of the highly resistant naval steel. The objective of the research is to design the technology of thermal or thermomechanical processing of naval steels with a certain chemical composition under conditions of technical, technological and economic efficiency.

Preliminary results show that physical-mechanical characteristics can be obtained within the limits prescribed by the delivery rules of the heat-treated naval steels with minimal costs, provided the technology (technological parameters) correlated with the quality of the steel (the chemical composition) are known and rigorously complied with.

Modification of the mechanical properties correlated with the chemical composition and the structural state conferred by the type or method of metallurgical processing (rolling, conventional heat treatment or thermomechanical treatment) leads to the following conclusions with significant relevance in naval steel manufacturing with characteristics rigorously prescribed by the naval rules.

1. The decrease of the end-of-roll temperature causes the mechanical properties of resistance (Rm, $Rp_{0,2}$) to increase, while the plasticity (A5) and tenacity (KV) decrease.

2. The optimal cooling environment after rolling and after thermal and thermo-mechanical treatment is the air considering that:

2.1. Very slow cooling leads to structures with low mechanical properties, mainly affecting the yielding point ($Rp_{0,2}$ / see regime 2) whose values are below the allowable value for these steels (min.355 N/mm^2).

2.2. Accelerated cooling performed in environments such as oil or water has resulted in a decreased in plasticity, expressed by breaking elongation (see regimes 4, 8, 9, 10), and whose values are significantly lower than the admissible ones in all experimental thermal and thermomechanical variants prescribed by the norm (min. 21).

3. Thermomechanical treatments in the austenitic and plastic deformation experimental variants with 10%, 30% and 40% deformation rates, respectively, generally result in increased mechanical resistance with the increase of the degree of deformation both during final air cooling and final water cooling. It is noted, however, that the plasticity properties do not follow the same linear evolution as the degree of deformation.

4. It is highlighted the variant of thermomechanical treatment that requires complete austenitization with plastic deformation at higher deformation degrees (40% / see variant 7) and air cooling.

5. In spite of the very high values of the mechanical properties achieved by the austenitic thermo-mechanical treatment, accelerated cooling after plastic deformation irrespective of the degree of deformation compromises plasticity and tenacity of the material (see variants 8, 9, 10).

6. Good results were obtained from the thermo-mechanical treatment in incomplete austenitizing variants, particularly the direct heating in the inter-critical range of steel, the degree of plastic deformation of 30% and air cooling.

Following the above observations, we recommend for the A36, D36 and E36 naval steel plates low-temperature heat treatment technology with beneficial technical and technological effects.

Obtaining a set of mechanical (strength, plasticity and tenacity) characteristics in accordance with the naval register standards is possible under economical rolling and/or thermo-mechanical treatment conditions.

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RISK ASSESSMENT AND WORKPLACE CONFORMITY AUDIT, BLAST-FURNACE WORKER, C.S. ARCELOR MITTAL GALATI

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ABSTRACT

Risk assessment is the first step towards safer and healthier jobs, and it is the way to reduce accidents at work and occupational diseases. Taking into consideration the need for good management of the risks of accident and professional disease at the unit level and the new legal requirements, the evaluation of the risk factors for injury and professional illness at the – blast-furnace worker- from C. S. ArcelorMittal Galati taken into consideration for this study.

KEYWORDS: risk assessment, blast-furnace, worker platform, INCDPM-Bucharest method

1. Introduction

The furnace is the actual iron-producing aggregate necessary for the steel process in the converter. The casting of the cast iron is a continuous process, feeding of the furnace with raw materials and coke is done rhythmically as the material column descends as a result of the coke combustion, the melting process and the periodic discharge of the resulting products.

The continuity of this process makes a complex and diverse range of risk factors for injury and occupational disease to act on service staff. Many of these measures have a direct impact on reducing the cost per tonne of cast iron, but all have an important contribution to lower the cost of incidents.

Consequences of incidents of any nature can be viewed as human, economic, environmental, social etc.

2. Objectives

Taking into account the need for good management of the risks of accident and occupational disease at the unit level and the new legal requirements, it was decided to carry out the evaluation of the risk factors for injury and professional illness at the workstations. For this the INCDPM - Bucharest method was used as a theoretical and working method. Based on the theoretical and practical premises, the steps of the method were carried out by making the hierarchy of risk factors.

Identifying deadlines that are more important at a given time to perform the measures is done in line with the generic hierarchical order:

- Intrinsic prevention measures;
- Collective protection measures;
- Individual protection measures.

3. Theoretical considerations

Risk assessment should be structured to ensure that all relevant hazards and risks are addressed. First, we try to eliminate them. If we cannot, we reduce them.

The starting point in optimizing the prevention of occupational accidents and occupational illnesses in a system is the assessment of the risks in the system.

The risk assessment involves identifying all the risk factors in the system under consideration and quantifying their size based on the combination of two parameters: the severity and frequency of the maximum possible effect on the human body.

The system of work can be defined as the set of components with intercondition relations between them during space and time of different activities in order to transform inputs into the system (materials, subassemblies, energy, bought / supplied) in the outputs of the system (products, services, delivered / sold) to meet market needs.

Components of the work system are the workload; worker (executor); means of production; working environment (Figure 1).

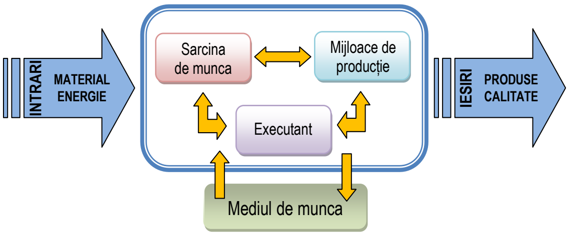

Fig. 1. *Components of the work system*

Risk factors in the work system show that the space of manifestation of the risk factors is the work process. By turning from possibility into reality, the action of the risk factors becomes an effective danger for the performer, which can lead either to the violent injury of the organism, by damaging anatomic integrity, causing the annulment of one or more of the physiological functions. In the event of such events, risk factors have been caused by (real) injury or professional illness.

Variations are movements that deviate from normal walking, i.e. sudden dysfunctions of the elements involved in the realization of the work process. By definition, they are specific to accidents at work. Variations are inherent to all elements of the work system: rolls objects, a machine starts off or does not respond to the stop command, the performer stops and falls, fluid jets, kickbacks, etc.

States are properties, properties, human deficiencies, defects in relatively permanent means of production, which is why we find them especially in the etymology of occupational diseases. Not just the static elements listed above represent states; through its relatively permanent character, and the functional movement of a toothed wheel is a condition that can lead to an accident at work and not a professional illness.

However, a very rigorous delimitation of the two categories is not possible. Under certain conditions, the specific difference is only given, the level and duration of exposure of the human body, so that a disease factor can become an injury factor and vice versa.

Legislation Romania. This risk assessment principle is already included in the European standards (IEC 812/85, EN 292-1 / 1991, EN 1050/96) and underlies the various practical methods. Thus, SR EN 292-1 / 1996, taken over in Romania according to the European standard mentioned, in chap. 6, states that the "factors" to be taken into account in the risk assessment are:

a) the likelihood of injury or damage to health;
b) predictable maximum severity of damage to or damage to health.

The obligation to assess the risks to jobs in our country derives from the current legislation in the field. Thus, in Law no. 319 of July 14th, 2006 to Art. 7, it is specified:

(3) The employer has the obligation to implement the measures stipulated in paragraph (1) and (2), on the basis of the following general principles of prevention:

a) avoiding risks;
b) assessing the risks that cannot be avoided;
c) combating risks at source;

(4) Without prejudice to other provisions of this law, taking into account the nature of the activities in the undertaking and / or establishment, the employer shall:

a) assess the risks to the safety and health of workers, including the choice of work equipment, chemical substances or preparations used and the fitting-out of workplaces;

The INCDPM method was endorsed by the Ministry of Labour and Social Solidarity in 1993 with constant improvements. Application of the method is useful to society because it allows:

- radiography of the existing situation at each workplace, highlighting the acceptable and unacceptable risks, as well as the measures to be taken;
- comparison and ranking of jobs by gravity criterion;
- rigorous economic and social justification for the managerial decision regarding the order of adopting the preventive measures;
- an objective basis in the discussions between the board of directors and trade union representatives and other workers on pay and compensation.

In order to carry out the assessment of the risks of injury and occupational disease for the workstation "furnace platform - Furnace Department", the field shift was made for the establishment of the analysis team. With this team, the following steps were taken:

- theoretical premises were presented to carry out a risk assessment in accordance with the new legal requirements and the new realities on the ground, including organizational ones;
- the purpose of the work system was identified by defining the work process.
- the means of production were identified on the ground and listed.
- for the determination of the workload, the job sheet was presented to us.
- determination bulletins for analysing work environment parameters were purchased.
- it has come to the practical identification of risk factors on the ground and discussions with workers. By direct observation and logic deduction the risk factors for each component were established;
- with the help of the physician and the Possible consequences of the action of risk factors on the human body (appendix to the course support), the

maximum foreseeable consequence for the identified risk factors was established;

- based on the identification of the maximum foreseeable consequence and using the grading scale, the introduction into seriousness classes was made;
- using the rating grid, based on the severity and frequency previously obtained, the factors at the appropriate risk levels;
- using the calculation formula, the weighted average risk factor was established, establishing the partial risk level for the analysed workstation;
- we have made the hierarchy of risk factors for the prioritization of prevention and protection measures according to the level of risk;
- a list of proposed preventive measures has been prepared to reduce risk factors;
- the report of the analysis with the interpretation of the evaluation results was drawn up.

4. Method of research

4.1. Work process

➢ ***The production of iron*** in the quantity required by the Business Plan and the quality established by the Company Standard.

4.2. Elements of the work system

4.2.1. Means of production

➢ ***The furnace itself, plant and machinery:***

- Caution for preheating the air;
- Dust bag, for blast furnace treatment;
- Apparatus for batch loading in the furnace;
- Water cooling system;
- Machine for punching and punching the cast iron hole;
- A blast furnace installation in the blast furnace;
- The base of the bunkers with the associated equipment for the preparation of the batch loading batch;
- The control room; synoptic panel

➢ ***Means of transport:***

- Railways for unloading slag and cast iron;
- Cast iron pots, slag pots; wagons;

➢ ***Raw materials:***

- Coke; crowded; pellets; iron ore; coal dust; hot air (t_{max} = 1250 °C); combustible energy fluids: (furnace gas; CH_4;) furnace cooling water; oxygen breathing pipes; iron bars (rods).

➢ ***Products obtained:***

- First fusion cast iron; slag; blast furnace powder.

➢ ***Refractory materials:***

- Table for closing the cast iron hole; refractory concrete; refractory materials for lining pig iron and slag gutters;

➢ ***Tools:***

- Row; crowbar; sledge - hammer; electric and pneumatic hammers; rolling stock; winches; winches.

4.2.2. Work task

➢ ***Arrival to the program:***

- Taking over the exchange; is appropriately equipped with E.I.P.; is trained for the operations to be performed; is assigned to the workplace;

➢ ***Maintain drainage gutters (cast iron, slag):***

- Performs operations to close the cast iron hole after cast iron and furnace slag;
- Evacuation of cast iron deposits on the bottom of the gutters and basin;
- Prepares discharge of cast iron and slag furnace;
- Preparation of concrete;
- Performs the operations for closing the cast iron hole and the separation basin;
- Tight fitting of the metallic section sections;
- Preparation of concrete;
- Applying the refractory concrete by casting or the stamping mass in successive thin layers;
- Executes the vibration of the cast concrete, i.e. the compaction of each stamped layer;
- Perform the drying and heating of the refractory mass, respectively the concrete according to the diagram;
- Removes the metallic pattern on the sections;
- Refract the threshold and the dips with refractory mass;
- Verifies compliance with the levelling between the slag gutter and the separation basin threshold;
- Mounts the methane gas burners on the bottom of the gutters;
- Covers gutters and basin repaired with caps or panels of thermal insulating sheet;
- Monitors the burning of methane gas and regulates the flame according to the heating diagram;
- Participates in planned and accidental repairs;

Damage and prevention and remediation

➢ ***Boiling of the cast iron in the trough***

prevention:

- Observation of drying and heating times or of the concrete diagram;
- Ensuring efficient drying with a sufficient number of methane gas burners;
- Thermal insulation of the outside surface of the gutters during drying and heating.

➢ ***Remedy:***

- Reducing the operation of the furnace;
- The iron drain hole is blocked;
- The upper slag is discharged;
- Changing the discharges to the other casting chamber, if possible;
- Rapid recovery of the affected gutter is carried out if there are no other evacuation possibilities.

➢ ***Perforation of the gutter or basin prevention:***

- Regular checking according to the graph, of the wear condition of the refractory lining and whenever deemed necessary;
- Observing the working instructions.
- ***Remedy:***
- Immediate reduction and closing of the furnace;
- Local repair of affected area by stamping with Kermix table or concrete.

➢ ***Passing the cast iron into the slag pot prevention:***

- Observing the distance of approx. 10 m from the main gutter to the slag and the threshold of the cast iron gutter after the basin;
- Verifying the section and the hole position of the basin shovel;

➢ ***Remedy:***

- Reduction of the furnace;
- Partial breaking of the cast iron threshold;
- Stopping the furnace.

➢ ***Passing the slag to the cast iron pots prevention:***

- Checking the diameter of the cast iron drain hole under the basin shovel;
- Control of the integrity of the basin separator;
- Compliance with the technology of closing the cast iron outlet in the pool.

➢ ***Remedy:***

- Partial breaking of the dyke from the slag;
- Reduction of furnace operation in order to reduce the casting and slag flow;
- Stopping the furnace.
- Provides cleanliness at work;
- Teaching exchange:
- Does not leave the workplace before the next exchange arrives;
- Check with the operator of the next shift the technical condition of the machines;
- Communicates to the master the deficiencies found, and he records them in the turnbook.

➢ ***Prohibited actions:***

- Stamping the refractory mass over the cast iron washings;
- The use of masses or concrete in places other than those for which they were intended;
- Applying superimposed layers of refractory mass or refractory concrete of 40 mm thicker;
- Accidental wetting of refractory lining with water;
- Insufficient compaction of each layer of the table;
- Failure to observe the drying and heating time of the stamped lining;
- Interruptions to the casting of refractory concrete;
- Non-observance of the heating rate of the refractory concrete of 30 °C / h;
- Non-observance of the temperature ranges when heating the concrete at 150 °C and 450 °C;
- The use of watertight or watertight gutters;
- The use of tilting gutters with solid edges or degraded lining, with the risk of splashes with cast iron and slag;
- Blocking with materials, or debris, the bridges serving the dump gutters.

4.2.3. Work environment

- The furnace operates on the furnace discharge platform. The main features of the work environment are specified in the analysis bulletins.
- We note that there are exceedances of the admissible values for the following noxes: inhaled powders, coke dust, noise level, CO, phenols, sulphur dioxide, HPA and 3,4 Bp.
- The level of illumination is reduced at some work points and is very high in the melt area.
- It is also noted: the presence of infrared radiation, air currents and high temperature variations between discharges, especially during the cold season.
- High level of noise at some points of intervention - especially in the area of winds.

5. Risk factors identified

5.1. Means of production

➢ ***Mechanical risk factors***

- Grip, driven by winches, winches, perforated machine and plugged into cast iron outlets.
- Hitting by car and / or CF vehicles when traveling through the combustion chamber.
- Self-locking cooling system operation.
- Sliding parts, materials - uninsured against

uncontrolled movements.

- Routing of parts, cylindrical materials.
- Flipping equipment, subassemblies, etc.
- Free fall of parts, tools, materials from the upper parts.
- Free spill of molten material – e.g. to perforating the gutters.
- Spillage of the cast iron and slag as a result of blocking or loss of geometric properties of exhaust ports or gutters.
- Design of bodies or particles - incandescent splashes, sparks, dust, various particles entrained by air currents.
- Deviation from the normal trajectory of the masses transported by the rolling bridge.
- Surprise by large-scale parts in the balancing phase.
- Jet, cast iron eruption, slag, incandescent coke - accidental perforations reinforcement - water vapor spray - scalding.
- Contact with dangerous surfaces or contours (stinging, sharp, slippery, abrasive, adhesive) - undamaged surfaces, dangerous contours, etc.).
- Work in the vicinity of pressure vessels (technical gas cylinders) and pressure circuits (hot air ducts).

➢ ***Thermal risk factors***

- High temperature of objects or surfaces - gutters, joists, pipes, bark etc.
- Flames, flame - bursts, accidental release of gaseous bags, burning of the material on the gutters with the burner.

➢ ***Electric risk factors***

- Direct-current electric shock - Unprotected current paths or damaged insulation;
- Indirect touch electrocution - Connections to the damaged earthling system;
- Electrocution by step voltage - ex. to access to the furnace bundles due to the lighting system and leaks and accumulations of water or water-soaked powders.
- Electrical equipment must be provided with operating instructions;
- Instructions for intervention and first aid in case of electric shock.

➢ ***Chemical risk factors***

- Work with flammable substances: ex. Coke;
- Carcinogens present in the workplace atmosphere (e.g. HPA, 3.4 Bp, etc.).

5.2. Work environment

➢ ***Physical risk factors***

- High air temperature - work in the vicinity of the furnace, slag, cast iron, etc.
- High temperature variations, especially during the cold season, between the discharge phase and the one in which the furnace is plugged.
- Airflow - sealing, natural and forced draft.
- High level of noise at some points of intervention - especially in the area of winds.
- Low illumination level on some travel paths.
- Glow - contrast between incandescent metal or slag and the general environment.
- IR radiation - in the vicinity of gutters, pots, etc.
- Natural disasters - ex. the surprise of earthquake.
- Massive dust accumulation.

➢ ***Chemical risk factors***

- Accumulation of toxic gases - ex. hydrogen sulphide, CO, N_2, SO_2, etc. - intoxications
- Accumulation of explosive gases or vapors - Dissociation of water into the furnace at accidental penetration - (Cooling unit destruction) - In the furnace discharge phase can lead to the occurrence of hydrogen - Explosion
- Carcinogenic substances present in the workplace atmosphere (e.g. HPA, 3.4 Bp, etc.)

5.3. Work task

➢ ***Inappropriate content***

- Omissions in preconditioning of work operations
- Allowing workers to move to work areas without having a gas mask or accessing it in case of danger

➢ ***Physical overload***

- Dynamic effort - large trails, manual handling of large masses.

➢ ***Psychological overload***

- Difficult short-term decisions - for corrections or liquidation of "INCIDENT" situations.

5.4. Worker (Executer)

➢ ***Wrong actions***

- Execution of unforeseen work tasks or in a manner other than technical working conditions.
- Incorrect routing of the cast iron or slag flows into the pot followed by empty discharge.
- Incorrect burying or clogging. Incorrect operation of the machine (e.g. non-cleaning of its components).
- Inappropriate fixing of working parts on machines.
- Spill in slag pots containing water, ice, foreign elements.
- Incorrect attachment of loads to lifting gear.
- Adjusting working parameters outside of the conditions imposed by technology.
- Non-synchronization - teamwork with other employees (e.g. with crane, winch, etc.).

- Travels, stops in dangerous areas - on the access roads, CF, under the load of the lifting means, in the area of the wind gullies, on any platform from the elevation of the wind gullies upwards.
- Falling at the same level: by unbalance, by sliding, by obstacles - uneven surfaces, loaded with dust, accumulations of water along the travel route, elements deposited on the surface of the access ways and covered with dust.
- Falling from height: walking, emptying, unbalance, and sliding - lack of railings, technological gaps, etc.
- Accidental communication - failure to observe the crane signalling code.

➢ ***Omissions***

- Omitting operations that ensure their own security.
- Not using E.I.P. and other means of protection (which have been provided by the employer).

5.5. Risk evaluation

The result obtained from previous procedures is identified in the Risk Assessment Grid and enrolled in the Job Sheet. With the help of the scale of risk / security levels, then these levels are determined for each risk factor in part. This gives a hierarchy of the size of the risks in the workplace, which gives the possibility to set a priority of the prevention and protection measures, depending on the risk factor with the highest level of risk.

The global risk level (Nr.) in the workplace is calculated as a weighted average of the risk levels set for the identified risk factors. For the result obtained to reflect as accurately as possible the reality, the risk factor rank is used as weighting element, which is equal to the level of risk.

In this way, the highest risk factor will also have the highest rank. This eliminates the possibility that the offset effect, which involves any statistical mean, masks the presence of the maximum risk factor.

The formula for calculating the global risk level is the following:

$$N_{rg} = \frac{\sum_{i=1}^{n} r_i \cdot R_i}{\sum_{i=1}^{n} r_i}$$

where:

- N_{rg} is overall job risk level;
- r_i, rank of risk factor "i";
- R_i, risk level for risk factor "i";
- n, the number of risk factors identified.

The level of security (Ns) per job is identified on the Risk/Security Level Scale, built on the inverse principle of risk and security levels.

Both the level of global risk and the level of security are enrolled in the Workbook.

The evaluation of the identified risk factors is done by completing the LABOR EVALUATION FILE, (Table 1) which contains, in addition to the risk factors and the manifestation form, the maximum consequence, the severity, the probability and the partial risk level for each identified risk.

Table 1

COMPANY: S.C. ARCELOR MITTAL - GALAŢI	**WORK EVALUATION FILE**	**NUMBER OF PERSONS EXPOSED:** -50
DEPARTMENT: BLAST-FURNACE		**EXPOSURE TIME:** 8 h/sch.
WORKING: BLAST-FURNACE WORKER		**EVALUATION TEAM:** Eng. AdrianVASILIU

COMPONENT SYSTEM FOR WORK	**RISK FACTORS IDENTIFIED**	**THE RISK FACTOR MANIFEST FORM**	**3[1]**	**4[2]**	**5[3]**	**6[4]**
MEANS OF PRODUCTION	***RISK FACTORS MECHANIC***	1. Grip, drive by winches, winches, perforated machine and plugged cast iron outlets.	DEATH	7	2	4
		2. Hitting by means of car and / or CF transport when moving through the combustion chamber.	DEATH	7	2	4
		3. Self-locking cooling system operation.	DEATH	7	1	3
		4. Sliding parts, materials - uninsured against uncontrolled displacements.	DEATH	7	1	3
		5. Routing of parts, cylindrical materials.	DEATH	7	1	3
		6. Flipping of equipment, subassemblies, etc.	DEATH	7	1	3
		7. Free fall of parts, tools, materials from the higher odds.	DEATH	7	1	3
		8. Free spill of molten material - e.g. to perforating the gutters.	DEATH	7	1	3
	RISK FACTORS THERMAL	9. Spillage of the cast iron and slag as a result of blocking or loss of geometry of the discharge holes or gutters.	DEATH	7	1	3
		10. Design of bodies or particles - incandescent sprays, sparks, dust, particles entrained by air currents.	DEATH	7	1	3
		11. Deviation from the normal trajectory of the masses transported by the rolling bridge.	DEATH	7	1	3
		12. Surprise by large-scale parts in the balancing phase.	DEATH	7	1	3
		13. Jet, cast iron eruption, slag, incandescent coke - accidental perforations reinforcement, water vapor spray, scalding.	DEATH	7	2	4
		14. Contact with dangerous surfaces or contours (stinging, sharp, slippery, abrasive, adhesive)	ITM 3-45 days	2	5	3
		15. Work in the vicinity of pressure vessels (gas cylinders) and pressure circuits (hot air ducts).	DEATH	7	1	3
		16. High temperature of objects or surfaces - gutters, joists, pipes, bark, etc.	INV gr. III	4	6	5
		17. Flames, flame - bursts, accidental release of gaseous bags, burning of material on gutters with burner.	DEATH	7	1	3
	RISK FACTORS ELECTRIC	18. Electrocution by direct contact - Unprotected current paths or damaged insulation.	DEATH	7	1	3
		19. Electrocution by indirect touch - connections to the damaged earthling system	DEATH	7	1	3
		20. Electrocution via step voltage - ex. to access the furnace's dimensions due to the lighting system	DEATH	7	1	3
	RISK FACTORS CHEMICAL	21. Working with flammable substances and fluids: ex. coke, methane gas, oxygen, hydraulic oil.	DEATH	7	1	3
ENVIRONMENT	***RISK FACTORS PHYSICAL***	22. High air temperature - work in the vicinity of the furnace, slag, cast iron, etc.	ITM 45-180 days	3	6	4
		23. High temperature variations in the cold season between the discharge phase and the one in which the furnace is	ITM 3-45 days	2	5	3

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[1] **PREVIOUS MAXIMUM CONSEQUENCE**
[2] **THE GRAVITY CLASS**
[3] **PROBABILITY CLASS**
[4] **RISK PARTIAL LEVEL**

COMPONENT SYSTEM FOR WORK	**RISK FACTORS IDENTIFIED**	**THE RISK FACTOR MANIFEST FORM**	**3[1]**	**4[2]**	**5[3]**	**6[4]**
FOR WORK		plugged.				
		24. Air streams - sealing, natural and forced draft.	ITM 3-45 days	2	6	3
		25. High level of noise at some points of intervention - especially in wind gullies.	INV gr. III	4	6	5
		26. Low illumination level on some moving paths - dirty body lighting).	ITM 3-45 days	2	6	3
		27. Brightness - contrast between incandescent metal or slag and the general environment.	INV gr. III	4	6	5
		28. IR radiation - in the vicinity of gutters, pots, etc.	ITM 3-45 days	2	6	3
		29. Natural disasters - ex. the surprise of earthquake.	DEATH	7	1	3
		30. Massive dust accumulations (according to attached measurement bulletins).	INV gr. III	4	6	5
	RISK FACTORS CHEMICAL	31. Accumulation of toxic gases - ex. hydrogen sulphide, CO, N_2, SO_2, etc. - intoxications	DEATH	7	6	7
		32. Accumulation of explosive gases or vapours - dissociation of water in the furnace at accidental entry - explosion	DEATH	7	3	5
		33. Carcinogenic substances present in the workplace atmosphere (e.g. HPA, 3.4 Bp, etc.)	DEATH	7	6	7
TASK FOR WORK	***CONTENT INCORRECT***	34. Omissions in preconditioning of work operations	DEATH	7	2	4
		35. Allowing workers to move to work areas without their gas mask	DEATH	7	1	3
	OVERUSE PHYSICS	36. Dynamic effort - large trails, manual handling of large masses	ITM 45-180 days	3	6	4
	OVERUSE MENTAL	37. Difficult short-term decisions - for corrections or liquidation of "INCIDENT" situations.	ITM 3-45 days	2	6	3
WORKER (EXECUTER)	**ACTIONS WRONG**	38. Execution of unforeseen work tasks or other than those, technical work provisions	DEATH	7	3	5
		39. Incorrect routing of the cast iron or slag flows into the pot followed by empty discharge.	DEATH	7	1	3
		40. Incorrect burying or clogging. Incorrect operation of the snapping machine	DEATH	7	1	3
		41. Inappropriate fixing of working parts on machines.	DEATH	7	1	3
		42. Spill in slag pots containing water, ice, foreign elements.	DEATH	7	1	3
		43. Incorrect cutting at the winds.	DEATH	7	1	3
		44. Incorrect attachment of loads to lifting equipment.	DEATH	7	1	3
		45. Adjusting working parameters outside of the conditions imposed by technology	DEATH	7	1	3
		46. Non-synchronization - teamwork with other employees (e.g. with crane, cowboy, etc.)	DEATH	7	1	3
		47. Travels, stops in dangerous areas - on the access roads, CF, under the load of the means of lifting.	DEATH	7	1	3
		48. Falling at the same level: by unbalance, sliding, and obstruction - uneven surfaces covered with dust.	ITM 45-180 days	3	3	3
		49. Fall from heights: idle, unbalanced, sliding - lack of railings, technological goals	DEATH	7	1	3
		50. Accidental communication - failure to observe the crane signalling code.	DEATH	7	1	3
	OMISSIONS	51. Omitting operations that ensure their own security.	DEATH	7	1	3
		52. Not using E.I.P. and other means of protection (which have been provided by the employer)	DEATH	7	1	3

The global risk level for the job is:

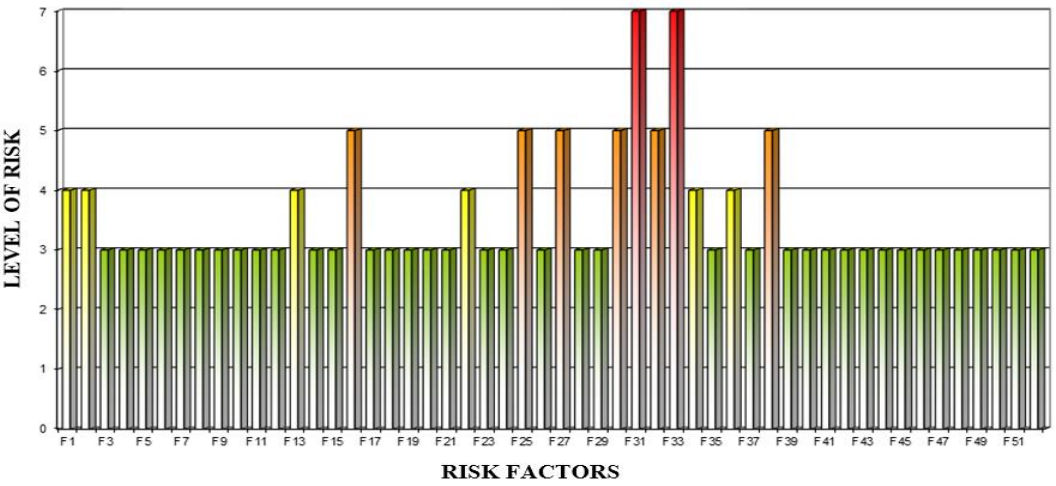
$$N_{rg52}=\frac{\sum_{i=1}^{52} R_i\cdot r_i}{\sum_{i=1}^{52} r_i}=\frac{2(7\cdot 7)+0(6\cdot 6)+6(5\cdot 5)+38(3\cdot 3)+0(2\cdot 2)+0(1\cdot 1)}{2\cdot 7+0\cdot 6+6\cdot 5+6\cdot 4+38\cdot 3+0\cdot 2+0\cdot 1}=\frac{9686}{182}=\mathbf{3,76}$$

6. The evaluation results

6.1. Global risk level

The level of global risk calculated for the workplace is equal to 3.76, which is considered to be an unacceptable level of employment. The result is supported by the "Assessment Sheet", which shows that out of the total of 52 identified risk factors, 14 exceeded as a partial risk level the value of 3, 2 being in the category of maximum risk factors 6, being in the category of high risk factors, and the other 6 falling within the category of medium risk factors (Graph 1).

From the Analysis Sheet analysis, 82.69% of identified risk factors can have irreversible consequences on the performer (DEATH or INVALIDITY).



Graph 1. *Risk factors for blast-furnace worker*

Table 2

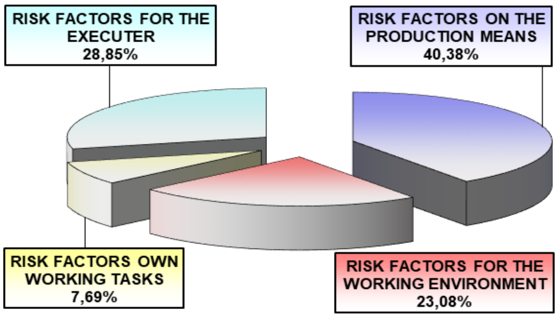
Number factor	RISK FACTORS WHICH ARE INCOMPATIBLE	Partial of risk
F31	Accumulation of toxic gases - ex. hydrogen sulphide, CO, N_2, SO_2, etc. – intoxications	7
F33	Carcinogenic substances present in the workplace atmosphere (e.g. HPA, 3.4 Bp, etc.)	7
F16	High temperature of objects or surfaces - gutters, joists, pipes, bark, etc.	5
F25	High level of noise at some points of intervention - especially in wind gullies.	5
F27	Brightness - contrast between incandescent metal or slag and the general environment.	5
F30	Massive dust accumulations (according to attached measurement bulletins).	5
F32	Accumulation of explosive gases or vapours - dissociation of water into the furnace at accidental penetration - during the furnace drain phase can lead to the occurrence of hydrogen - explosion	5
F38	Execution of unforeseen operations, or in a manner other than technical working conditions.	5
F1	Grip, drive by winches, perforated machine and plugged cast iron discharge holes.	4
F2	Hitting by means of car and / or CF transport when moving through the combustion chamber.	4
F8	Free spill of molten material – e.g. to perforating the gutters.	4
F13	High air temperature - work in the vicinity of the furnace, slag, cast iron, etc.	4
F34	Omissions in preconditioning of work operations	4
F36	Dynamic effort - large trails, manual handling of large masses	4

In order to reduce or eliminate the 14 risk factors (which are in the unacceptable field), the generic measures presented in the "Proposed Action Sheet" are required. Regarding the distribution of risk factors on generating sources, the situation is as follows:

- The factors of the means of production (40.38 %);
- The factors of the working environment

(23.08 %);

- The factors of the work load (7.69 %);
- The factors of the executer (28.85 %).



Graph 2. *Distribution of risk factors*

7. Conclusions

Taking into account the need for good risk management at the unit level and the new legal requirements, it has been decided to carry out an assessment of the risks of occupational injury and illness at the workstations. For this, the method of the National Institute for Research and Development for Labour Protection was used as a theoretical and working method. The team that has been set up has proceeded on the basis of the theoretical and practical premises of the method by making the Job Assessment Sheet and the proposed Measures Sheet.

After determining the partial risk levels for the risk factors identified on the components of the work system, we have the following distribution:

- risk factors for the means of production 40.38%;
- risk factors for the contractor 28.85%;
- risk factors related to the working environment 23.08%;
- risk factors related to the work load 7.69%.

It can be concluded that the workload is too risky but produced with means of production that have many risks in a moderately hazardous environment through less risky performers.

Another interpretation, closer to reality, can be made according to the proportion of unacceptable risk levels in each component of the work system, as follows: The worker performs risky, risk-free tasks with little risk with too low-risk means.

It is certain that the risk level of the environmental factors, the important decrease of the level of the workstation certified by the analysis bulletins, is the highest and the achievement of the proposed measures can be achieved. The levels of the risk factors of the contractor are high and, by diminishing them with technical and organizational measures, significant decreases in risk levels can be achieved.

The prioritization of the deadlines for the implementation of the measures is done in accordance with the generic hierarchical order:

- measures of intrinsic prevention;
- collective protection measures;
- individual protection measures.

The decrease in the number of technical incidents and incidents and accidents must be the general risk target of 4.53 to 3.67 for the blast-furnace worker Platform has shown the possibility of raising the level of safety through technical and organizational measures, the employer in all stages of the production process. In the Blast-Furnace Department by lowering the number of accidents and lowering the level.

This is a beginning for the continuous improvement of all the components of the work process (people, the environment, working processes, material goods).

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STUDIES AND RESEARCHES ON OBTAINING ELECTROCHEMICAL COMPOSITE COATINGS IN NICHEL - Ni / KAOLIN MATRIX

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ABSTRACT

The paper presents the electrochemical obtaining of nickel matrix composite coatings using kaolin particles as dispersed phases. Watts electrolytes were used, with a pH = 4.5 current densities of 6, 9, 12 A/dm^2, a dispersed phase concentration of 20 g/L, shaking speeds of 500, 700 and 900 rpm, deposition time of 60 minutes. Their characterization has been achieved both from a microstructural point of view and from the point of view of layer thickness, microhardness and behaviour in salt mist corrosion. The presence of dispersed phase particles, which acted as nucleation centres, led to the reduction of the nickel crystallites, which further decreased the roughness of the coatings while increasing hardness. By correlating the current density with the rate of stirring, respectively the increase their, thicker layers were obtained.

KEYWORDS: Ni composite coatings, electrodeposition, kaolin, microhardness

1. Introduction

The field of composite materials is in a rapid and continuous expansion due to the large number of possible combinations between two or more components and the advantage of obtaining a wide range of materials the use of which can be expanded in almost all technical fields (aerospace, naval, automotive, electrical and electronics industries) as a result of the possibility of modelling their structure and properties. In this respect, the following properties are to be improved: hardness, wear resistance, high temperature resistance, dimensional stability, corrosion resistance, vibration damping capacity, lubrication [1, 2, 4, 5].

ACE electrochemical composite coatings have a number of advantages such as high deposition velocity (rate), simple automation equipment, easy control of microstructure and thickness deposition (from nanometer to micrometric level), uniform coverage capability of both complicated geometry surfaces and large ones [1, 2, 4, 5].

Ni - kaolin composite materials are used in the aerospace, automotive industry, in applications requiring good behavior to wear, abrasion, fatigue, corrosion [3].

The properties of the composite materials depend on the type, structure, shape, size, morphology and content of the complementary phase particles, as well as their distribution in the metal matrix.

The functional properties of composite coatings are strongly influenced by their structure, tensions developed in the layer as well as by the orientation of the complementary phases which can determine the anisotropy of the properties.

Nickel was chosen as a coating material because it is one of the most common industrial coatings used for decorative and functional applications [4].

Kaolin - $Al_2O_3*2SiO_2*2H_2O$ - is a very fine grain, white 2.65 g/cm3 density clay (mineral) of low-plasticity, high temperature resistance and by burning it turns solid and very compact. A mineral layer has a triclinic crystalline symmetry made up of octahedral Al_2O_3 and tetrahedral formations of SiO_2 that share a common plan formed by oxygen atoms. The layers thus formed are linked together by hydrogen atoms [bonds] [3]. The mechanical properties of the composite materials depend on their microstructure (nanocrystalline, microcrystalline), correlating with dislocation theory, strength and ductility. The addition of dispersed phase particles in order to obtain composite materials acts as a barrier against the displacement of dislocations followed by blocking them at the grain boundary which results in increased resistance to deformation and hardness [6].

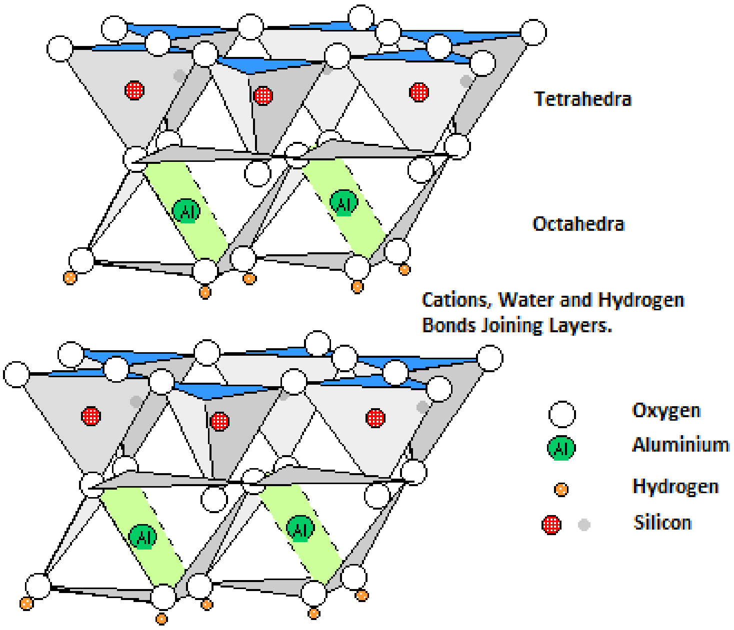


Fig. 1. *Crystalline structure of kaolin [3]*

The research carried out in this paper has as a general objective the development of a technology for the electrochemical production of composite coatings in nickel matrix using as dispersed phase kaolin particles with dimensions of approx. 2 μm and their characterization in terms of microstructure, layer thickness, microdurity and behaviour in salt mist corrosion.

2. Experimental research

To obtain nickel coatings and composite coatings in a nickel matrix, a DC source, a device provided with a magnetic stirrer and a bath temperature control system with an electrolyte receptacle were employed. A volume of 300 ml solution was used and the experiments were carried out at 50 °C.

Watts electrolytes consisting of $NiSO_4\ 6H_2O$ – 300 g/L, $NiCl_2\ 6H_2O$ – 50 g/L and H_3BO_3 – 40 g/L, pH = 4.5 current densities of 6, 9, 12 A/dm^2, a dispersion phase concentration of 20 g/L, stirring speeds of 500, 700 and 900 rpm, with a 60 minutes deposition time.

The electrodeposition was achieved by vertical alignment of the electrodes at a distance of 14 mm from each other. As anode, high purity nickel (99%) was used, the cathode being copper strip, representing the support material for 76 x 20 x 1 mm coatings.

The copper band used was prepared by degreasing (organic solvents - trichlorethylene), pickled (HNO_3 + HCl at room temperature for 1-2 minutes) followed by washing with distilled water.

The metallographic analysis of the samples was carried out on a Neophot 2 microscope, with the acquisition of data on the computer and revealed the appearance of the nickel deposition surface compared to the composite coatings, their adhesion, the way electrodes have grown, as well as the presence of defects such as pores, cracks, exfoliations. The EDS analysis was performed with a SEM Quanta 200 electronic scanning microscope provided with an energy dispersion spectrometer.

To determine the microdurity, the PMT-3 micro-hardness durimeter was used with a load of 50 g.

The corrosion behavior in salt mist of the composite layers was performed according to ISO 9227/2012 for a period of 96 hours. For the test, the sodium chloride solution was prepared by dissolving in distilled water with a conductivity of less than or equal to 20 μS/cm^2 at 25 ± 2 °C, of a quantity of sodium chloride to give a concentration of 50 ± 5 g/L.

The relative density of a solution with this concentration is between 1.00255 and 1.0400. The pH of the saline solution was adjusted so that the pH of the solution collected in the spraying chamber ranged between 6.5 and 7.2. This was measured with a pH meter HI 991001, produced by "Hanna Instruments", also provided with a temperature indicator.

3. Experimental Results

Characterization of composite coatings in nickel matrix with dispersed phase

$Al_2O_3*2SiO_2*2H_2O$ kaolin obtained electrochemically

Characterization of ACE composite coatings was performed compared to pure nickel coatings and consisted of macro and microstructural analysis, layer thickness and micro hardness determinations.

Fig. 1 shows the appearance of pure nickel coatings for different current densities and different agitation/stirring rates. It can be seen that the deposited layers are homogeneous, without cracked and have good adhesion to the copper supports. It can also be seen that increasing the density of the current increases the thickness of the obtained layer, keeping the temperature and deposition time constant. Increasing the current density leads to the formation of finer structures as a result of the multiplication of the crystallization germs on the cathode.

This influence of the current density can be explained by increasing the active surface of the cathode, the crystalline germs being formed on the inactive parts of the less active cathode [5].

As to the influence of the stirring speed (correlated with the current density), it has been found that when this grows compact, smooth, fine grain deposits of a high current efficiency can be obtained; the higher the current density, the more stirring should be done.

The primary role of stirring/agitation is to favour the homogenization of the ionic concentration in the cathode film and in the rest of the solution. It maintains the concentration of the solution constant, avoiding concentration polarization.

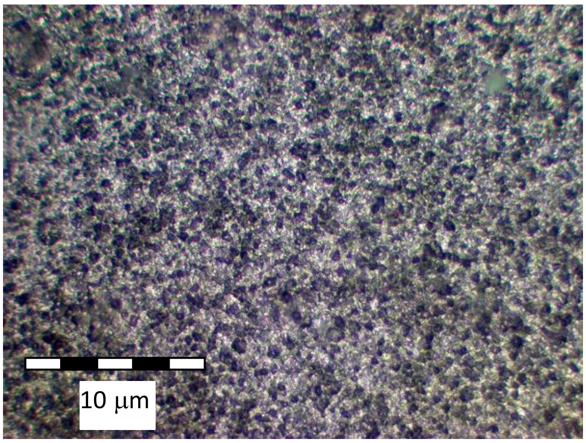
Fig. 2 shows the microstructural aspect of the electrochemical composite coatings in nickel matrix using kaolin particles as dispersed phase.

Analysing Fig. 2 it can be seen that the electrochemically obtained composite coatings in nickel matrix using kaolin particles as dispersed phase exhibit good homogeneity and compactness. Increasing the current density increases the degree of inclusion of the dispersed phase.

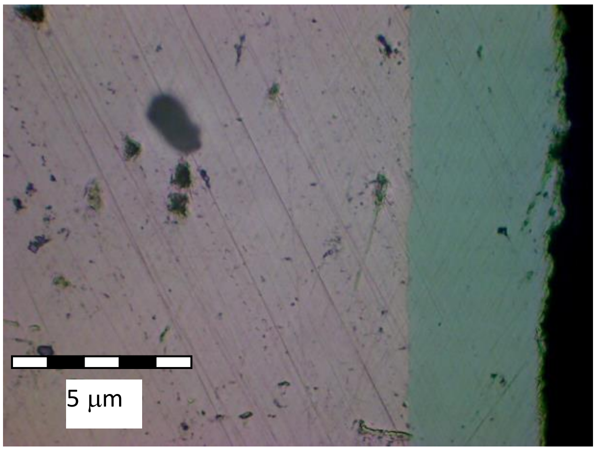
The kaolin particles led to the decrease of the crystallites' dimensions (compared to the pure nickel deposits) which further led to the decrease in the roughness of the deposits and the increase of the hardness (concomitantly blocking the displacement of the dislocations in the nickel matrix) (Fig. 7).

For the current density of 6 A/dm^2 it was considered that the optimal deposition regime was that of sample P3 (D_{crt} = 6 A/dm^2, v = 900 rpm, t = 60 minutes). At low stirring rates and low current densities (P1, P2), the growth rate of the crystalline germs exceeds the germination rate, which results in larger, less homogeneous and less compacted macrocrystalline deposits.

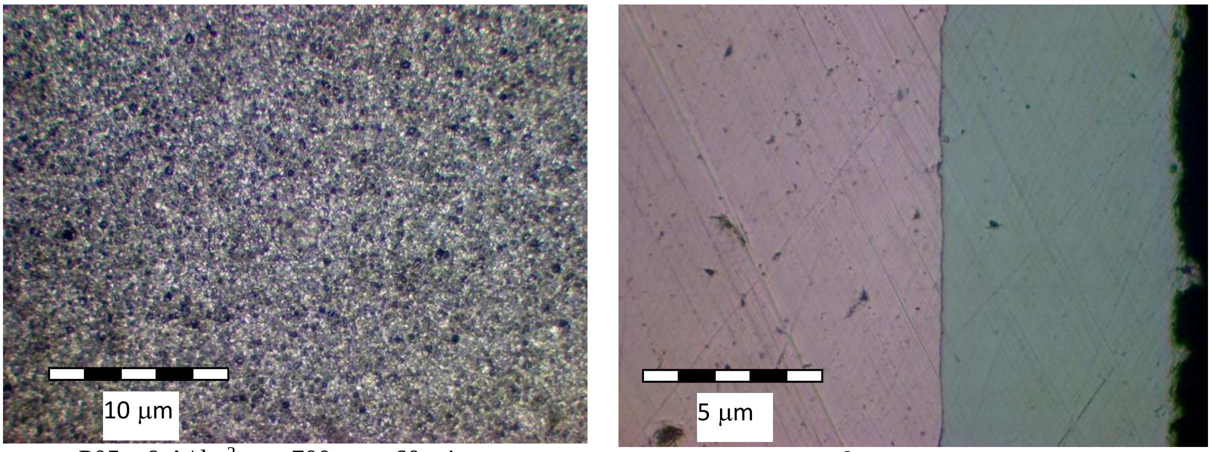
For the current density of 9 A/dm^2 it was considered that the optimal deposition regime was that of the P6 sample (D_{crt} = 9 A/dm^2, v = 900 rpm, t = 60 minutes). This has led to a compact, homogeneous, adherent deposit. As the current density increases, the germination speed increases and leads to more and more microcrystalline, fine-grained deposits.



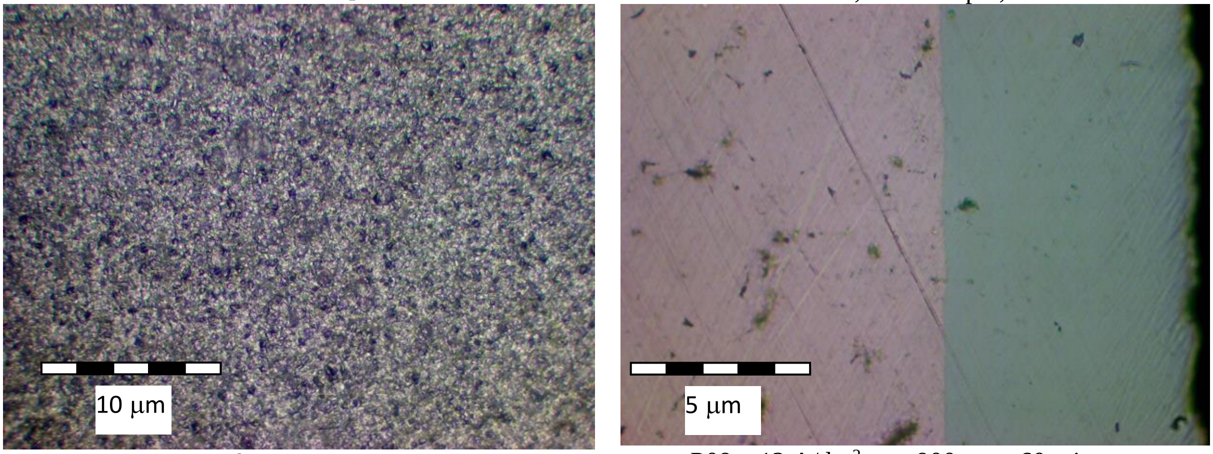
P01 – 6 A/dm^2, v = 500 rpm, 60 minutes



P01 – 6 A/dm^2, v = 500 rpm, 60 minutes

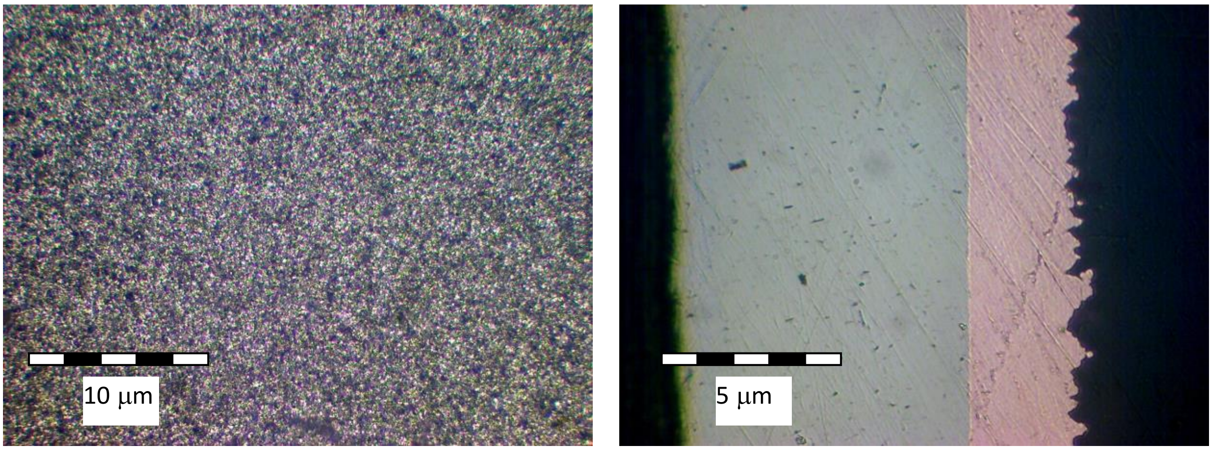


P05 – 9 A/dm^2, v = 700 rpm, 60 minutes   P05 – 9 A/dm^2, v = 700 rpm, 60 minutes

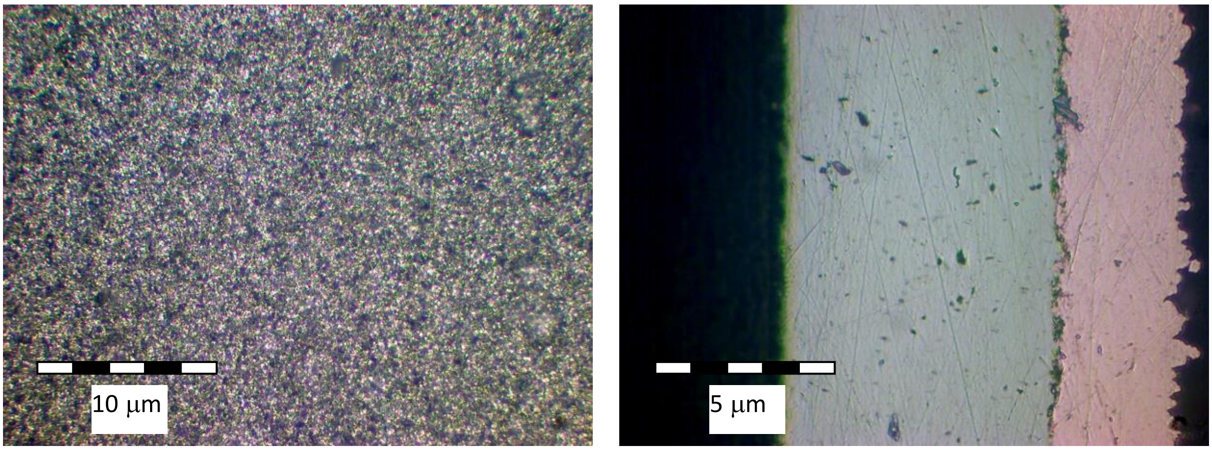


P09 – 12 A/dm^2, v = 900 rpm, 60 minutes   P09 – 12 A/dm^2, v = 900 rpm, 60 minutes

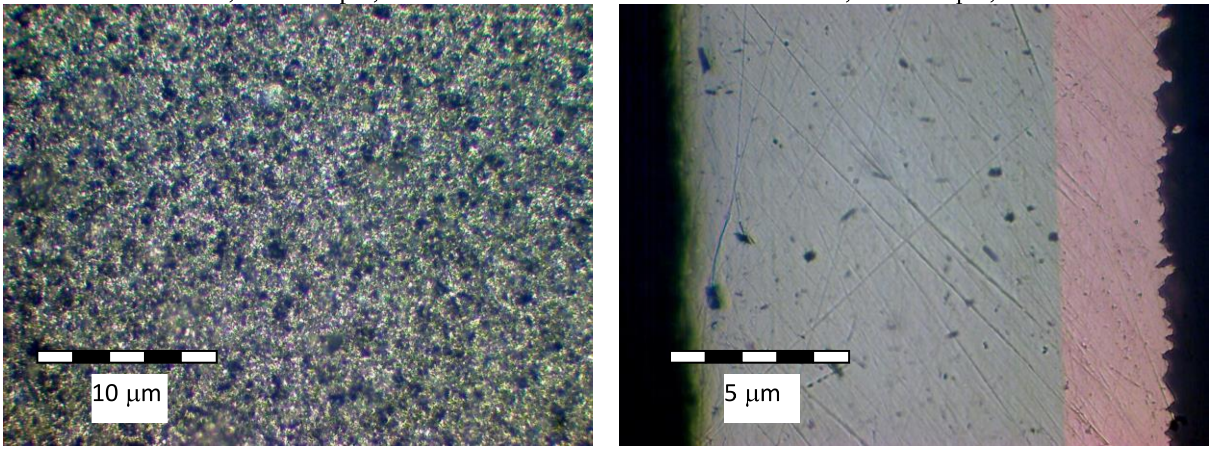
Fig. 1. *Microstructural appearance of pure nickel coatings*



P3 – 6 A/dm^2, v = 900 rpm, 60 minutes   P3 – 6 A/dm^2, v = 900 rpm, 60 minutes



P6 - 9 A/dm^2, v = 900 rpm, 60 minutes   P6 - 9 A/dm^2, v = 900 rpm, 60 minutes



P7 - 12 A/dm^2, v = 500 rpm, 60 minutes   P7 - 12 A/dm^2, v = 500 rpm, 60 minutes

Fig. 2. *The microstructural aspect of the electrochemical composite coatings in the nickel matrix using kaolin particles as dispersed phases*

By adding kaolin particles at a concentration of 20 g/L, it has been found that layer thickness increases relative to pure nickel deposits which confirms the inclusion of dispersed phase particles into the metal matrix. As regards the morphology of the layer, there is a binary symmetry, both pyramidal and pseudo-pentagonal (Fig. 3).

Following the EDS analysis performed on the P6 sample both on surface and punctually, it was found that the distribution of the dispersed phase in the deposited layer is relatively uniform (Fig. 4 and 5).

For the current density of 12 A/dm^2, it was considered that the optimal deposition regime was that of the P7 sample (Dcrt = 12 A/dm^2, v = 500 rpm, t = 60 minutes), the other regimes leading to less adherent and compact deposits.

With higher current densities, the concentration of metal ions in the immediate vicinity of the crystals decreases a lot and the crystals tend to grow towards the edges of the sample where the concentration of these ions is higher. Dendritic or spongy structures are thus obtained. Fig. 6 shows the influence of current density and stirring velocity on the layer thickness of pure nickel coatings and on electrochemical composite coatings in the nickel matrix using dispersed kaolin particles. It can be seen that increasing the current density and the stirring speed, the thickness of the obtained layer increases, while the temperature and the deposition time remain constant. The resulting composite coatings feature higher thicknesses compared to pure nickel deposits.

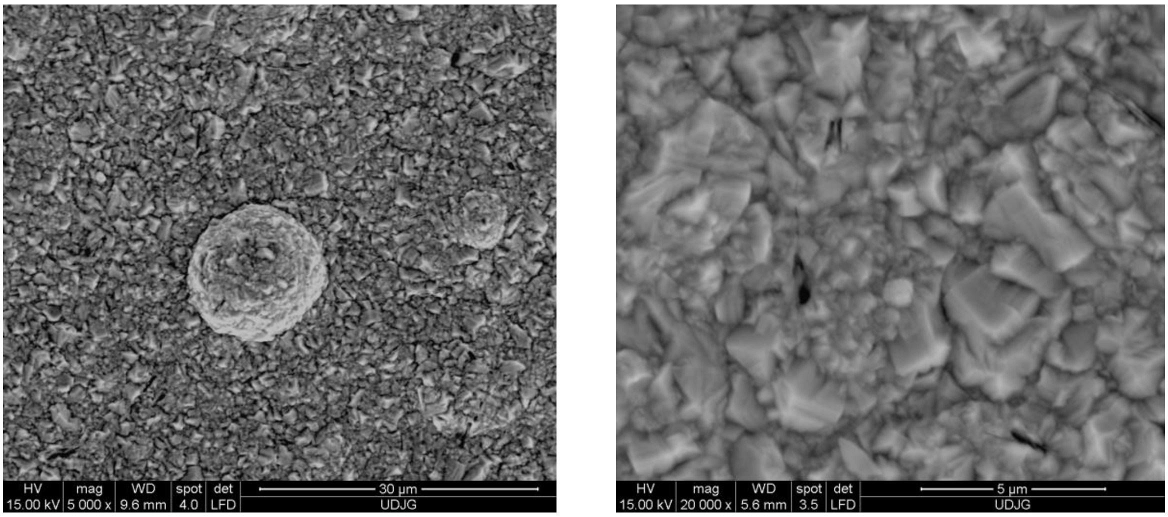


Fig. 3. *SEM image of the deposited layer for sample P6*

Fig. 7 shows the influence of the current density and stirring velocity on the microdurity of pure nickel coatings and on electrochemical composite coatings in nickel matrix using dispersed kaolin particles.

It can be seen that when increasing the density of the current and the rate of stirring, the microhardnessy of the obtained layer increases, the temperature and the deposition time being kept constant. This increase is due, on the one hand, to the increase in the stresses in the layer with the current density, and on the other hand to the better inclusion of the dispersed phase particles into the deposited layer.

Following the accelerated corrosion test performed in saline mist, it has been found that composite coatings exhibit a better corrosion behaviour compared to the pure nickel coating, as shown in Fig. 8. The presence of kaolin particles in the nickel matrix, correlated with the deposition parameters (current density, stirring rate), led to increased corrosion resistance in saline mist, the best behaviour being with samples P2, P5, P6, P7 where a higher passivation of the deposited layers was found.

4. Conclusions

The following conclusions can be drawn from the experimental researches:

- the nickel coatings obtained from variations in current density and stirring rate are homogeneous, crackles and have good adhesion to copper supports; the increase in the current density also increases the thickness of the obtained layer;
- the electrochemical composite coatings in nickel matrix using dispersed kaolin particles are homogeneous and crackles; the increase in the current density leads to the formation of finer structures as a result of the multiplication of crystallization germs on the cathode;
- when increasing both the current density and the stirring speed, the thickness of the layer thus obtained increases from 0.05 mm for pure nickel coatings obtained at a current density of 6 A/dm^2 and a stirring speed of 500 rpm at 0.12 mm for pure nickel coatings obtained at a current density of 12 A/dm^2 and 900 rpm, from 0.059 mm for ACE Ni - kaolin obtained at a current density of 6 A/dm^2 and a stirring speed of 500 rpm to 0.135 mm for ACE Ni - kaolin obtained at a current density of 12 A/dm^2 and 900 rpm, the temperature and deposition time being constant;

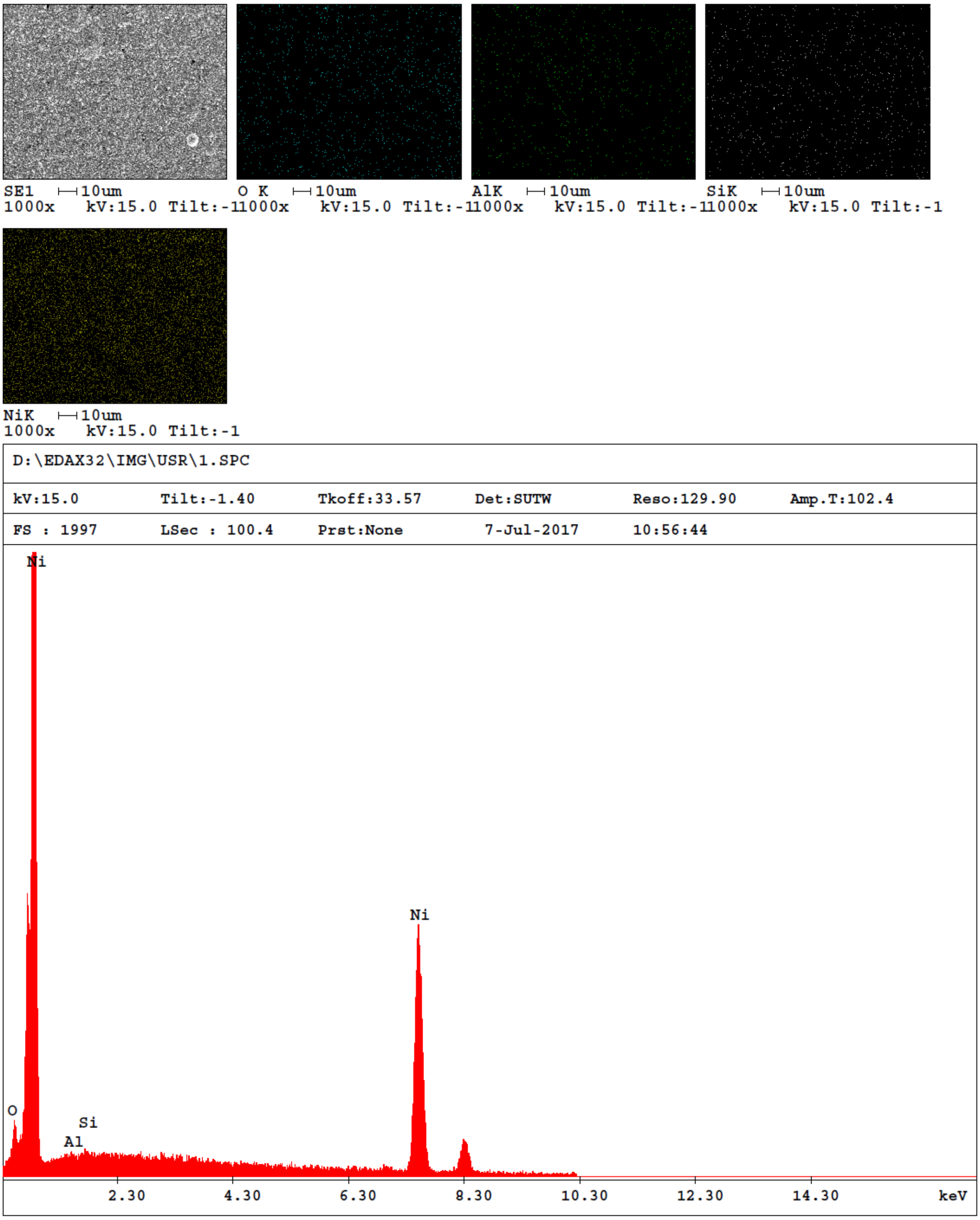
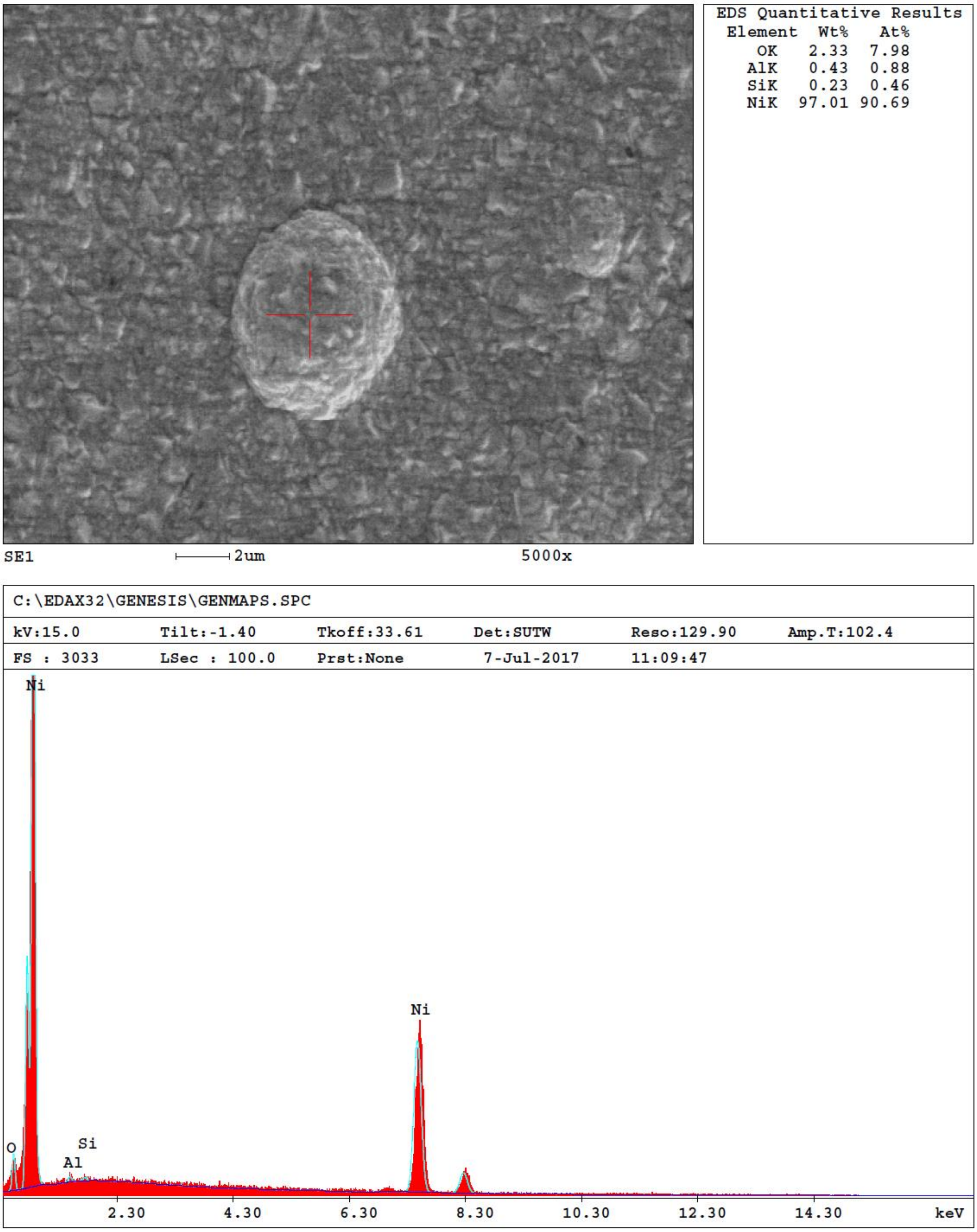


Fig. 4. *Surface EDS analysis for sample P6*



EDS Quantitative Results

Element	Wt%	At%
OK	2.33	7.98
AlK	0.43	0.88
SiK	0.23	0.46
NiK	97.01	90.69

```
C:\EDAX32\GENESIS\GENMAPS.SPC
kV:15.0        Tilt:-1.40    Tkoff:33.61    Det:SUTW       Reso:129.90    Amp.T:102.4
FS : 3033      LSec : 100.0  Prst:None       7-Jul-2017    11:09:47
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Fig. 5. *Punctual EDS analysis on the dispersed phase particle*

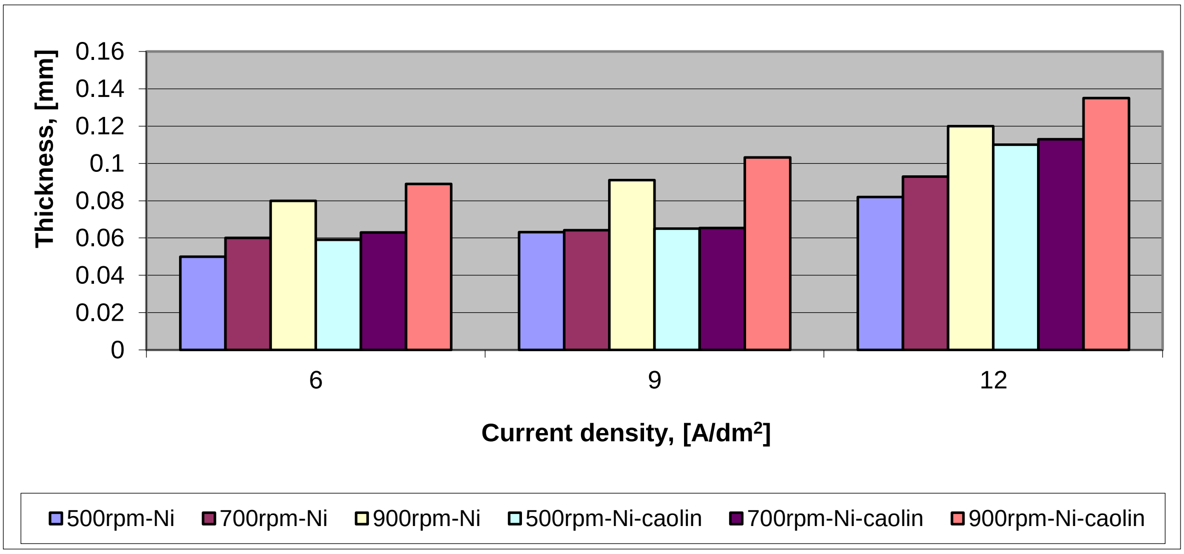

Fig. 6. *The influence of current density and stirring velocity on the layer thickness of pure nickel coatings and on electrochemical composite coatings in nickel matrix using kaolin particles as dispersed phase*

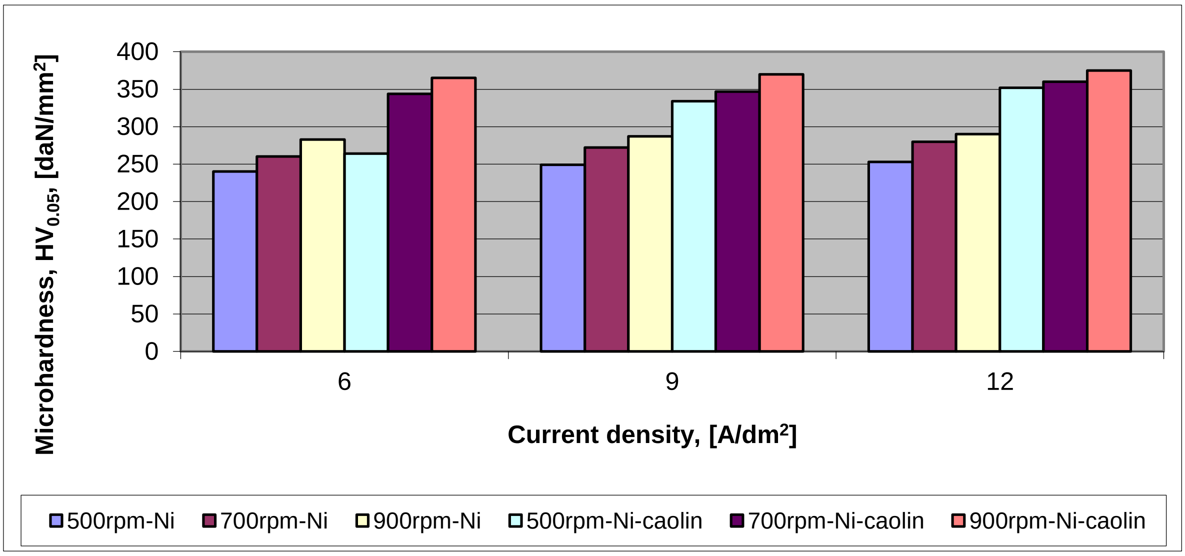

Fig. 7. *The influence of current density and stirring velocity on the microdurity of pure nickel coatings and on electrochemical composite coatings in nickel matrix using kaolin particles as dispersed phase*

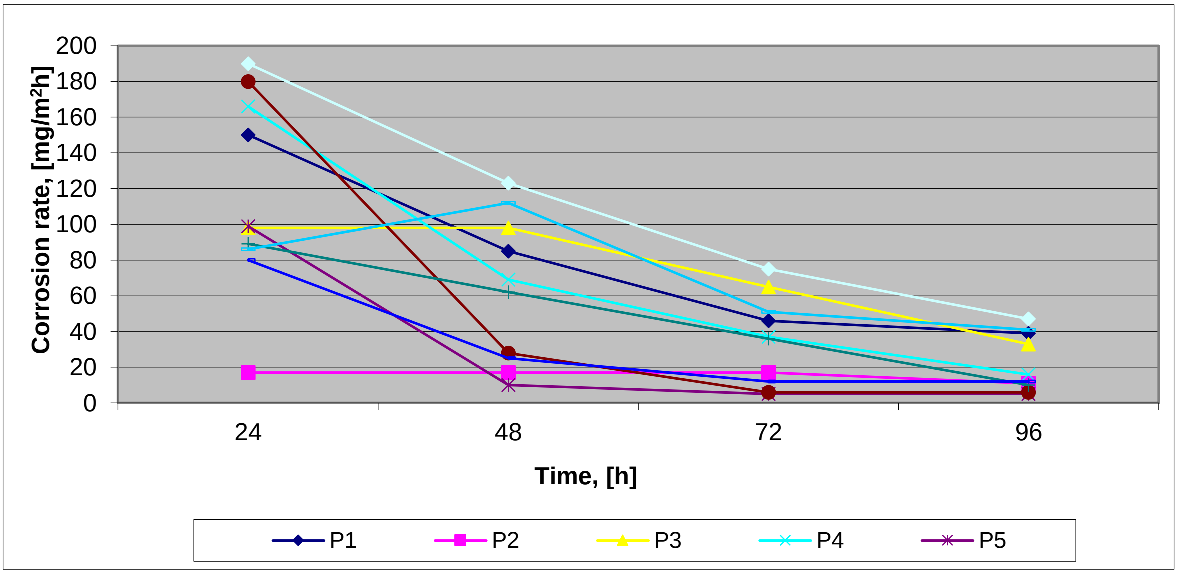

Fig. 8. *Corrosion behaviour of electrochemical composite coatings in nickel matrix using kaolin particles as dispersed phase*

❖ the electrochemical composite coatings in nickel matrix using dispersed kaolin particles exhibit higher microhardness compared to pure nickel coatings; thus the microdurity increases from 104.4 daN/mm^2 for copper support at 240 - 290 daN/mm^2 for pure nickel coatings, to 264 - 375 daN/mm^2 for ACE Ni - kaolin coatings obtained at different current densities and stirring velocities, temperature and deposition time being maintained constant; this increase is due, on the one hand, to the increase in the stresses in the layer with the current density, and on the other hand to the good incorporation of the disperse phase particles in the deposited layer and its hardening;

❖ salt mist corrosion behaviour of electrochemical ACE Ni - kaolin was superior to pure nickel layers, due to the passivation during the test.

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PSYCHOSOCIAL RISK FACTORS INFLUENCING MANAGERIAL DECISION IN ENVIRONMENTAL FIELD

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ABSTRACT

Managerial decision represents the most important activity in manager’s work. Studying managerial decision means deepening all the factors involved in the entire decisional process. The aim of this paper is to underline the main risk factors mixed up in making managerial decisions concerning the managers that operate in the environmental field. Once these factors are discovered, it’s much easier to have a complex view of all links and of the manager behavior in taking decision.

KEYWORDS: psychosocial risk factors, managerial decision, manager, environment, manager’s activity

1. Introduction

The role of manager in the organization is a subject always open for new researches and for a better understanding of his role and importance in common good of organization strategy [1]. That’s why managerial decision, the one which defines better manager’s activity, represents an absolutely necessary direction of study for a better understanding of the complex processes which occur in organization. A category of decisions, known in Management field, and, probably the hardest to avoid in manager activity is taking decisions at-risk situations. These are defined by being those circumstances, when the manager has to make decisions, without sufficient or not completed information, and, in this case, it is difficult to reach the target [2]. What does manager need in these situations? Which are his allies in taking risk decisions? The authors from specific literature point out some of them, that help managers in situations like this: self-esteem, being self-confident, with a positive self-image [3]. Moreover, there is a list made up by authors, containing the manner manager perceives the risk situations in making decisions [4].

2. Literature review

Speaking about managerial decision in organization means to overall see the events and factors involved in it, and to therefore to have a big perspective especially on factor risk that may interfere in this important activity. More or less, every manager is aware of his implication, which require their activity to be more careful, but also more exposed. That’s why it is absolutely necessary for manager to be conscious about the presence and action of these factors. Some of authors prefer to underline the importance of psychological side in taking decisions. The managerial decision depends on a lot of factors, and of great importance are the psychosocial factors [5]. Psychosocial risk factors are those that can influence psychological moods of employees (manager in this case), and also can produce health problems [6]. They play a key role in determining a person to tackle with a difficult situation [7]. Psychosocial risk factors at work are problematic, having negative effects on employees, and this is one of the reasons why there is a need in looking for solutions to solving the problems produced by these. There is also a reaction from people regarding the action of these factors and it may consist in rejection, prevention, engagement (fighting), looking for solutions to reduce the effects, and other. Obviously, there are some situations when manager doesn’t even realize the presence or action of these factors, but they’ll see later the effects produced by these. This is one of the reasons why managers, and not only they, must have ideas about the influences produced by psychosocial risk factors at work, to reduce the effects and to use strategies concerning this fact. When defining risk psychosocial factors, authors prefer to use words like: impact, action, influence, consequences, and so on. Strongly linked by the results of these factors in manager activity is the impact of manager illness. In this sense, Gatchel shows that managers are more exposed to risk of infarct than another professional category professional [8]. It is clear that these factors have a negative influence in manager's activity and especially in taking decisions. It is very important and also very well written in literature how these factors are acting on manager when he decides. Where do they influence? What is the sensitive point in manager personality that offers space to these factors and contributes to the changes in the whole decision process? All these questions are destined to help understand the way these factors are determinant on manager personality in taking decisions.

There are several ways of action of these factors, depending on every individual, and also on the way every manager reacts to this action.

In the literature there are some examples of these factors, many of them being very well known in everyday life. We can also find a list (no less than 13 risk factors) affecting the employee's work. [9].

One of the most known psychosocial risk factors is stress, probably the one with the biggest implication in manager's activity. The consequences of stress in our daily life are not an unknown subject. The effects it produces in organization is one of the most commonly presented topics by authors. One of them was talking about stress factors, highlighting the primacy of these in human activity. Manager's activity is a very complex one, having different duties, regarding both organization and employees that make the most fundamental and central point of Management. There is a certain thing that manager will feel stress especially in moments of strategic decisions that are so important for organization and for proposed strategies. This is explicable, especially from the importance of managerial decision, one the one hand, and also from the manager's personality, on the other hand. A decision is manager's duty, and stress seem to be the principal risk factor that can influence judgment, safety and manager efficacy in taking decisions. Stress in taking decision may be associated with time pressure, felt by manager in his organizational activity [11]. When authors speak about stress in manager's activity, they also use the term psychic exhaustion [12].

Generally, psychosocial risk factors may affect the work done by employees, and also managers. They can believe, as a result of the psychosocial risk factors, that they are no more productive in their work, [13], which means reduction of self-esteem and of self-confidence in their activity.

3. Research

To obtain results, we used qualitative research, and the semi-structured interview as instrument, a technique that offer possibility to explore the research problem. Ours was strongly related to the way managers act in environmental field and perceive the influence of psychosocial risk factors in taking decisions. This is a research that opens new perspectives in understanding the processes and the mechanisms that occur in managerial decision in the environmental field.

The Interview:

1. What does it mean for you the act of taking a good and safe decision? What does it involve from your point of view?
2. How do you think your decision may be affected by different psychosocial factors? How do they act in your activity?
3. How do you feel the implication of stress in the decisional process? How is it like for you?
4. What are your personal strategies to manage the impact produced by these factors when taking decisions?
5. Do you feel you are exposed to such factors?
6. How do you manage to take a decision in the presence of psychosocial risk factors?
7. Do you think psychosocial risk factors act different in the field you work?

The participants:

The participants of this research are managers (15) that activate in environmental field at two different organizations in Iași.

4. Results

The results derived from manager's responses generally show that managers' awareness on the impact of psychosocial risk factors in taking decisions in organization. The results of this research have been divided in three main categories:

1. **The reality of the presence and impact of psychosocial factors in taking decisions at managers from environmental field.** There is no doubt about that manager's perception is linked to the implication of psychosocial factors in taking decisions. All the managers noted that they felt the presence and the impact of psychosocial factors in taking decisions in organization. At the beginning of

the interview, they received a list with some of psychosocial factors. After that, they’ve been asked to answer the questions. The notion of psychosocial factor seemed to be familiar for few managers, but once they’ve seen the list, they understood the significance of the term.

Managers preferred to detail about the main factor, which seemed to be the stress. When talking about the impact of stress in decisions, managers used words and expressions like: difficult, hard to decide, negative action, negative feelings, etc. For example, one of managers said: “It is almost impossible to make good decisions if you’re felling stressed. And, stress is so present in managers’ activity, that is almost impossible to say I’m feeling out of stress”. Another example shows us that stress can produce different behavior: “When I take decision, and I feel stress, I get nervous, irritated, and I have no patience. It is very important to stay calm and stay focus, to decide what’s better for organization”.

Another perspective of this topic showed us that some managers are already familiar with the presence of these factors: “Sometimes, I realize the influence of these factors, but I am so used to all of these, that I’m not surprised anymore. Somehow, I got used to be stressed when I have to take special decisions that are important for the future of organization”.

There is also, a different perspective, that showed an opposite view of managers about the presence of these factors in manager’s main activity. It is about the lack of importance given to these risk factors. On this issue, one of manager stated: “From my point of view, it is not important what factors influence your personality, but is more important to overcome all these actions, and stay calm, be yourself, and decide better and better. It is a duty to be like that”.

2. The way psychosocial factors influence managers’ personality in taking decisions in organization.

This topic presented us very interesting answers from managers, important aspects that must be known by them into organizations. If all of managers are aware of the presence of psychosocial risk factors, only a part of them can distinguish the strategy used for these factors in taking managerial decision. Few of them tried to avoid the answer in different ways.

For example, one manager said: “I cannot say clearly, how they act...it just happens”. An alternative to avoid answer was to speak, generally, about decisions and manager’s behavior in taking it. The managers that discern on the way psychosocial risk factors act on manager’s personality, discussed about the manner these factors proceeded in taking managerial decision. For example, one of them preferred to link the way of action with the effects produced: “These factors can change the way you think, you’ve prepared the decision, and also can produce different outcomes…anyway, there are perceptible changes because of these”.

3. Personal tools used to manage the impact of these factors in taking decisions.

It is clearly that every manager has personal ways to respond to the action of risk factors. Even if for some of these they weren’t immediately aware of, after some discussions and exploration, managers named some qualities or internal resources meant to offer self-confidence to manager, and to show that he responds and reacts to the action of these factors. Some of them claimed that the principal tool in these situations is power, understood as the way to react with all the heart into these situations: “I use my power to get over this influence”. “I realize I must be very powerful when I’m stressed…otherwise, I can’t take the best decisions”. Sometimes, power is placed next to other resources: “You must have power and confidence to succeed”. Another asset that managers own is past experience: “How to not use my experience to protect my decisions? I have experience, and I know how to react if I’m stressed, or anything like that”. An interesting answer in describing personal strategy in managing situations related to the impact of risk factors is the following: “I use my whole personality to face these factors. It is a very good and efficient strategy”.

4. The perception of manager in relation to the impact of psychosocial factors in environmental field.

Most managers state that taking decisions in environmental field isn’t much different from other areas. They believe that, generally, there are not remarkable differences between the field they act and other ones.

However, there were few managers that claimed a difference related to this topic: “I believe it is more difficult to decide as manager working in this field. It is different from other areas…It is more stress; it is harder to decide”.

5. Conclusions

The presence and the impact of psychosocial risk factors in taking managerial decisions represent a reality in all organizations. This study highlighted the managers’ perspective about the impact and effects produced by these factors, with a particular focus on stress. For managers that work in the environmental field, psychosocial risk factors affect and leave tracks in their personality in the process of taking decisions. Managers’ vision about the influence of these factors shaped up different aspects linked to managerial decisions taken under uncertainty. Nevertheless, managers have their own tools that help them find the best alternatives in such situations.

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DETERMINATION OF THE GRINDING ROLLER GRINDING ARROW IN A LBC FINISHER

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ABSTRACT

The required profile of the cylinders is achieved by their proper correction after the change due to wear.

In this paper I studied how the profile of the working cylinders can influence the profile of hot rolled steel strip.

KEYWORDS: manufacturing, lean manufacturing, cost, optimization, Romanian automotive industry

1. Introduction

The profile of the cylinders can be used as an effective factor for ensuring the optimal width variation of the strip if the following conditions are met:

- ensuring a uniform distribution of temperature along the length of the cylinder bar;
- supply to maintain a constant cylinder temperature;
- cooling water is adjusted to take up the entire amount of heat that tends to increase the cylinder temperature.

Cylinders change immediately when their wear causes the tolerances admitted to the tape to no longer be guaranteed.

2. Experiments performed

To illustrate how to determine the quartz coulter grinding arrow in an LBC finisher, we will consider the roll forming profile for rolling the 1500 mm bands.

We take, for example, laminating a strip of 5 mm final thickness and 1500 mm wide, grade steel OL 37.

The rolling forces and reductions are given in Table 1.

Calculate the bending of the support cylinders with relation 1 and obtain the results in Table 2.

$$f_{sb} = f_s \cdot \frac{b}{a} \qquad (1)$$

Calculate the bending stroke of the work cylinder due to the contact between the working cylinder and the bearing with the relationship 2, the results being given in Table 3.

$$f_l = F\,(b\text{-}KB/L)\cdot 10^{-5} \qquad (2)$$

where: F is the rolling force in N;

b, K - coefficients that can be taken from nomograms according to reports and

B / L - the ratio of the width and length of the cylinder bar.

We will calculate the average wear of the supporting cylinders when changing the work cylinders by nomograms, the results being given in Table 4.

The thermal dilatation of the working cylinders with relations 3, 4 is calculated, its values are shown in Table 4 and the temperature difference between the middle and the edge of the work cylinder slab in Fig. 1.

$$\Delta t_l = \frac{\alpha \cdot D(t - t_i)}{2} \qquad (3)$$

$$\Delta t_l = \alpha \cdot R(t\text{-}t_i); \quad \text{or} \quad \frac{\alpha \cdot D(t - t_i)}{2} \qquad (4)$$

Since the temperature difference of the support cylinders between the middle and the edges is small (maximum 2 ^{o}C), according to the relationship 2, Figure 1, this can be neglected.

Table 1. *Rolling forces and reductions in rolling a 5x1500mm strip*

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
Force, MN	1.6	1.8	1.6	1.5	1.4	0.7
Thickness, mm	18	12.4	8.9	6.5	5.5	5

Table 2. *Bending of Supporting Cylinders*

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
f_{st}	0.066	0.075	0.066	0.062	0.057	0.029

Table 3. *Bending of working cylinders*

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
f_l	0.016	0.019	0.016	0.015	0.014	0.006

Table 4. *Average wear of supporting cylinders*

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
u_m	0.140	0.130	0.110	0.110	0.100	0.100

Table 5. *Thermal expansion of working cylinders*

	F1	**F2**	**F3**	**F4**	**F5**	**F6**
$t-t_i$	30	28	25	20	15	10
Φ cil.	715	770	730	740	745	750
Δt	0.212	0.197	0.180	0.146	0.110	0.075

Since the temperature difference of the support cylinders between the middle and the edges is small (maximum 2 °C), according to the relationship 2, Figure 1, this can be neglected.

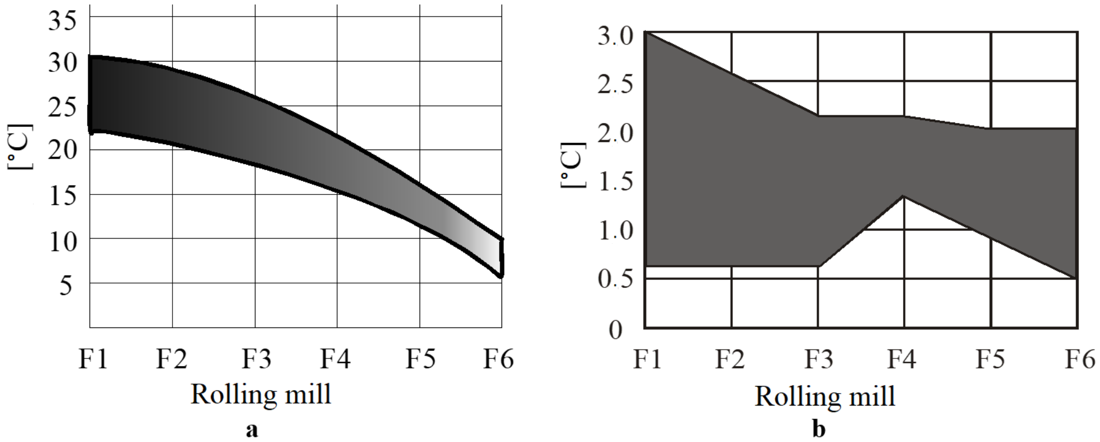

Fig. 1. *Temperature difference between the middle and the edge of the slab: a. Working cylinders; b. Supporting cylinders*

We calculate with the relationship 5 the required arrow at each cage to assure the shape condition (according to Figure 1), the data obtained being given in Table 6.

$$\delta_n = \delta_{6-7} \frac{h_{in}}{h_{6-7}} \qquad (5)$$

in which:

δ_n is the difference in thickness between the middle and the edge of the band at passage n, in mm;

δ_{6-7} - the difference in thickness between the middle and the edge of the strip at the last finish, in mm;

h_n - the thickness of the band at passage n, in mm;

h_{6-7} - the thickness of the band at the last pass, in mm.

According to the relationship 6 the correction arrow will be given by the calculations in table 6.

$$f = 2f_l + 2f_{st} + u_m - (2\Delta t_l + \Delta t_s + \delta) \qquad (6)$$

in which:

δ is the difference in thickness between the middle and the edge of the strip;

f_l - the bending arrow of the working cylinder due to the elastic compression of the working cylinders in contact with the supporting cylinders in mm;

f_{st} - the bending arrow of the supporting cylinders in mm;

u_m - the average wear value of the support rollers when mounting the working cylinders in the cage, in mm;

Δt_l - thermal expansion of working cylinders in mm;

Δt_s - thermal expansion of supporting cylinders in mm.

The calculated values are rounded to values of 0.005 mm, as shown in Table 7.

Tabel 6. *Cylinder rectification arrow (calculated values)*

	Cylinder rectification arrow, **f**	
	Calculus	**Value**
F1	0.132+0.032+0.140-(0.424+0.180)	0.290
F2	0.150+0.038+0.130-(0.394+0.124)	0.200
F3	0.132+0.032+0.110-(0.360+0.089)	0.175
F4	0.124+0.030+0.110-(0.292+0.065)	0.093
F5	0.114+0.028+0.100-(0.220+0.055)	0.031
F6	0.058+0.012+0.100-(0.150+0.050)	0.030

Table 7. *Cylinder rectification arrow*

	Cylinder rectification arrow, f	
	Calculate value	**Adopted value**
F1	0.290	-0.300
F2	0.200	-0.200
F3	0.175	-0.150
F4	0.093	-0.100
F5	0.031	-0.050
F6	0.030	0

The calculated values represent the maximum arrow at the centre of the cylinder bar. The value of the arrow should decrease parabolically, from the middle to the edge, on one side and the other, the calculation at any point of the tile can be done with the relationship:

$$f_x = f \cdot \left[1 - \left(\frac{z}{z_0}\right)^2\right] \qquad (7)$$

in which: f_x is the roll grinding arrow at point x in mm;

f - the trimming arrow at the centre of the slab in mm;

L - drum length in mm;

z - the distance from the middle of the tile to the edge thereof, in mm.

Graphically, the arrow will appear according to the diagram in Figure 2.

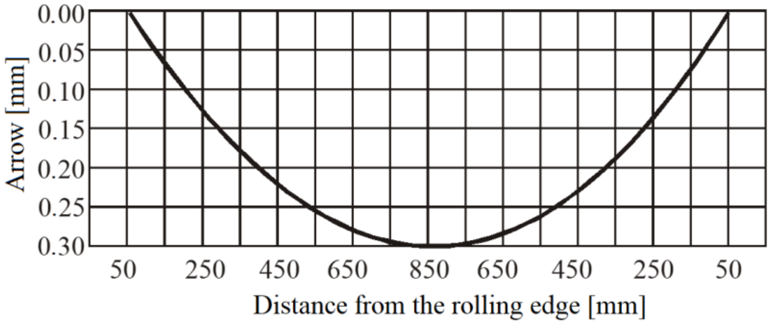

Fig. 2. *The resulting arrow for F3*

3. Conclusions

In the hot rolling of the strip, there is a thickness limit (reduction) until the band profile can be effectively influenced; the cross-flow of the material below this limit being strongly impeded, the relative profile remaining almost constant. This limit moves to higher thicknesses for tougher steels because, with increasing resistance to deformation, the cross-flow of the material is difficult.

An effective influence of the strip profile for the laminated strip at thicknesses below 5 mm can be affected in the thickness range of 8-16 mm.

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