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OPTIMISING THE COMPOSITION OF NATURAL MOULDING SANDS INCLUDING THERMAL ASPECTS

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Abstract

The paper discusses the problem of the choice of the moulding sand mixture composition in terms of the sand behaviour in contact with molten metal. Studies of high-temperature phenomena make assessment of the sand composition ability under real operating conditions possible, thus leading to the elimination of sand-originating casting defects. The research was conducted on selected moulding materials included in the composition of traditional moulding sand mixtures without the addition of carbon. The effect of moulding sand composition and moisture content on the linear dilatation and stress-induced allotropic changes of quartz was examined. The analysis of these phenomena was based on 3D charts and maps generated from data collected during the tests.

KEYWORDS: METALCASTING; MOULDING; MOULDING MIXTURE; MOULDING SAND

1. Introduction

Moulding properties mean this state of the moulding sand, in which it has optimal properties as regards its applicability in moulding operations [1]. The vast majority of studies on the sand mouldability, while its behaviour under real conditions, i.e. at elevated temperatures, is checked only when final effects, i.e. the ready castings, are examined. Only then the composition of the sand mixture is corrected, taking into account the defects specific castings and their causes. The sand composition is usually selected after studying a complex of multi-curve diagrams (Fig. 1) [1], which are drawn up as a result of the investigations of the basic mechanical and technological properties.

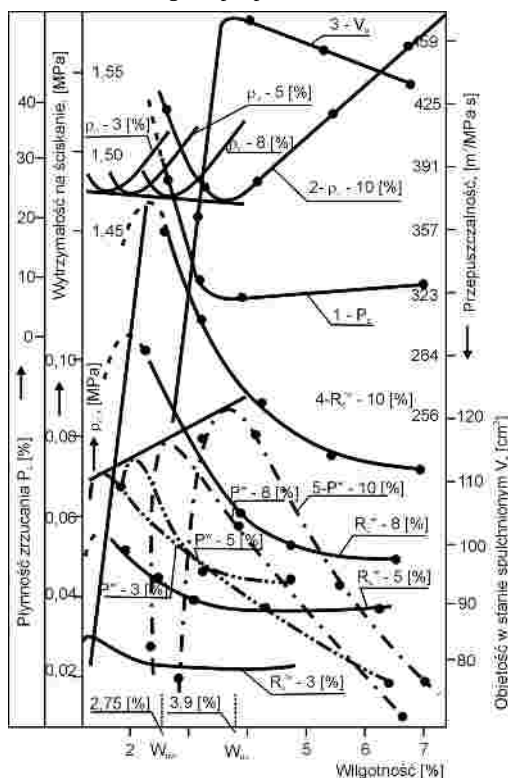


Fig. 1. Effect of moisture content on the sand mouldability
Wytrzymałość na ściskanie – compression strength, Płynność zrzucania – discharge flow, Przepuszczalność – permeability, Wilgotność – moisture content

Sand, on which moulding mixtures are based, is the main and most important component of foundry mould in terms of volume changes taking place in this mould. In the case of the most commonly used sand, its main ingredient is silica (quartz and its varieties), whose polymorphic transformations taking place between the major variations, i.e. quartz, tridymite and cristobalite, decide on volume changes and their derivatives occurring during the process of mould pouring and casting solidification.

The most important transformation in terms of the moulding sand dilatation is the transformation of β -quartz into α -quartz, occurring with high speed at a temperature of 572.4°C. At the point of the transformation one can see a sudden change of density (β -quartz 2.51 [g/cm³], α -quartz 2.655 [g/cm³]) and the change of thermal expansion coefficient. The dilatation changes that occur during this transformation amount to about 1.4 [%] (linear expansion). They are relatively small compared to the dilatation changes that take place during the transformation with restructuring of α -quartz into α -tridymite, amounting to about 14 [%], except that the latter process occurs very slowly due to very strong ionic bonds between Si⁴⁺ and O²⁻.

Using sand as a main component of moulding mixture gave rise to a theory that the behaviour of a foundry moulding mixture is determined by dilatometric changes taking place in the sand alone. However, more detailed investigations enabled combining the effect of dilatation changes originating from the sand and binder (bentonite) [5]. This is particularly important in the case of sand mixtures with high content of binder. Bentonite expands earlier than the sand (lower temperature) and then undergoes sintering. The calculated dilatation curve of moulding sand containing 15 [wt.%] of bentonite is presented in Figure 2.

2. Methods and scope of studies

Studies were conducted on moulding mixtures prepared from moulding materials used most commonly in production of iron and steel castings, i.e. the sand from Krzeszów and Zebiec, and medium-grain size sand from Bukowno, and bentonites - Bentomak and ZGM. The content of binder (bentonite) was 5, 7, 10%, the sand moisture content was 2,3,4 and 5%. The choice of these materials was based on the results of fundamental research determining the following technological properties:

$R_c^w, R_r^w, P^w, S^w, W_{bent}^w, W_{masy}^w$. Specimens for the measurement of free dilatation (FRI method) and dilatation under loading (Dietert furnace) were prepared according to the specification made by H. Dietert and others [3].

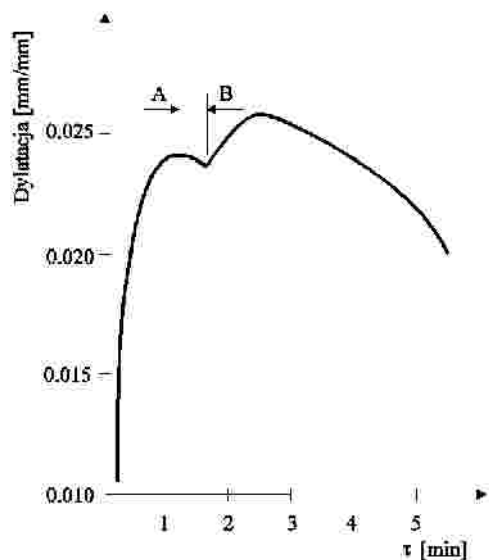


Fig. 2. Theoretical thermal dilatation curve of moulding sand with 15 [%] of Western Bentonite.

A – bentonite dilatation is predominant, B – sand dilatation is predominant [5].

Dylatacja – dilatation

For dilatometric tests, 19 most characteristic sand mixtures were selected from the whole set of 72 sand mixture compositions.

On each of the selected sand mixtures the following tests were carried out:

1. Determination of free dilatation (FRI method):
 - a) at a temperature of 500°C;
 - b) at a temperature of 600°C;
2. Determination of dilatation under preliminary loading (Dietert method)
 - a) at a temperature of 500°C;
 - b) at a temperature of 600°C.

The test temperatures used in the determination of both free dilatation and dilatation under preliminary loading were selected in accordance with the temperature of the polymorphic transformation of quartz (β -quartz into α -quartz at a temperature of 572.4°C).

In the above mentioned methods, standard cylindrical specimens of $\varnothing 286 \times 50$, 8 [mm] dimensions prepared in an appropriate sleeve-shaped test mould by three blows of the rammer weighing 3.175 [kg], falling from a height of 66.7 [mm] as recommended by H. Dietert, were used. Specimens prior testing of the thermal expansion were dried in a furnace.

The measurement of dilatation under preliminary loading was carried out in a H. Dietert furnace. The specimen was in the furnace chamber heated to appropriate temperature with eight sillite rods mounted on a movable pivot (resistance furnace). The axial pressure on the specimen was exerted by aligning plates. The dilatation was measured with spring-actuated sensor, which every 1 minute recorded changes in the specimen length; the measurement started after the specimen was placed in furnace, preliminary loading of 1[pound/inch²]/0,0073[MN/m²] was applied, and sensor recording the increase in length was set to zero.

3. Test results

The test results after graphical processing are shown below. The above presented 3D graph and the respective map have been plotted for one of the several examined moulding sand mixtures. A comparison of test results obtained for sands containing different binders showed that the effect of these binders on the dilatation and stress increase was almost negligible. Therefore, it was decided to depict graphically only the sand effect on the examined parameters (Figs. 4 and 5).

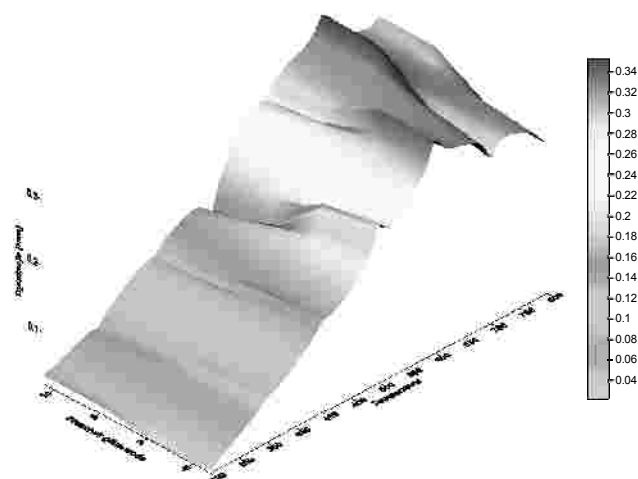


Fig. 3 Graphically illustrated relationship of Δl in function of temperature and clay/water – sand ratio for Krzeszów sand and ZGM domestic bentonite [7,8,9]

Dylatacja – dilatation, Temperatura – temperature

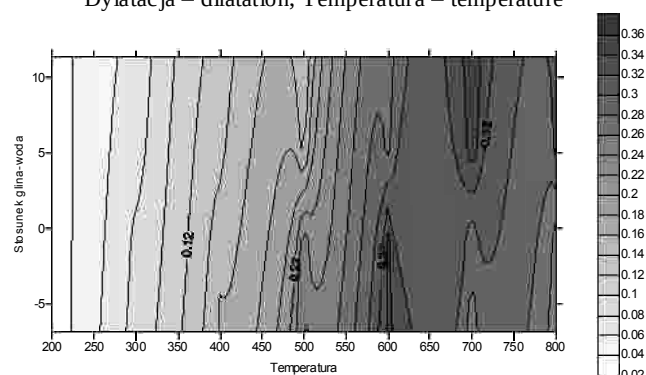


Fig. 3a Graphically illustrated relationship of Δl in function of temperature and clay/water – sand ratio for Krzeszów sand and ZGM domestic bentonite – a map [7,8,9]

Stosunek glina-woda - clay-water ratio, Temperatura - temperature

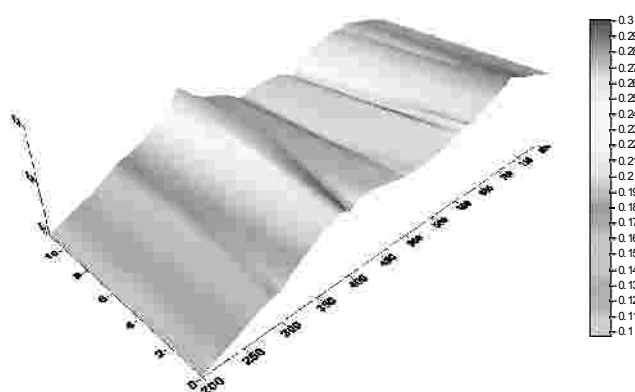


Fig. 4 Graphically illustrated relationship of Δl in function of temperature and clay/water – sand ratio for Krzeszów sand [7,8,9]

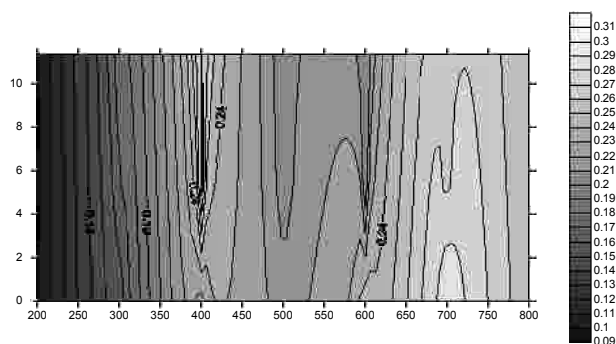


Fig. 5 Graphically illustrated relationship of ΔR_c in function of temperature and clay/water – sand ratio for Krzeszów sand [7,8,9]

Table 1

Relationship between increment in stress ΔR_c^t , water-clay ratio (w/c) and temperature [7,8,9]

temp	c/w	ΔR_c^t	temp	c/w	ΔR_c^t
200	1,66	0,031	500	3,5	0,201
200	1,4	0,088	500	1	0,231
200	2,33	0,095	500	2,5	0,262
200	3,5	0,097	600	1,66	0,302
200	1	0,102	600	1,4	0,168
200	2,5	0,146	600	2,33	0,277
300	1,66	0,119	600	3,5	0,201
300	1,4	0,089	600	1	0,253
300	2,33	0,153	600	2,5	0,316
300	3,5	0,175	700	1,66	0,311
300	1	0,153	700	1,4	0,136
300	2,5	0,124	700	2,33	0,211
400	1,66	0,139	700	3,5	0,269
400	1,4	0,182	700	1	0,304
400	2,33	0,153	700	2,5	0,263
400	3,5	0,276	800	1,66	0,18
400	1	0,207	800	1,4	0,153
400	2,5	0,194	800	2,33	0,251
500	1,66	0,026	800	3,5	0,251
500	1,4	0,168	800	1	0,252
500	2,33	0,189	800	2,5	0,309

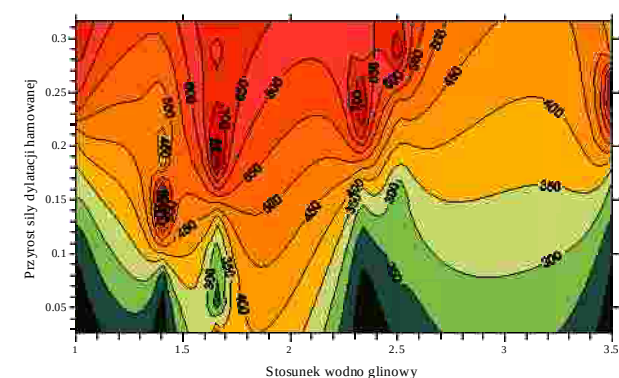
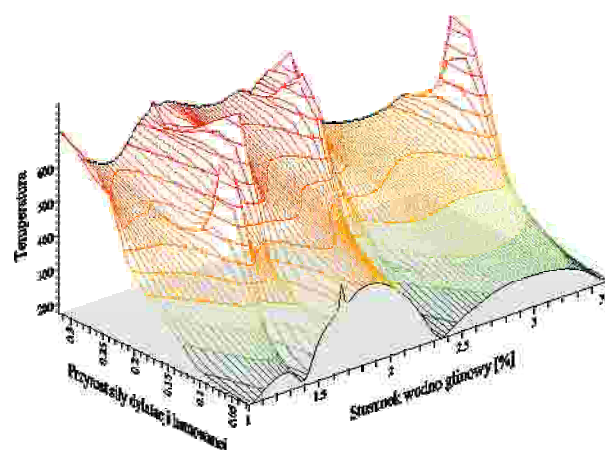


Fig. 4 Relationship between increment in stress ΔR_c^t , water/clay ratio and temperature [7,8,9]
temperatura – temperature
stosunek wodno-glinowy – water/clay ratio
przyrost siły dylatacji hamowanej - increment in force of impeded dilatation

4. Conclusion

The analysis of the results allows drawing the following conclusions:

1. The largest thermal dilatation gives the mixture based on Krzeszów sand. Probably the main role in this case plays not so much the sand granulation as the shape of grains and the content of polymorphic quartz variations.
2. The largest thermal dilatation has the sand mixture, where the water-clay ratio is about 0.2.
3. A characteristic increase in elongation Δl related with the transformation of β -quartz into α -quartz at temperatures around 600 [°C] was observed.
4. The values of the increase in both length and stress reach a very high level of 1% and 0.3 MPa, respectively. Unfortunately, so far, they have been ignored in analysis of the casting producibility.
5. The analysis neglecting different types of bentonite enabled plotting uniform graphs representing relationships between the water-clay ratio and temperature in function of the dilatation changes and stress increase.
6. These types of charts, and maps in particular, can be used in the choice of moulding sand composition allowing for temperature variations.

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INFLUENCE OF NANOSIZED SILICON NITRIDE ADDITION DURING CASTING ON THE MICROSTRUCTURE OF X210Cr12 STEEL

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Abstract: The objective of this study is to investigate the effect of modification and nitrogen alloying of X210Cr12 tool steel by addition of nanosized Si_3N_4 during the casting process. This is an air hardening, high-carbon, high-chromium tool steel which displays an excellent wear resistance and has good dimensional stability and high compressive strength. Of great importance for the tools fabrication of this steel is the ledeboritic structure after casting and the influence of its characteristics on the next processes of forging, machining and heat treatment for obtaining of optimal properties. In this case a modification at the cast process and obtaining of finer structure is a precondition for better results on the next stages of tool manufacture. The role of nitrogen for obtaining of fine grained structure is already proved for many types of steels and the alloying process is precise developed. Si_3N_4 is one of the most suitable nitrogenous alloying agents for production of alloyed with nitrogen steels because of its high nitrogen content and stability. The investigations show a considerable improvement of the cast structure of X210Cr12 tool steel after the addition of small amount of nanosized silicon nitride during the casting process.

Keywords: MODIFICATION, NANO-DYSPERSED Si_3N_4 , X210CR12 STEEL, HEAT TREATMENT

1. Introduction

The alloying of tool steels with nitrogen is a perspective direction for improvement of their wear resistance, hardness, tribological characteristics and for better performance. The advances of nitrogen addition in these steels is connected with grain size refining, significant increasing of strength without restriction of ductility, formation of nitrides and carbonitrides with high hardness in the structure. The nitrogen can be introduced in the steel by remelting in nitrogen atmosphere at higher pressure or by addition of high-nitrogen ferroalloys and nitrides such as nitrated ferrovanadium, ferrochromium, ferromanganese or silicon nitride. In the case of high-carbon, high-chromium cold work tool steels with ledeboritic as-cast structure the addition of nitrogen as a stable silicon nitride with about of 30 % nitrogen content will modify and refine the structure, stabilize the austenite, increase the strength, wear resistance and resistance to tempering. The role of nitrogen for obtaining of finer grained structure is already proved for many types of steels and the alloying process is precise developed. Si_3N_4 is one of the most suitable nitrogenous alloying agents for production of alloyed with nitrogen steels because of its high nitrogen content and stability [1].

2. Materials and Procedure

The material for the experiments was a standard tool steel X210Cr12, with or without addition of nanosized Si_3N_4 at the casting process. The chemical composition of the prepared samples is shown in Table 1. Steel 2 is modified with nanosized silicon nitride added in the mould before casting.

Table 1: Chemical composition of the studied steel samples

Element, wt. %	C	Si	Mn	P	S	Cr	
Steel 1	1.91	0.51	0.46	0.031	0.046	11.60	
Steel 2 (+N)	1.98	0.51	0.46	0.031	0.045	11.38	

Element, wt. %	Ni	Mo	Cu	V	As	Al	N
Steel 1	0.23	0.077	0.10	0.052	0.031	0.006	-
Steel 2 (+N)	0.33	0.076	0.10	0.053	0.031	0.11	0.061

The two types of steel were obtained by remelting in induction furnace and casting in graphite molds with a conical shape, shown in Figure 1, left. The samples used for the study were cut vertically from the ingot and after that prepared according to the standard methods. The dimensions of the samples are shown in Figure 1, right.

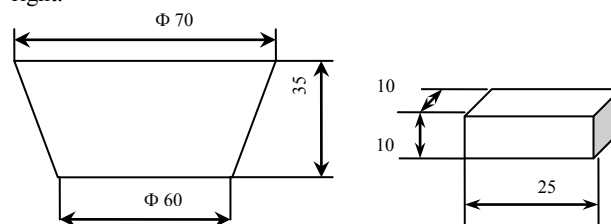
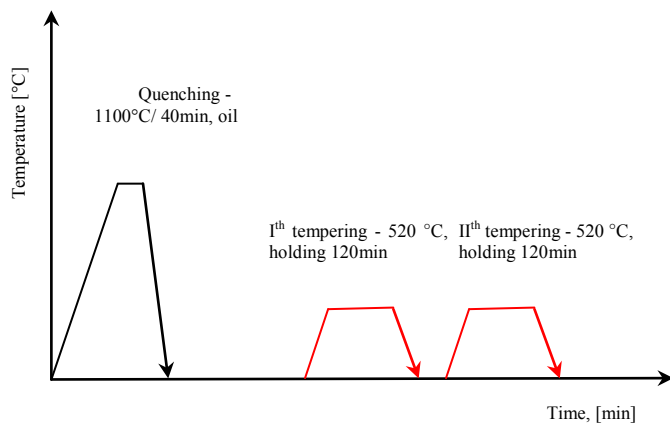


Fig. 1. Shape and dimensions of the cast ingots(left) and of the cut samples (right)

After casting some of the samples were 25 % hot deformed by stamping at temperature of 1150°C and after that heat treated by quenching from 1100 °C in oil with followed double high temperature tempering at 520 °C for obtaining of secondary hardness. In table 2 and Figure 2 are shown the heat treatment parameters for the samples from the both steels.

Table 2: Heat treatment parameters

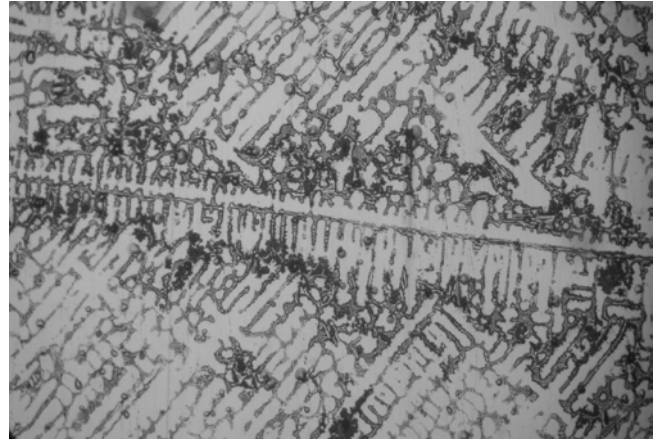
Steel type	1	2
Quenching (temperature, [°C] and medium)	1100, oil	1100, oil
Hold, [min]	40	40
Hardness after quenching, HRC	61	62
Tempering (temperature, [°C] and medium)	520, air	520, air
Hold, [min]	120	120
Hardness after I th tempering, HRC	63	60
Hardness after II th tempering, HRC	58	57
Hardness after casting, HRC	46	50

**Fig. 2.** Heat treatment of the both types X210Cr12 steel

3. Results and Discussion

Booth steels 1 and 2 have the typical chemical composition of X210Cr12 tool steel according to the producers and standards [2, 3].

The measured hardness of the as-cast samples shows that the modified with nanosized Si_3N_4 steel has hardness higher than HRC 50 and the hardness of non-modified steel is about HRC 46. The added nanosized silicon nitride refines the coarse dendrite structure of the cast steel and creates more homogeneous distribution of the ledeburitic eutectic. The presence of complex carbides and carbonitrides into the microstructure has the same effect. The as-cast microstructures of steels 1 and 2 are shown in Figure 3 and Figure 4. The non-modified as-cast steel 1 has a coarse dendritic structure, which can not be observed in Figure 4 for the modified with nanosized silicon nitride steel 2, and higher amount of ledeburite between the longer austenitic dendrites.

**Fig. 3.** As-cast microstructure of steel 1: Primary dendrites from partially transformed alloyed austenite (white zones) and ledeburite eutectic (dark zones). Optical micrograph of an etched sample, magnification 100x

The deformation in this case of stamping is not enough to break up the ledebouritic eutectic and it remains in the structure of both steels in about the same amount – Figure 5 and 6.

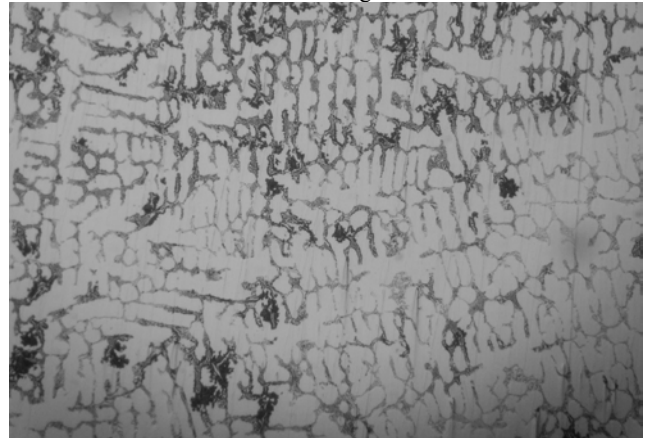
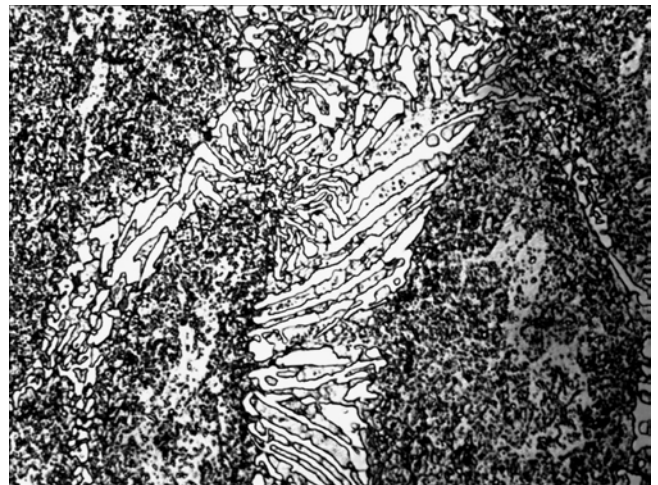
**Fig. 4.** As-cast microstructure of steel 2. Optical micrograph of an etched sample, at magnification 100x**Fig. 5.** Ledebouritic eutectic in steel 1 after stamping, 800x



Fig. 6. Ledebouritic eutectic in steel 2 after stamping, 800x

Figures 7 and 8 show optical micrographs of heat treated samples from X210Cr12 steel which are not modified with nanosized Si_3N_4 . The microstructure of the sample quenched in oil from 1100 °C is shown in Figure 7 and the microstructure of the same sample after double tempering at 520 °C for 180 min is shown in figure 8.

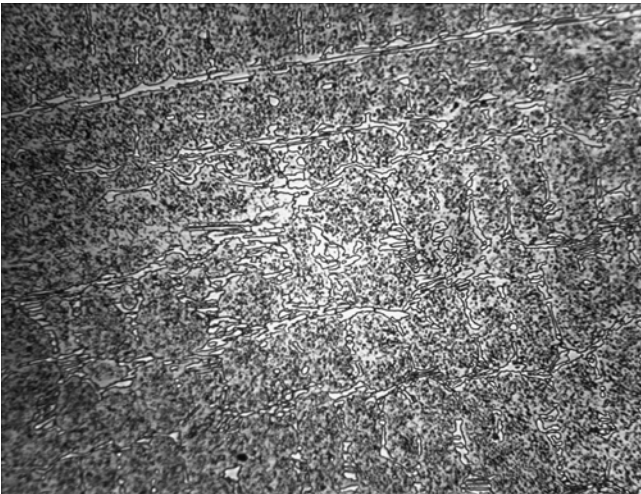


Fig. 7. Non-modified with Si_3N_4 microstructure of steel 1 after quenching from 1100°C. Optical micrograph of etched sample at magnification 400x.

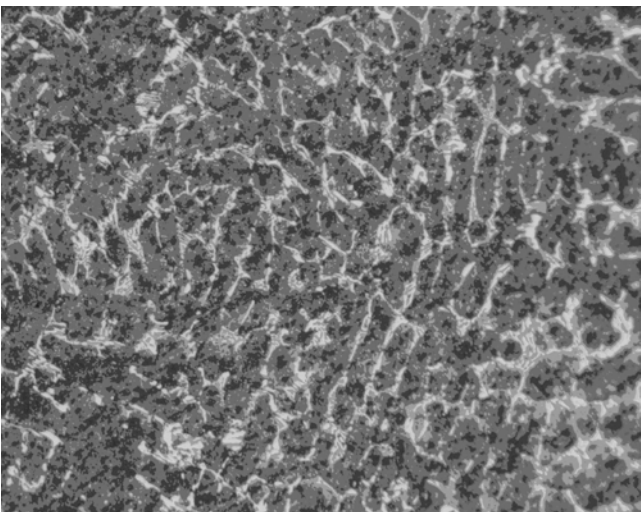


Fig. 8. Non-modified microstructure of steel 1 after quenching from 1100°C and double tempering at 520 °C. Optical micrograph of etched sample at magnification 320x.

In Figure 7 can be seen the microstructure of steel 1 consisting of martensite, retain austenite and ledeburitic eutectic surrounding the martensitic grains. It can be also seen by higher magnifications carbides which are homogeneously distributed in the grain structure [4-6]. The tempered microstructure, shown in Figure 8, consists of tempered martensite, ledeburitic eutectic and secondary carbides. It can be observed that the dendritic structure remains in approximately same type.

Figure 9 and Figure 10 show the microstructures of steel 2 after quenching in oil from 1100°C and double tempering at 520 °C. It can be observed the finer ledeburitic net around the martensitic grains.

In Figure 11 are shown the values of measured hardness of investigated steels in the discussed conditions. After casting and quenching the modified with nanosized silicon nitride samples of steel 2 have higher hardness than those of steel 1. After tempering at 520 °C the modified structure is with lower hardness, because of finer ledeburitic net and smaller amount of retain in the structure eutectic.

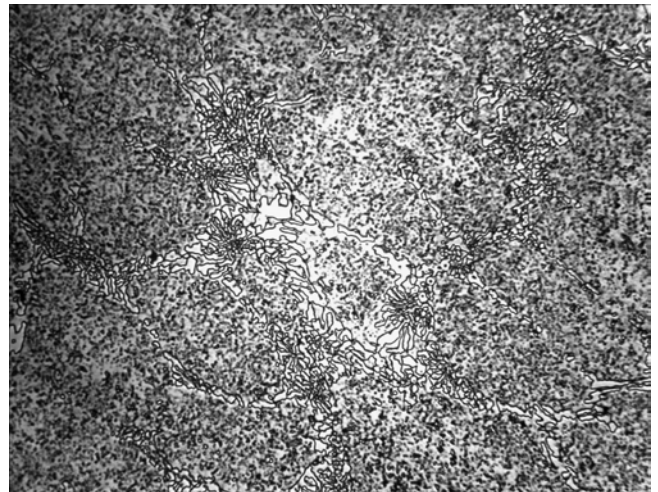


Fig. 9. Si_3N_4 -modified microstructure of steel 2 after quenching from 1100 °C. Optical micrograph of etched sample at magnification 400x.

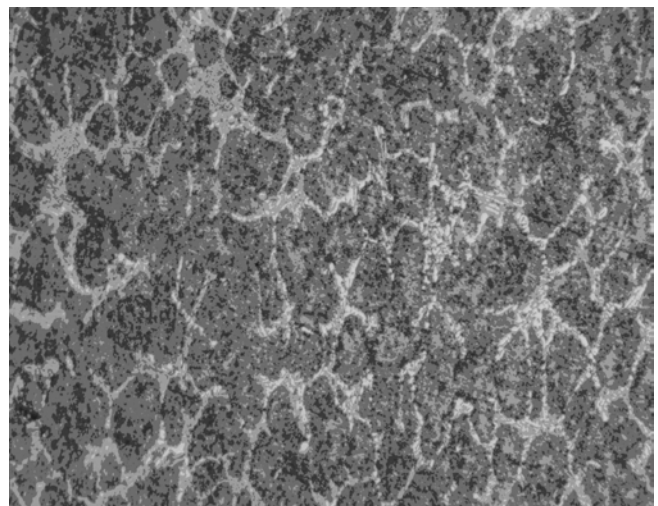


Fig. 10. Si_3N_4 -modified microstructure of steel 2 after quenching from 1100 °C and double tempering at 520 °C. Optical micrograph of etched sample at magnification 320x

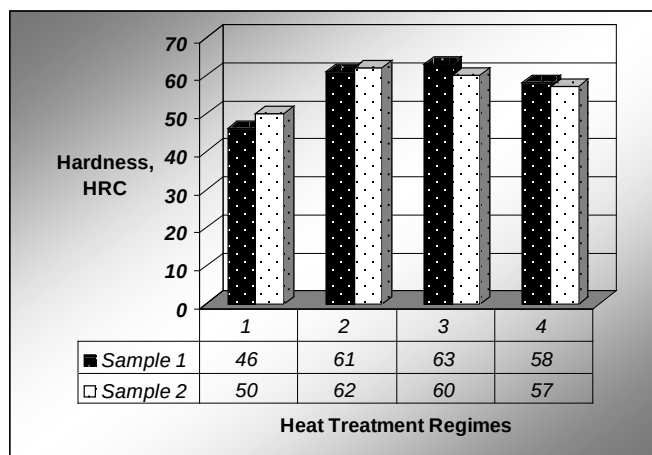


Fig. 11. Hardness of samples from steels 1 and 2 after: 1- casting; 2- quenching from 1100 °C; 3- Ith tempering at 520 °C ; 4- IIth tempering °C.

4. Conclusions

The modification of steel X210Cr12 with nanosized silicon nitride gives more homogeneous distribution of the phases (ledeburitic eutectic, alloy martensite, retain austenite and dispersed carbides) after casting, plastic deformation, oil quenching from 1100°C and double tempering at 520 °C. The applied heat treatment can not remove the dendritic structure remained after the applied plastic deformation. It can be observed more homogeneous distribution of the ledeburitic eutectic and its finer structure in the samples from modified with silicon nitride steel.

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MODERN METHODS OF METAL MATRIX COMPOSITE ALLOYS PRODUCTION AND NEW APPROACHES TO REALIZATION OF REINFORCING SCHEME

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Abstract: *In present work classification of known liquid-phase methods of manufacturing metal matrix composite alloys is offered. Methods of exogenous reinforcing provide input of prepared reinforcing particles in matrix melt. Methods of endogenous reinforcing provide formation of endogenous reinforcing phases directly in the melt due to flowing of controlled exothermic reactions between components of initial composite mixes. Distinctive features of interaction of phases at flowing of processes of liquid-phase high-temperature synthesis provide opportunity for realization of new conceptual approaches to realization of scheme of the reinforcing, based on combination of endogenous and exogenous reinforcing of a matrix alloy with particles of various nature and sizes.*

KEYWORDS: METAL MATRIX COMPOSITE ALLOYS, LIQUID-PHASE TECHNOLOGY, EXOGENOUS AND ENDOGENOUS REINFORCING

1. Introduction

Effective development of modern engineering is impossible without creation and implementation of new advanced materials corresponding to constantly increasing requirements and capable to successful work in hard operation conditions. Traditional alloys don't have all characteristics which are required for modern growth of industry production; therefore one of the most perspective ways in this direction is development of metal matrix composite alloys (MMC's). Application of MMC's allows reaching of significantly increasing of mechanical and operational properties of products [1].

Composite alloys are a special class of heterophase materials for functional and structural purposes, consisting of a metal base (matrix) reinforced with uniformly distributed high-melting and high-modulus particles of exogenous or endogenous nature, which aren't dissolving in matrix metal at temperatures of manufacturing and exploitation. These materials differ from conventional alloys by increased values of physic-mechanical and operational properties, including high specific strength, damping capacity, heat resistance, wear resistance in the conditions of dry and abrasive wear in wider temperature and power interval of operation.

Currently as matrices for producing of MMC's using aluminum, magnesium, zinc, copper, titanium and their alloys [2]. Disperse particles of oxides, carbides, nitrides, borides, intermetallics and other high-melting compounds are used as a reinforcing phases.

2. Modern methods of MMC's production

At present time the development of technological processes of MMC's production has received considerable attention. Searches of effective technologies of composites production are important for expansion of a range and volumes of their perspective applications because areas for their use potentially exist in every industry where the increased performance characteristics are critical. Active researches in this area carried out by scientific groups and organizations in practically all countries with developed industry and high innovative activity, including USA, Germany, Japan, China, India, Russia, etc. [3].

The first works aimed at production of cast MMC's began in the mid-sixties of the XX century and were executed by Prof. P. Pohatgi in Suffern, New York (USA) [4]. Early experiments in this area were focused on the creation of composites of systems Al-graphite, Al-SiC and Al₂O₃ by mechanical stirring of reinforcing particles in matrix aluminum melt. Subsequently this method of MMC's production has been adopted by many foreign companies, and repeatedly improved and modified. American company Alcan Aluminium Ltd. one of the first started developments of MMC's manufacturing in industrial scale. Examples of production are composites based on aluminum matrix reinforced with SiC particles with sizes of 3..40 microns. Pioneers in industrial development of aluminum matrix composites are also known companies Duralcan and Alcoa.

Currently the most intensively studied and applied in industry methods of MMC's production are liquid phase methods based on the input of reinforcing particles in the matrix melt (exogenous reinforcing methods) or on formation of endogenous reinforcing phases directly in the melt due to flowing of controlled exothermic reactions between reactionary active components of initial composite mixes (endogenous reinforcing methods). The main problem in case of liquid-phase consolidation of matrix alloy with reinforcement is problem of physical and chemical compatibility of matrix and reinforcing phase with optimal level of interphase interaction. A crucial role is played by the phenomenon of high-temperature wettability, adhesion and contact interaction, defining behavior of interphase boundaries and strength of adhesive contacts in manufactured products, and as a result the quality and operational properties of composite alloys [7].

For producing of castings from MMC's uses such methods of casting as gravity-die casting, pressure-die casting, liquid metal forging and centrifugal casting. Technologies of gravitational moulding are usually used for composites containing less than 15 vol.% of dispersed phase. Since MMC's have higher viscosity in comparison with traditional alloys, in many cases it is preferable using of forced moulding. It should also be noted that application of pressure at producing of composite alloy castings allows to practically eliminating of porosity which inevitably arises at producing of MMC's by exogenous reinforcing methods.

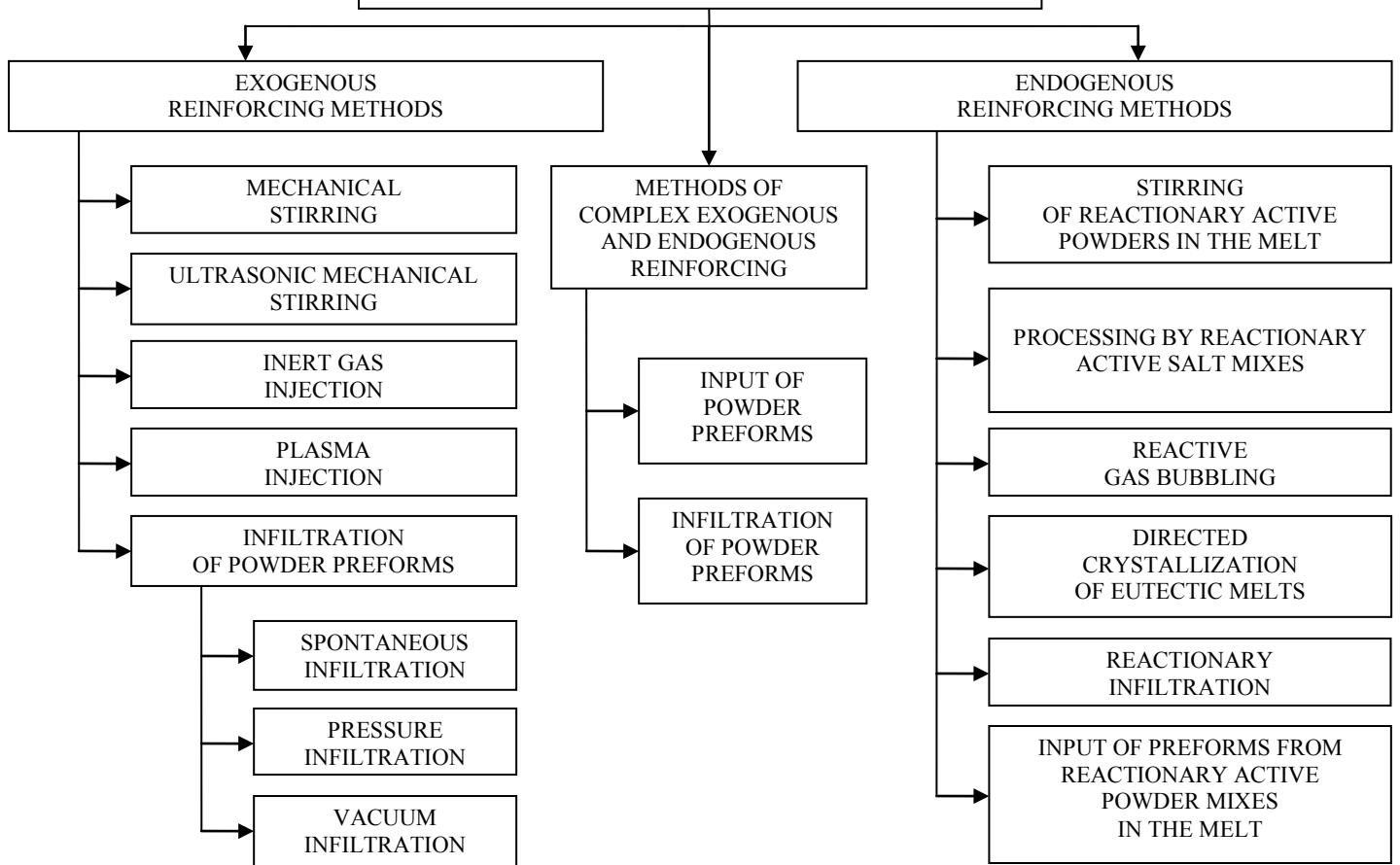


Fig. 1. Classification of liquid-phase methods of MMC's production

2.1. Exogenous reinforcing methods

Methods of exogenous reinforcing (Fig. 1) provide input of prepared reinforcing particles in matrix melt and include mechanical stirring, ultrasonic stirring, inert gas injection, plasma injection and infiltration of powder preforms. Method of mechanical stirring of discrete high-melting particles in liquid metal is now the most widely used due to its simplicity and universality. Units for this process include the crucible with the matrix melt, set in the oven, and a mechanical activator for melt mixing. Reinforcing particles are introduced by backfilling on rotating impeller blades. After preparing the slurry it is poured into the mold [8]. Stirring of composite alloy for uniform distribution of particles can be carried out not only by the impeller, but also by means of exposure of ultrasound on the melt [9]. In [10] noted that in the ultrasound field observed wetting of ceramic particles not-wettable under normal conditions.

There are various modifications of this method: mechanical stirring of insoluble particles in the melt by using of a gas or plasma jet using the plasma torch injection [11, 12]. However, the mechanical stirring method has some significant drawbacks: oxidation and gassing of matrix alloy during active mixing (as a consequence, increased porosity of composite castings), coagulation of reinforcement, low adhesive bond at the interface between the matrix and reinforcement, the need for special equipment. From the viewpoint of thermodynamics composite alloys obtained by this method are far from equilibrium, in which may be intense reactions between the reinforcing components and the matrix alloy, leading to degradation of the reinforcing phase and to formation of undesired products of such interaction. Furthermore, it is difficult to ensure continuous and full contact of matrix and reinforcing phase, the optimal level of interfacial interaction, which is often caused to poor mechanical and operational properties of the material.

2.2. Endogenous reinforcing methods

Other direction in manufacturing of composite alloys are methods of liquid-phase reactionary synthesis (in-situ-process) when new endogenous reinforcing phases formed as a result of controlled exothermic reactions between initial components directly at the stage of alloys production or at during subsequent thermal or thermomechanical processing, providing reinforcing through the precipitation (crystallization) of new phases from the amorphous state or a supersaturated solid solutions. The composites obtained in such processes have a maximum level at the interface boundaries due to small lattice mismatch of the contacting phases, thermal stability, better distribution and dispersion of reinforcement, which ultimately provides a high mechanical and performance properties. Size of the new phases can be adjusted by selecting of the combination of components participating in the in-situ-reactions, and also their form and volume content. It is no need for special equipment, which greatly simplifies and reduces the cost of technology of MMC's production [13].

Liquid-phase reactionary synthesis can be carried out by the following ways:

- mechanical stirring of reactionary active powders, interacting with the matrix melt to form a new reinforcing phases;
- infiltration of preform (preheated and placed in a crucible) by matrix melt;
- bubbling of matrix melt by active gas;
- mixing in the melt of salt mixes containing a reactionary active components;
- directed crystallization of eutectic melts;
- input of preforms containing reactionary active components in the matrix melt.

Considerable practical interest is represented by technology of MMC's production in which reinforcing of a matrix is carried out due to input of the preforms consisting of reinforcing components. This technology allows excluding the active mechanical stirring of the melt, thereby reducing its gas-saturation and oxidation. In addition, this technology allows to enter into a matrix high-dispersible (including nanosized) reinforcing components which can't be entered by mechanical stirring.

2.3. New approaches to realization of reinforcing scheme

Distinctive features of interaction of phases at flowing of processes of liquid-phase high-temperature synthesis provide opportunity for realization of new conceptual approaches to realization of scheme of the reinforcing, based on combination of endogenous and exogenous reinforcing of a matrix alloy with particles of various nature and sizes. The composites produced in these processes have two levels of reinforcing of a matrix, i.e. contain the endogenous reinforcing phases which are forming at flowing of in-situ reactions in matrix melt, and exogenous reinforcing phases, conditions for wetting and assimilation of which are created at flowing of exothermic reactions of synthesis of endogenous phases.

According to the offered scheme of reinforcing compositions and technology of production of complex reinforced aluminum matrix composite alloys of system [Al]-TiO₂-B(C)-Ti-SiC are developed. The liquid-phase technology of complex-reinforced MMC's production is based on input in a matrix melt of the pressed preforms consisting of reactionary active components [14]. For formation in volume of a matrix alloy of endogenous phases as the initial components powders of aluminum, dioxide of titanium, the amorphous boron, graphitized coesic and titanium as in case of their interaction with each other and with a matrix aluminum melt pass the intensive exothermic reactions leading to formation of the new endogenous reinforcing and modifying phases TiB₂, TiC, Al₂O₃, Al₃X, AlX, AlX₃ (where X – Ti, Zr, V, Fe, Ni) are used. Additional regulation of physic-mechanical and operational properties of a composite alloy over a wide range can be carried out by adding in composition of the initial powder preform of exogenous ceramic particles.

Conducted researches of properties and characteristics of new complex reinforced MMC's shows that the hardness of composite alloy increases by 35-40% at a normal temperature and to 30% at an increased temperature, the friction coefficient decreases by 5-7 times, and the wear resistance increases at 10-12 times in comparison with a matrix alloy [15].

Technology of production of developed complex-reinforced MMC's implemented at foundry plant "Litmash, LLC" (Shuya, Ivanovo region) at manufacturing of castings for tribotechnical purposes [16].

3. Conclusion

Complex approach to creation of MMC's based on reinforcing of a matrix alloy with endogenous and exogenous phases of different nature and the sizes significantly expands opportunities for purposeful achievement and regulation of properties of composite alloys. The received results convincingly testify that developed MMC's can be offered as effective changeover of traditional alloys in high-loaded friction units of different technological equipment and transport.

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THEORY AND TECHNOLOGY OF LIQUATION REFINING OF MAGNESIUM MELTS

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Abstract: The characteristics of types of process of liquation refining of metal melts from impurity elements is given. Efficiency of extraction-crystallization-liquation refining (ECL-process) of magnesium melts with use of additive elements is shown. The results of experimental studies on the refining of magnesium from metal impurities using additives Ti, Zr and Mn are in good agreement with the calculated data. The highest efficiency of ECL-process of refining is achieved when cleaning of magnesium from impurities of iron by titanium additives.

KEYWORDS: LIQUATION REFINING, MAGNESIUM MELTS, REFINING ADDITIVES, IMPURITY ELEMENTS

1. Introduction

Modern physical and physico-chemical methods of refining of metal melts are characterized by their efficiency, level of development and application extent.

The most simple, economical and implemented on a large industrial scale method is a liquation refining of melts from impurity elements, which based on the separation of components of heterogeneous metal systems with phases significantly different in physico-chemical properties.

2. Preconditions and means for resolving the problem

Liquation processes of refining of melts from metal impurities, gases and non-metallic inclusion, depending on a character of interaction between impurity elements and refined metal, can be classified as shown in Fig. 1.

Brief description of types of melts refining processes and its relationship with the phase diagram is given below.

Liquation refining (L-process) is based on changes of the solubility of impurities during cooling of the melt and separation of formed phases by density. L-process is a two stage process:

- formation of a heterogeneous system with two liquid phases (L_1, L_2) from a homogenous liquid melt (L), i.e. $L \rightarrow L_1 + L_2$;

- separation of formed liquid phases of heterogeneous system followed by formation of two isolated products.

Mechanism of liquation refining process consist of an idea that on cooling at first a new liquid phase as stable drops is formed in the old one. Then the two phases are separated because of the difference in density. The temperature range for the L-process lies in the area of phase separation but the most preferable temperature is a little bit higher than that of the monotectic transformation [1-3].

Examples of L-process are real systems (Pb – Cu, Zn – Pb).

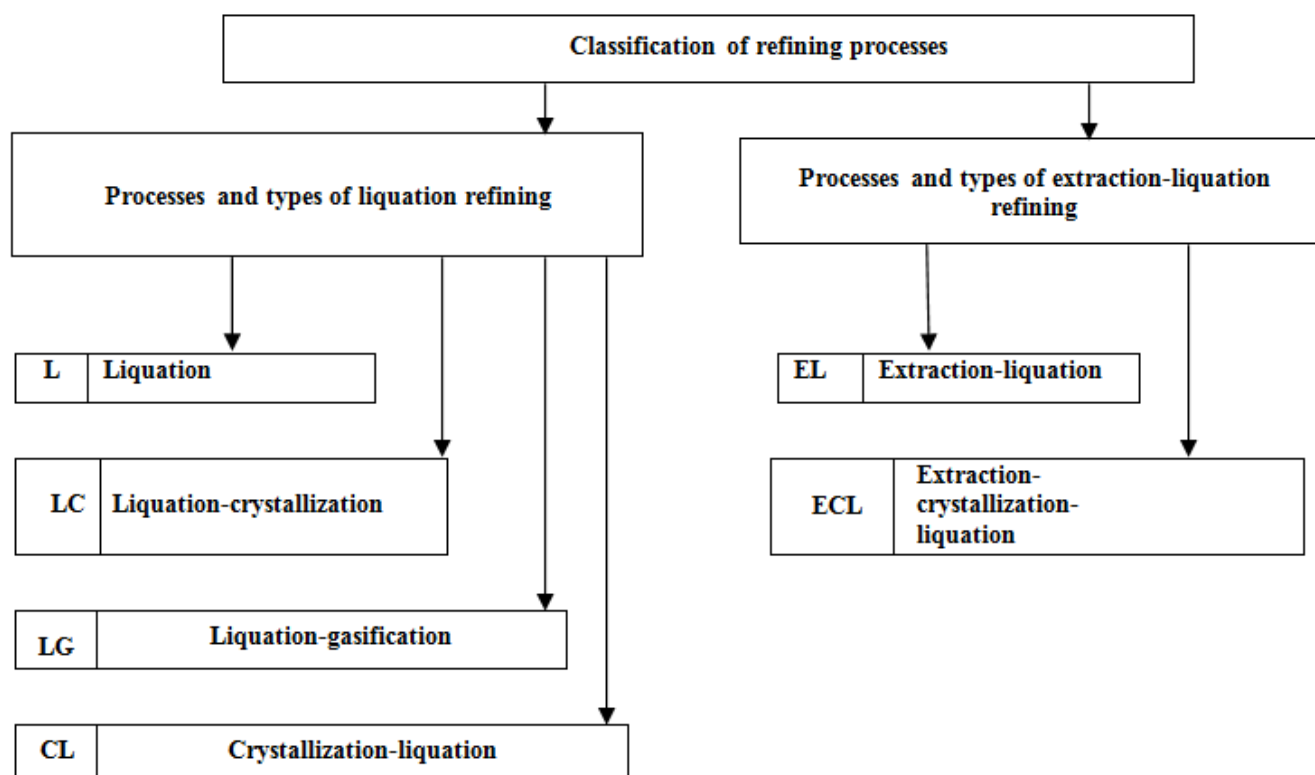


Fig. 1. Classification of liquation refining methods

Liquation-crystallization refining (LC-process) is based on changes in the solubility of impurities followed by formation of a solid crystal phase with a constant or variable composition. LC-process consist of two stages:

- formation of a heterogeneous system from a homogenous one (L) with a liquid (L_1) and solid (S) phases, i.e. $L \rightarrow L_1 + S$;
- phase separation of heterogeneous system followed by formation of two isolated products.

At full solubility of the system components in the liquid and solid state the area of the process possibility is defined by the liquidus and solidus temperature intervals. The temperature being close to the solidus temperature is preferable for the LC-process. Examples of LC-process are real systems (Al-Si; Al-Fe; Mg-Mn; Zn-Fe) [1, 3 - 5].

Liquation-gasification refining (LG-process) is going on in the melts with temperature decreasing due to the formation of a gaseous phase presented by hydrogen bubbles that form with metals endothermic introduction solid solutions. Formation of gas bubbles in the metal melts at cooling is linked with changes in the hydrogen solubility, that is the LG-process is going on with the further liquation – the separation of melts into gaseous and liquid phases. It seems that LG-process is also a two stage process:

- formation a heterogeneous system with one liquid (L_1) and another gaseous (G) phases from a homogeneous melt (L), i.e. $L \rightarrow L_1 + G$;
- separation of the gaseous and liquid phases formed in the heterogeneous system.

So, the mechanism of the LG-process can be described as follows. At first stable gaseous bubbles are formed in the melt and only after that the separation happens due to the distinction in density. By slowly cooling down to the melting point and further intensive heating to the moulding temperature the most hydrogen might be eliminated from the melt. In practice this method is known as degasification by “melt freezing”. Examples of LG-process are real systems Al- H_2 , Mg- H_2 , Cu- H_2 [2, 6, 7].

Crystallization-liquation refining (CL-process) is based on the separation of system components by addition of a third component. This additive should have a higher chemical affinity to the impurity than affinity of impurity to the base metal. The additive is fed in such amounts so as to provide the formation of a solid solution based on a metal-solvent and possibly a full capturing of the impurity through the formation of intermetallic compounds at a temperature slightly higher than the melting point of the main metal. The CL-process can be illustrated with the refining of liquid lead, performed by addition of some amount of sulfur. The sulfur having a higher chemical affinity to copper than to the lead forms high-melting and low soluble compounds Cu_2S that come to the surface, being separated from the melt of lead [1, 3, 4].

Extraction-liquation refining (EL-process) is based on the selective extraction of impurity (B) from a solution (A) by extraction agent (E). It is considered that the extraction agent serves for dilution, not being dissolved in the initial solution. For this case (according to the solution theory) it is true a ratio: $(C_B)_A : (C_B)_E = K$, where $(C_B)_A$ – concentration of the impurity (B) in the solution (A) after extraction: $(C_B)_E$ – concentration of the impurity (B) in the extraction agent, i.e. in the solvent (E); K – distribution coefficient.

It is important for the EL-process that the dissolving agent should be in the liquid state. Refining on this type ends with a separation of the products forming during the liquid extraction ($L \rightarrow L_1 + L_2$).

The zinc and magnesium methods of aluminum refining from iron can serve as examples of the EL-process [4, 8].

Extraction-crystallization-liquation refining (ECL-process) occurs in the systems in which the dissolved impurity is extracted from a liquid (metallic) phase into a solid phase by addition of extracting reagent forming with the impurity a solid solution or chemical compounds of a stable or variable composition. Probably, such extraction can be called as the liquid-solid extraction unlike just the liquid extraction [9].

The method of refining by ECL-process is based on assessment of chemical affinity of impurity elements to some metals that form insoluble or difficulty soluble products settling to the bottom of crucible.



A – refined metal,

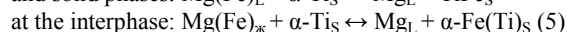
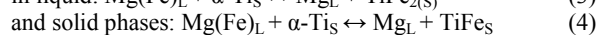
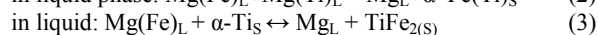
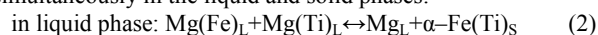
B – impurity,

C – refining additive,

$C_n B_m$ – products of interaction.

Example of refining by ECL-process is cleaning of magnesium melts from metal impurities with use of extracting additives [10-11].

Mechanism of refining of magnesium from iron by ECL-process can be represented by the following reactions occurring simultaneously in the liquid and solid phases:



the promotion of reaction processing from (2) to (5) can be provided by increasing the amount of added titanium.

The calculated parameters on magnesium refining from metal impurities by means of Ti, Zr and Mn additives were confirmed by experimental results (Fig. 2). The efficiency of magnesium refining was estimated by a refining coefficient, $K = (C_b - C_a) / C_b \cdot 100\%$

K – refining coefficient, %

C_b – impurity content before refining, %

C_a – impurity content after refining, %

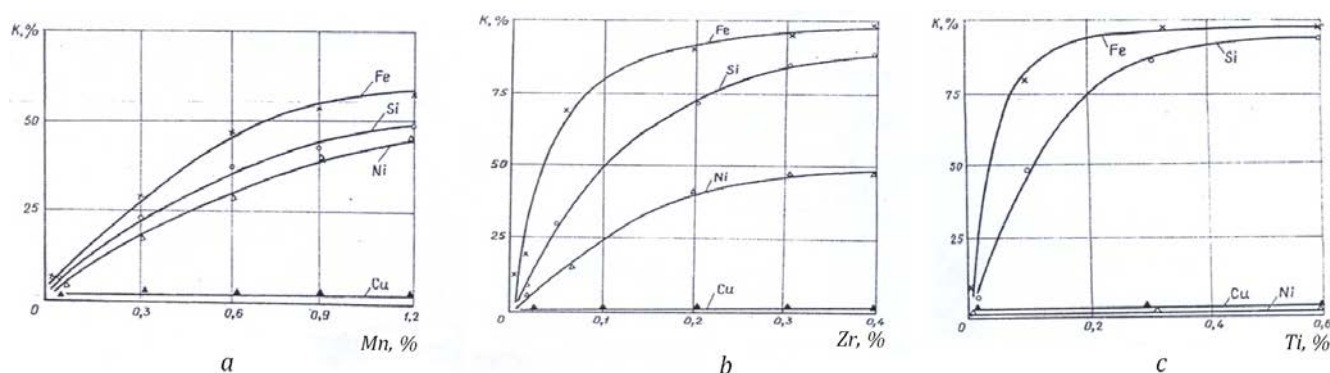


Fig. 2. Effect of manganese (a), zirconium (b) and titanium (c) on the refining coefficient of magnesium from impurities

Analysis of the results suggests the possibility of refining of magnesium from individual impurity elements (Fig. 2). Here titanium is considered as the best refining additive.

Additional experiments allowed establishing the optimal dosage of titanium additive to provide deep magnesium refining from iron impurities (Fig. 3).

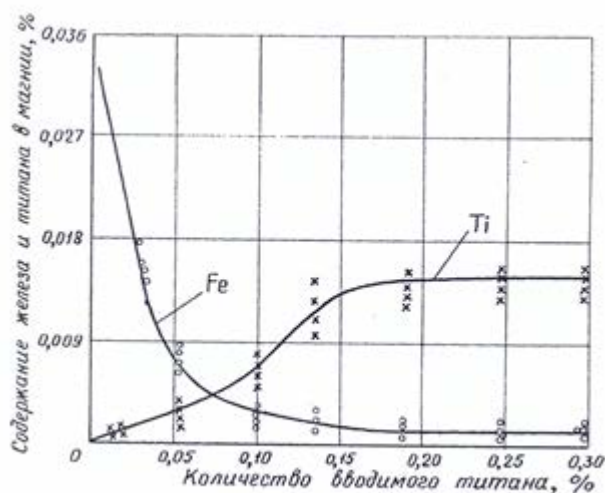


Fig. 3. Changes in iron (1) and titanium (2) content depending on titanium dosage.

3. Conclusion

1. It is suggested a classification of liquation processes for magnesium refining from impurities that allows establishing the type of a refining process and its efficiency on the basis of elements interaction at given temperatures.

2. The characteristics of types of processes of liquation (L, LC, LG and CL) and extraction-liquation (EL, ECL) refining of metal melts is given.

3. Experimentally confirmed the high efficiency of ECL-process for refining of magnesium from metal impurities using additives of titanium, zirconium and manganese.

4. The technology of production of magnesium with content of iron to 0,004% with use of titanium as the refining additive.

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CAST COMPOSITE ALLOYS BASED ON ALUMINUM: TECHNOLOGY, PROPERTIES, APPLICATION

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Abstract: General problems, which restrict wide application of aluminum matrix composite alloys (AMCA) in production sector, are discussed. Possible ways of solving the problem are recommended: using of inexpensive fillers, secondary matrix alloys; development of new methods of complex reinforcing of matrix (*in-situ* u *ex-situ*); development and updating of technological decisions about multipurpose processing of aluminum matrix composite alloys; coordination and consolidation of scientific-technical potential of scientists and engineers of Scientific-Research Institutes (SRI), Institutions of Higher Education and enterprises on the field of development and research of aluminum matrix composite alloys.

KEYWORDS: ALUMINUM MATRIX COMPOSITE ALLOYS, LIQUID PHASE METHODS

1. Introduction

Modern tendencies of development of machine-building complex are inextricably linked with development and wide use of new highly-effective materials and new technologies of their obtaining. New materials should provide increased demands of techniques of strength, minimum of weight, increased reliability of the resource, durability of exploitation of details and structural components in extreme conditions of temperature-strength impact and aggressive surrounding [1]. Composite materials are most fully specified for this. That's why, last decades are characterized by constantly increasing interest in virtually all industrialized countries of the world to cast a discrete-reinforced composite alloys based on aluminum.

2. General Problems, which Restrict the Use of Aluminum Matrix Composite Alloys

Aluminum matrix composite alloys are perspective for widespread use in friction units of processing equipment, automotive, road construction equipment, and other areas instead of copper alloys or aluminum alloys antifriction. A pioneer in terms of industrial development of aluminum matrix composite alloys, reinforced by dispersed SiC particles and Al_2O_3 , are well-known foreign companies DURALCAN, ALCAN and ALCOA.

However, it should be noted that the growth of the industrial use of aluminum matrix composite alloys is not yet adequate to technical and operational capabilities of these new materials. This is due to a number of objective and subjective reasons. One of the main reasons is the absence to the present moment of universal theory and practical suggestions, which help to predict guarantee choose the composition of ingredients of AMCA purposefully adjust the necessary degree of interfacial interaction and create the necessary framework to implement a given level of physical and mechanical properties and performance of products from AMCA available at their value.

It is well known that artificially synthesized AMCA have a higher cost when compared with conventional aluminum alloys, due to the relatively high cost of the reinforcing components and more complex production process of products from AMCA. Therefore, technical and economic factors are often a barrier to widespread use of the AMCA in mass industries. However, in most cases, the use of AMCA is not only advisable, but sometimes you just do not have alternatives, due to the unique operating characteristics, higher reliability and durability of their work in extreme conditions.

According to general opinion of experts, the further development of the application of the competitive AMCA today requires large-scale systematic studies and pilot projects in the following groups of problematic issues: the initial charge materials, production processes, technological aspects associated with the

complex treatment, including recycling; fundamental and applied research and development [1, 2].

3. Possible Solutions

3.1. Using Inexpensive Fillers and Secondary Matrix Alloys

As the high cost of most artificially synthesized reinforcing fillers, their scarcity make a negative contribution to the cost of AMCA, the first group of questions put forward the task of creating new economic game using as reinforcing fillers powders and fibers of cheap mineral - mullite, basalt, schungite, aluminosilicates and others, as well as matrix alloys – secondary raw materials, including scrap and chip wastes.

An example of a successful resolution of questions of the first group of problematic issues is the development of perspective AMCA by Physical-Technological Institute of Metals and Alloys of National Academy of Science of Ukraine, which are reinforced by relatively cheap and non-deficient nature of the oxide non-metallic particles (cupola slag, waste and fireclay stoneware productions) [3].

Using AMCA as the matrix alloys rejects and low grade aluminum alloy requires the development of new highly refining methods, providing virtually complete absence of gas products and salt component of flux, because, otherwise, the absorption and uniform distribution of reinforcing components in the liquid phase becomes consolidation problematic. For this purpose, in the technology of refining VSU proposed new combined fluxes, where the main refining agent (up to 80-96%) are used dispersed particles of refractory oxides of aluminum and silicon[4].

These options will provide additional technical and economic benefits through more efficient recycling of aluminum alloys and non-metallic materials.

3.2. Complex Reinforcing of Matrix (*in-situ* u *ex-situ*)

Technological processes for the production of products from AMCA in industrial scale must perform the following basic tasks: provide given the physical and mechanical properties and performance of AMCA, to ensure the stability of product quality in terms of production.

Analysis of current scientific and technical information shows that currently the most intensively studied and applied in industry liquid phase methods for the AMCA. Various methods for combining a liquid phase of the matrix alloy with dispersed hardening phase impregnation melts (spontaneous in vacuo under pressure, combined) conglomerate fiber preforms (Pramex-process) or particles (Squeeze Casting Method); mechanical kneading of discrete particles or fibers in a metal melts (Compocasting Method);

Dimox-process allowing to obtain ceramic matrix composites by direct oxidation of the metal directly in the mold; processes based on the flow of controlled chemical reactions, high-temperature synthesis of endogenous strengthening phases in the matrix alloy (in-situ- process) and etc.

Of these modes of production of AMCA most technologically advanced and cheaper is the cast with a mechanical kneading the filler in the matrix melt. To improve wetting of the particles by the coating process is applied by chemical vapor deposition or the matrix or modify the surfactant additive (Mg, Ca, Li, Na, etc.). Technologically significant parameters is the design and installation of technological modes of mixing. However, this method of introducing the reinforcing phases in the molten matrix, and has a number of drawbacks: fairly strong gassing and oxidation of the melt during the mechanical mixing of the active and, as a consequence of insufficient quality adhesive bonds at the interface of the particle-matrix.

Structure refinement of the matrix alloy, increasing the density, providing a more uniform or a given distribution of particles in the volume of reinforcing, strengthening the adhesive interaction of particles with the matrix can be achieved through the use of external influences: pressure, ultrasound and centrifugal forces, electromagnetic fields and other technological methods.

The most perspective of manufacturing isotropic AMCA embodiments provide methods of synthesis or reaction molding (so-called in-situ process) when endogenous reinforcing fillers including nano-sized, formed as a result of controlled exothermic reactions between the starting components in the manufacture of directly AMCA [5]. AMCA obtained in such processes have a maximum level of bonds at the interface "filler - matrix" due to the small lattice mismatch contacting phases, thermal stability, better distribution and higher dispersion of the filler, which provides higher mechanical and performance properties.

Moreover, the exothermic reactions occurring in the melt in the synthesis of new endogenous phase of hardening, can improve the wetting of the matrix melts introduced exogenous addition of ceramic fillers, including nanoscale. Polireinforcing of matrix by endogenous and exogenous fillers of different nature and size opens another large reserves in the purposeful regulation given the physical and mechanical properties and performance of AMCA. [6]

With increasing concentration of reinforcing fillers in AMCA isotropic process and deteriorated mechanical properties and machinability pressure, the fluidity of the composition and the properties of the plastic material. In connection with this, a promising direction is the use of centrifugal casting methods for anisotropic functionally graded or reinforced composite materials [7].

Currently industrial synthesis technology products from AMCA are still under development or mining and industrial development. Such a state is partly due to the fact that technology is usually contain a know-how" and constitutes a commercial secret.

Further improvement of technologies for the production of game requires time and investment, and will be the accumulation of experience in the production and application of game based on fundamental metallographic studies.

3.3. Multipurpose Processing of AMCA

Another important area of research to expand the use of AMCA in real product engineering is the development and improvement of technological solutions for multipurpose processing of AMCA - thermal, thermal cycling and thermoplastic, mechanical, laser, fusion welding and surfacing etc.

Important area of work for the implementation of AMCA in production is to find the most efficient methods of machining of AMCA. Unfortunately, it must be noted that this issue is now being given very little attention.

Successful application of AMCA in the construction engineering and transport is often constrained by difficulties resulting from their specific connection between themselves or with alloys that do not contain reinforcing fillers. AMCA welds having

physico-chemical characteristics similar to the starting material can be obtained, provided the minimum degradation properties of the components of AMCA, preservation of code reinforcement volume fraction and distribution of reinforcing filler in the weld zone. In this connection, preference is given to the solid-phase welding methods of AMCA (diffusion, friction). However, is known positive experience making permanent connections fusion welding methods, which opens up prospects for expanding the range of welded structures of AMCA. Recently, much attention is given to developing ways surfacing composite layers with special properties. Surfacing of such layers can be one of the main ways to obtain functional gradient materials.

In the manufacture of products from AMCA are inevitably formed rejects defect of castings, gates, profits, bursts, and other exhaust components, so overall techno-economic balance of production and operation of game are important questions of recycling or recovery of products for reuse.

Choosing an effective method of processing depends on the composition and properties of AMCA reinforcing components.

For AMCA reinforced ceramic and thermally stable intermetallic phases can be applied to a limited extent the traditional method of refining, while keeping in mind that the 3-fold remelting of composite alloys can lead to significant degradation of the reinforcing phase and reduction properties of the composite. This brings up the problem of regeneration game in order to fully remove the reinforcing phase. This problem can be effectively solved with the use of new conceptual approaches that are based on the fact that the reinforcing phase performs refined function by adsorbing impurities themselves. [4]

AMCA reinforced by particles of metal-carbide TiC, ZrC, and borides TiB₂ and intermetallic TiAl₃, can be used as effective ligatures for modifying aluminum alloys.

Recovery of products from AMCA to the required dimensions can be accomplished by welding.

3.4. Coordination and Consolidation in Researching and Development of AMCA

Significant scientific contribution to the development of theory and practical use of AMCA are works of Gavrilin I.V. (Vladimir State University), Aksyonov A.A. (Moscow Institute of Steel and Alloys), Scheretsky A.A. (Physical-Technological Institute of Metals and Alloys, Ukraine), Chernyshova T.A. (Institute of Metallurgy and Metal Science named after A.A. Baykov, Russian Academy of Sciences) etc.

Obviously, the further development of the theory and practice of composite molding is impossible without a coordinated research, the effectiveness of which is greatly enhanced when the consolidation of scientific and technical potential of scientists and engineers of scientific research institutes, universities and businesses. An example of this fruitful scientific and technical cooperation is the long-standing successful joint activities of Vladimir State University and Institute of Metallurgy and Metal Science named after A.A. Baykov of the Russian Academy of Science. Combined efforts of research teams of these organizations conducted a large set of scientific studies on the interaction of metal matrix with reinforcing fillers, the choice of composition and manufacturing technology discretely reinforced AMCA, study tribological properties and physical mechanisms of wear, industrial testing and implementation of AMCA in friction industrial equipment and transport.

AMCA are relatively new functional materials and all their advantages, features and maximum operational capability not defined yet. Although today we can safely say that AMCA have significant advantages as wear-resistant tribological materials.

Reliability of work of AMCA in friction units of different kinds of technics proved by years of industrial testing and implementation in many enterprises. Small-scale production of castings and parts from AMCA on the orders of enterprises established on the base of

scientific-production enterprise "Aluminum Matrix Composite Materials" (Vladimir, Russian Federation).

4. **Conclusion**

Currently, in the field of composite materials science, development of efficient industrial technologies of production and application of AMCA working and have recognized achievements leading companies and research organizations of practically all developed and developing countries, including the U.S., UK, Germany, Japan, China, Russia, Ukraine etc.

Above are formulated only the most basic problems from solutions of which largely depend prospects and temps of implementation of discrete-reinforced AMCA in industrial production, as well as variation among consumers in a better way trust to AMCA, strengthening of motivation for their wider application in industry.

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INFLUENCE OF MECHANICAL ACTIVATION OF QUARTZ SAND ON PHYSICAL AND MECHANICAL PROPERTIES OF FOUNDRY MIXTURES BY THE METHOD „NO BAKE”

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Abstract: At the contemporary conditions of cast production there has been a permanent interest in economically more profitable technologies for obtaining moulds and cores of controlled properties. A part of this interest is related to quartz sands as a basic and the most common component in the practice of foundry mixture productions. State of sand surface and its influence in formation of foundry mould and core physico-chemical properties are of particular importance.

In this report, various conditions of mechanical activation on the surface of quartz sand in “a fluidized bed” are discussed. The theory of such activation necessity has been partly explained. The “time” factor in preserving the activated layer potential is noticed. The efficiency of the activated layer in producing foundry mixtures strength by the method “No Bake is shown..

KEYWORDS: CASTING, QUARTZ SAND, MECHANICAL ACTIVATION, PHYSICAL AND MECHANICAL PROPERTIES

1. Introduction

In relation to improving the properties of foundry mixtures, special attention has been paid to the modern conditions of production. The mixture itself could be regarded as a dispersive system which is composed of solid non-metal particles (in our case quartz particles) wrapped up by a thin layer of binders. According to the second law of thermodynamics, foundry mixtures would have an optimum structure if they were in state of balance. Therefore, conditions have been created still at the time of homogenization where in the process of mixing two basic tasks are resolved – attaining a necessary homogeneity and maximum strength at limitation of other properties.

The mixture structure is formed at the expense of some physico-chemical processes taking place at the border: quartz sand (solid) – binding composition (liquid system).

2. Presentation of the problem and ways to resolve

The modern binders, based on the use of organic resins, hardened in various kinds of liquid hardening agents, can roughly be classified into “No Bake” systems.

Strength formation is explained with an increase of the binder's molecular mass through linking many oligomer resin molecules when hardening in larger polymeric ones. Simultaneously with that “formation of adhesive strength”, it begins processes of adhesion with the surface of sand particle, i.e. “creating adhesive strength” (AS).

Finally, the strength of mixtures is an entirety of two simultaneously performed processes at setting – formation of an adhesion link between quartz sand and the binding composition and cohesive strengthening of the composition itself. The difference between them is too great and according to some opinions [1,2] it reaches up to 15-20 times in favour of the cohesive strength.

The issues of growth of furan resin adhesion to quartz sands are exceptionally important for the practice. Even a minimum raise in (AS) would result in decrease of binding composition content in mixtures, improvement in conditions at the border layer: “metal-form” and workplace environment.

The microrheological processes at the joint surface have a great effect upon the value of adhesion to quartz sand. These also are the beginning of the (AS) formation, and are determined by different factors as relief, surface cleanness etc.

Quartz sand surface is characterized by multiple of unevennesses defining the roughness. The unevenness reaches dozens to hundreds of angstroms. It is known that AS is increased when the degree of roughness and angularness raise [3].

Quartz sands are typical with the presence of great amount of “deaf pores” which is observed in most real pore bodies. In these cases, the front of binding composition entry is hindered by the presence of these pores or other products of sufficient penetrating ability that finally lead to AS reduction.

Different “activation” methods on the contact surface in order to control the mixture properties through governing the state of the limiting unit have been known. One of those methods is the performance of mechanical activation (rubbing through of quartz sand particles – either each other or on a separate surface) on the filler surface – quartz sand in the case.

The task assigned in the present job is to determine the rate of influence of the mechanical activation method on physico-mechanical properties, and particularly on AS in foundry mixtures.

3. Decision on the investigated problem

The quartz sands PK, UKSS1, and KLP of different nature and morphology (Fig.1, 2, 3) from Kaolin AD, in amounts of 2.0 kg. +/- 0.001 kg.) are put in a laboratory unit (“fluidized bed”). Sands are of homogeneity over 90%, grain size 0.25 mm.

Intensity of processing sand surface, tuned by change in the process duration, at flow = const., was chosen as an influence factor.

Following activation, mixtures were produced in a vibrating mixer, type STATORMIX 22 of Klem with automated dosing of constant amount and ratio of the same type components. The binding system (resin + hardener) was Huttenes – Albertus.

Test bodies were obtained with the help of a laboratory press with cylindrical specimens of sizes $\Phi=50$ mm. and $H=50$ mm., and for beams with $A \times B \times L = 24.5 \times 24.5 \times 172.5$ mm, respectively.

Adhesive strength is determined at tensile under the method [4].

The activation process is composed of continuous rubbing between particles at normal environment temperature.

Mixtures' physico-chemical properties (strength of pressure, erosion resistance and gas permeability based on test bodies) are measured with the help of respective laboratory testers LRu and LfR1 on IO PI.

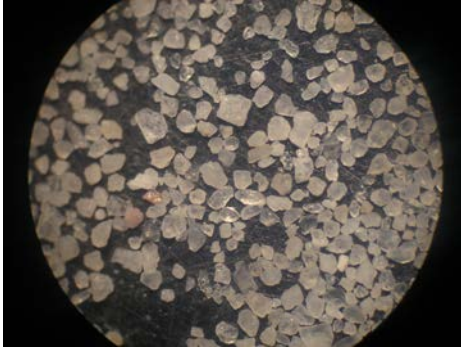


Fig. 1. Sand 01PK025

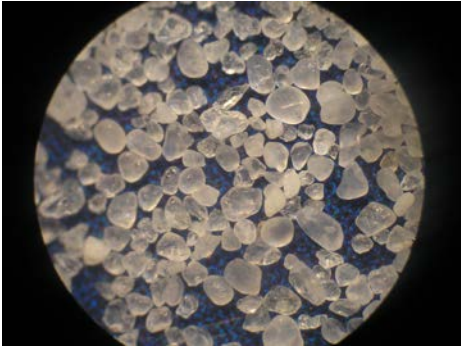


Fig.2 Sand UKSS 1

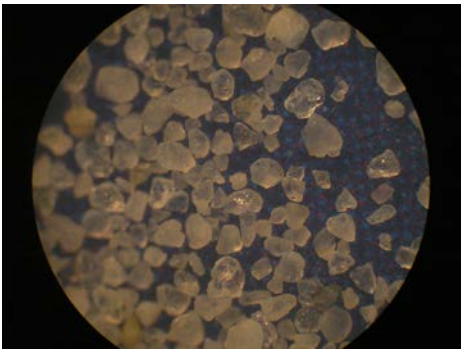


Fig.3 Sand KLP026

4. Results from the discussion

The results from pressure strength tests on test bodies (Fig.4) with sand 01PK025, at various duration of processing, show an increase in strength, as a whole. Thus, for example, in the first 0.5÷1.0 hours when a “manipulating strength” is created, strength values raise by 30 to over 70% at different times of processing. That difference is kept until the fourth hour is reached. After 24 hours, differences in strength of processed and unprocessed sand reduce down to 15÷20%.

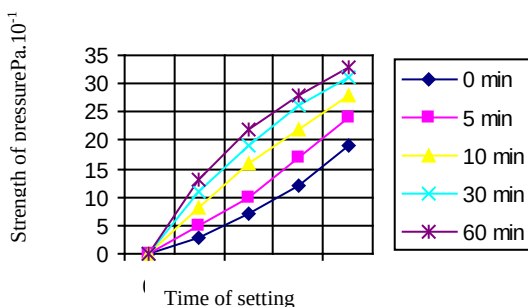


Fig. 4 Strength of pressure at different times of activation, in min. for a mixture with sand 01PK025

In the process of influence on sand surface, at conditions of “fluidized bed”, at rubbing through, in addition to the increased agility of the atomic layer, from the surface itself it is detached contamination particles, stuck harmful oxides as well as adsorbed different gases and air, especially in sectors of microscopic cracks and unevenness. This is visually shown in sands of different origin and nature. For this purpose, three kinds of sand were selected: 01PK025, KLP026 и UKSS 1, differing in this case by the degree of morphology and state of surface [5].

In Fig 5, it is shown strength test data at constant parameters and processing conditions in different selected sands

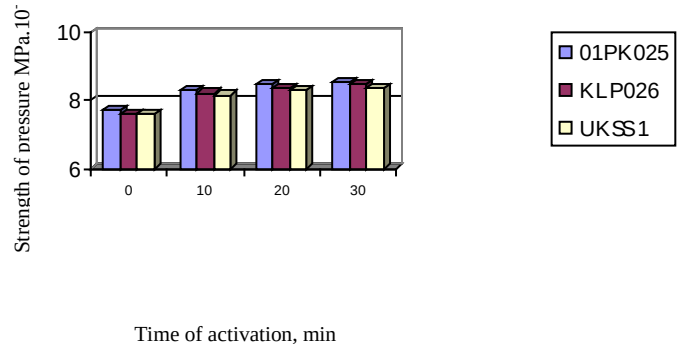


Fig.5. Strength of mixtures, in MPa from sands 01PK025, KLP026 и UKSS 1 depending on time of activation at setting time 1 hour

It is evident that strength is most intensively increased during the first 5 to 10 minutes of activation with gradual attenuation over the time. Morphology degree of these sands varies from $K_M=0.82$ for 01PK025 to $K_M=0.96$ for UKSS 1.

The first sand strength is higher mainly because in a better morphology the number and area of the contact points between particles is less in comparison to sands of worse morphology like 01PK025. The presence of cracks and unevennesses at 01PK025 is greater [5] compared to KLP026 и UKSS 1, which additionally creates conditions of improved adhesion contact. Adhesive strength measurement data [4,6,7] confirms the given explanations. In the figure, the results coming from strength change values show an increase by 10÷15% for the first hour from the start of setting, and almost equal dynamics change for the three kinds of sand for the strength ratio change among them.

Another essential technological characteristic of state of the shape hardened is the erosion resistance. It is measured by the so called “surface strength”, and is directly dependant with the conditions of formation of strong bond in the contact surface between the sand grain and the binding composition. The level of this stability is directly related to the geometrical accuracy and quality of the cast.

Measurement is most often performed gravimetrically by determining the loss of weight of a cylindrical specimen of $\Phi=50$ mm. and $H=50$ mm. when rolling on an abrasive surface.

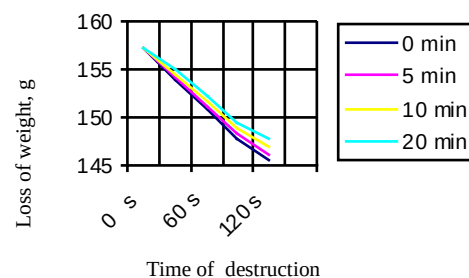


Fig.6. Erosion resistance of a mixture with sand 01PK025 at different times of activation.

The test data is shown in Fig.6. It is evident that the erosion resistance is increased with a raise of processing time through activation of quartz sand surface, and within the set limits of tests the difference reached 6÷8%.

One very important operation parameter is the gas permeability in a mould. The requirements for it are very high due to the direct relationship to the mould quality, use of accessory materials and additional measures.

The test results given in Fig. 7 show that with increase of activation time on the surface of the tested sands, gas permeability is elevated by 4÷6% at KLP026. At 01PK025, increase is by 3÷4%, and the greatest is at UKSS1 - 7÷10%.

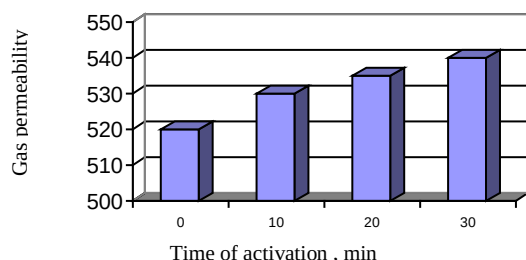


Fig.7 Gas permeability, ($\times 10^{-8} \text{ m}^2/\text{Paxs}$) of a mixture with sand KLP026 after 24 hours at different time of activation

It is worth noting that one of the parameters being recently seriously addressed is gassing. It is logical that when taking out different fluids from the sand surface to expect gassing reduction after activation. However, in the concrete work that parameter has not been investigated.

In this work, no tests have been done on one very important condition for applying the quartz sand mechanical activation method in practice, namely, keeping the properties of the activated layers at longer preserved conditions.

It would be also expedient to determine and compare the method's technical and economical advantages and disadvantages, and the efficiency potential of its use.

5. Conclusions

1. The results obtained allow us to assert that the methods of mechanical activation on the surface of quartz sands can improve their efficiency at the border with the biding system.
2. There is a possibility for an optimized reduction of the binder content, at equal other conditions, particularly in cases of limited manipulating strength.
3. It is proved that by improving the conditions of adhesive strength formation, the properties and effectiveness of foundry mixtures are enhanced.

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METHOD FOR DETERMINING ADHESIVE STRENGTH ON THE BORDER QUARTZ SAND – BINDING SYSTEM " NO BAKE "

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Abstract: As a whole, the contemporary self-hardening foundry moulds and cores represent a result of chemical reactions between quartz sands and binders at mould formation after good homogenization in mixers. Mixtures are hardened, obtaining the necessary physico-chemical characteristics; thus they realize the geometry of the future cast. One of the most important characteristics is the strength of mixtures, especially the adhesion strength that is formed on the border between sand and binding composition.

In this report, an improved method on adhesive strength determination of foundry mixtures is presented. Some theoretical protection aspects of the shown method are considered. A technological sequence of the method work and way of measurement are given. In figures, practical results from measurements of adhesion strength according to "No Bake" are shown.

KEYWORDS: CASTING, QUARTZ SAND, METHOD ADHESIVE STRENGTH, PHYSICAL AND MECHANICAL PROPERTIES

1. Introduction

Creation of foundry mixtures strength, respectively copying and preserving a set mould and core geometry is a process of formation of adhesive strength at the border surface between the filler and binding composition, and cohesion strengthening of the binder itself. Of course, the above said relates to single destructible foundry moulds which application in practice has been prevailing [1,2].

The study of mixture hardening processes is of particular importance to govern and optimize the content of components which topicality is still important against the background of the economical crisis. Knowledge also is necessary when inventing new binding systems and their performance tests.

About the question of improving foundry mixtures properties, a special attention has been paid to modern production conditions. The mixture itself can be regarded as a dispersive system consisting of solid non-metal particles (quartz sands in our case) wrapped up by a thin layer of the binding system.

In some authors' opinion, for variety of objective reasons, destruction of foundry mixtures is predominantly of adhesion character [2,3].

2. Presentation of the problem and ways to resolve

In the process of development of the foundry organic chemistry, we can distinguish two basic groups from the used hardeners- liquid and gaseous, and depending on their interaction with resins the processes of formation of strength's cohesive component can be polycondensation, polymerization, and others where different products of the chemical reaction are separated.

The contact of the binder with sand in real conditions cannot be perfect. Along the separating border almost permanently there exist morphological disparities to the ideal condition – microcracks, cavities, pockets etc. (Fig 1 and Fig. 2). Influence is also affected by viscosity of the binding composition, its duration in liquid state, amount and kind of products remaining after setting etc.

All these factors are a reason to reduce the actual area of contact and the rise of seats where adhesion bond is broken, considered as strength.



Fig.1 Defects – cracks and pores on surface of the sand grain

Size of the contact area at the border of contact between separate grains as well as the value, geometry and volume of the linking bridges are of essential importance. (Fig.3).

The latter, at the same filler nature, is basically affected by the state of sand particles surface. Particles of more round shape (Fig. 5a) create bridges of less area and weaker adhesion bond. The same is valid for sands of smoother surfaces – Fig 5b.

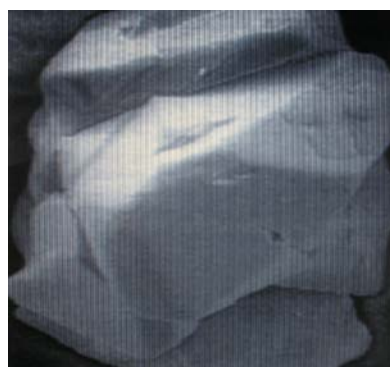


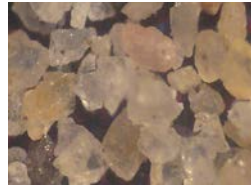
Fig. 2. Defects – unevennesses and "pockets" along the surface of a sand grain



Fig. 3. "Linking bridge" between two sand grains



(a)



(b)

Fig.4 Geometry of a sand grain and sand with conditions of better adhesion to the binder



(a)



(b)

Fig. 5. Geometry of a sand grain and sand of more unfavourable conditions for good adhesion to the binder

In contrast, a quartz filler surface predominantly saturated with cracks and pores (Fig.4a; Fig 4b) contributes to adhesion.

The earlier said considers only one small part of the factors and problems at formation of an adhesion limiting component of the foundry mixture strength. And the main reason for this is its incomplete study because of lack of data on the working conditions at the border contact surface.

In this regard, there are a series of methods created to determine the force of adhesion which however are not always suitable to test foundry products.

For instance, at this stage, we have not come across a proper method to measure the force in question for binders operating with gaseous hardeners which is substantial disadvantage basically explained by the inability to create suitable conditions for test preparation and performance.

This and also the lack of data are the basic reason for the choice made to develop a method suitable for resins with liquid hardeners, summarized for convenience as "No Bake" processes.

3. Decision on the investigated problem

It is known that most stable and accurate data could be obtained when applying a force to destruct the adhesion bond perpendicular (normal direction) to the contact surface [5,6,7]. The suggested method (Fig.6.) is just based on such a requirement.

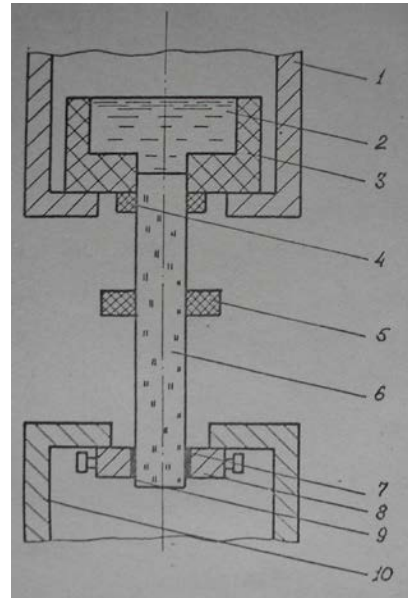


Fig.6. Components of the method's device

Device components as per the method are the following:

- 1 – machine's grip for a tensile test;
- 2 – biding compositions;
- 3- bushing made of polytetrafluoroethylene;
- 4 – centering bushing;
- 5 – guiding bushing;
- 6 – cylindrical body;
- 7 – abrasive band;
- 8 – clamp;
- 9 – clamp screw;
- 10 – machine's grip for a tensile test;

The test bodies are prepared as follows: the prepared binding composition "2" is pored over in a bushing "3" made out of polytetrafluoroethylene with an orifice put in it; beforehand a quartz cylindrical body which front surface can be processed additionally creating interaction conditions modelled by the examiner. After a certain time of delay, the device together with the specimen are put into the grips of the tester (PM-30 in the case), and the force needed to tear the link between the binder and quartz base is measured. The rate of the force applied was constant = 0.5 mm.s.

Adhesion is determined according to the formula:

$$\Sigma_A = 4 F / \pi D^2 \quad (1); \quad \text{where:}$$

- Σ_A – adhesive strength;
- F - force of tear;
- D – diameter of the quartz specimen

4. Results from the discussion

To check the efficiency of the method, a series of tests have been done. Below we will illustrate a part of them.

In Fig.7 there are data presented from measurements of adhesive strength at constant content of resin and different content of a hardener with density = const. Temperature is also constant.

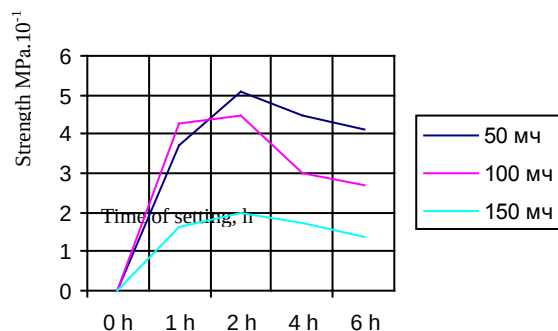


Fig. 7 Change in adhesive strength over time at different content of hardener

Adhesive strength increases during the first 2 hours of setting reaching maximum values for the respective binding composition and sufficient manipulating strength for moulds and cores, respectively. Then, it gradually reduces, towards the end of setting being some 20÷50% lower than the maximum one. That difference is markedly seen at less content of hardener.

After the second hour from the start of setting, because of natural ventilation it starts evaporation and liberation of chemical reaction's products with the prevailing part being monomolecular ones (for example polycondensation at furane-no bake). The linking bridges shrink, and in the contact zone, tearing stresses appear causing cracks on the film that are different in size and orientation. The process of evaporation passes through a peak with maximum jam releasing forces in the adhesion zone after which it follows a decrease of the harmful impact with stabilization of the strength value.

It is worth noting (Fig. 8) the fact of defects present into the set resin layers, in different amounts but as a function of the hardener content. This additionally reduces the bond strength.



Fig. 8 Gasous pores and canals in the hardened binding composition

Similar but with a different value are the data from the influence graphics of hardener density related to formation conditions and adhesive strength values in the contact layer.

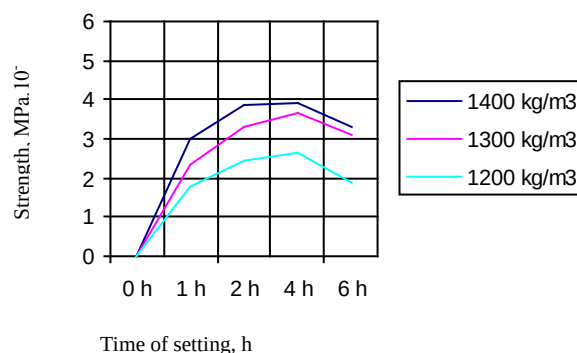


Fig. 9 Change in the adhesive strength over time at different density of the hardener

Hardener's density directly influences the speed and completeness of the chemical reaction of setting. At a denser filler, the amount of reacting molecules is greater, and buffer residue of monomers - less. Despite this, the physico-chemical conditions are identical, and the results are similar.

5. Conclusions

1. A method is developed for determining adhesive strength between quartz sand and binding systems, "No Bake".
2. The method is tested on traditional contents of binding compositions and provides good repeatability and accuracy of results.
3. The cylindrical body applied during the tests can be of origin different from the quartz nature and in size.
4. The method allows measurement and determination of other factors influencing the adhesive strength – wetting, various processings of test body, and others.

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MECHANICAL AND PHYSICAL PROPERTIES FE-MN-AL-C-N ALLOYS

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Abstract

Warm and hot compressive tests, bending test, measurement of density, heat capacity and thermal conductivity were applied to study of feature mechanical and physical properties of cast alloys Fe + (16,8 - 25,6) % Mn + (0 - 14,4) % Al + (0,02 - 2,18) % C + (0,001 - 0,135) % N.

1. Introduction

Last some years considerable researchers force is directed to design of the newest high-tensile steels, so-called advanced high-strength steel (AHSS). Toughening of transport safety requirements and automobile owners desire to raise own safety in a crash and a trend to fuel economy increase stimulated wide application of the newest high-tensile steels in automobile body construction elements [1]. Among other steels high-manganese austenitic TRIPLEX-steels with high contents of aluminum (transformation of a retained austenite into martensite at a strain is accompanied by a strain hardening) belong to this class. They are ductile and capable to hardening. Low-magnetization is important property of these steels. It is shown, that these alloys is perspective applied in cryogenic engineering to transportation and storing of the liquefied gases.

Physical properties can be important criteria at projection and choice some aspects cryogenic equipment materials.

Importance of density as physical material performance is caused by use of cryogenic systems in such branches of engineering, as transport engineering industry, in particularly, transport capacities

for cryogenic liquids, and, especially, the aviation and space-rocket engineering. For such installations one of solving conditions of application of this or that material is weight minimization.

TRIPLEX steels are characterized by a combination of high strength and toughness, and the high aluminum content (5 - 15 %) allows to achieve decrease of density to 15 - 20 % in comparison with traditional high-tensile complex alloyed steels [2, 3].

Except high level mechanical properties modern materials should possess and certain physical properties [4]. A thermal capacity plays essential role at maintenance of the cryogenic equipment, and chill down speed directly depends on thermal conduction. Besides, thermal conduction essentially influences heat treatment engineering processes.

2. Results and discussion

The chemical composition experimentally examined high-manganese alloys with high aluminum content is shown in Table 1.

Table 1 - Chemical composition of the investigated Fe-Mn-Al-C(-N) alloys

Alloy №	Mass fraction of element, wt. %						
	Alloy group	Mn	Al	Si	Mo	C	N
1 (32K)	I	16,8	0,01	0,86	2,0	1,62	0,020
2 (35K)		21,2	6,2	0,50	0,20	1,10	0,006
3 (36K)		19,1	7,5	0,60	1,20	1,47	0,002
4 (33K)		19,1	9,0	0,50	0,03	2,18	0,001
5 (34K)		23,9	4,0	0,54	0,01	1,80	0,032
6 (38K)	II	25,3	0,01	0,20	<0,001	0,02	0,014
7 (45K)		23,8	4,6	0,20	<0,001	0,05	0,020
8 (41K)		25,6	0,01	0,20	<0,001	0,03	0,135
9 (44K)		24,1	5,3	0,32	<0,001	0,04	0,024
10 (39K)	III	23,7	7,5	0,20	<0,001	0,05	0,008
11 (40K)		22,6	14,4	0,20	<0,001	0,05	0,007
12 (42K)		23,7	8,1	0,20	<0,001	0,05	0,008
13 (43K)		24,3	11,5	0,20	<0,001	0,03	0,045

The resistance to hot deformation $\sigma_{\max}$ (at 950 – 1000 °C) increases with the increase of the content of aluminum, carbon and nitrogen and it is less for ferrite alloys ($\sigma_{\max}$ 50 – 150 MPa) in comparison with austenitic ($\sigma_{\max}$ 120 - 180 MPa). The high-carbon cast Fe-Mn-Al-C alloys are well hot deformed up to 40 - 50% reduction without hot cracks formation is important result of hot compressive test.

The greatest warm strain resistance (at 550 °C) 1450 – 1810 MPa have high-carbon Fe-Mn-Al-C(-N) austenitic alloys of 1st group, strength of alpha-phase alloys of 3rd group at warm strain temperature makes 920 – 1290 MPa. Low-carbon Fe-Mn-Al-C(-N) austenitic alloys 2nd group possess the least strength at T = 550 °C: 660 - 1000

MPa. At similar chemical compositions within each of observed groups the alloys microalloyed by nitrogen is stronger.

To high-tensile condition corresponds toughness adequate supply. Deformation amount of all alloys without failure at warm strain is 25 - 50 %.

Strength levels it is much more in comparison with a hot deformation. With carbon content and aluminum growth and decrease of manganese content strength is increased. The microalloying nitrogen also deposits the contribution to strength increase.

At estimation mechanical properties of investigated alloys at room temperature it is necessary to note that alpha alloys of 3rd group were crashed in elastic range like brittle materials (cast irons,

ceramics). Austenitic low-carbon alloys of 2nd group, on the contrary, shown high toughness with high enough bending strength (σ_b to 1070 – 1770 MPa) combination. The greatest bending strength with satisfactory toughness combination, despite a high carbon content, was shown by alloys from 1st group (σ_b to 1880 MPa).

The minimum density made no more than 6,5 g/sm³ at the aluminium contents approximately 14 % (Table 2). It is equivalent to relative decrease of density approximately on 17 - 18 % in comparison with density of pure iron. Overall decrease of density is connected as

to smaller average molar mass of alloys at the expense of alloying by considerable quantities of manganese to 25 % ($\rho_{Mn} = 7,21$ g/sm³) and, especially, aluminium to 14 - 15 % ($\rho_{Al} = 2,69$ g/sm³), and with considerable decrease of atomic density of low level cells, i.e. lattice dilatation. For an alloy with 12 % aluminum overall decrease of specific density makes approximately 17 % (at density of 6,6 g/sm³), thus density decrease only because of dilatation γ -lattices are made approximately by 10 %.

Table 2 - Structure and properties Fe-Mn-Al-C (-N) alloys

Alloy	The phase compositions	Density ρ , g/cm ³	Specific heat capacity 25-100 °C, J/kg*K	Thermal conductivity 25-100 °C, W/(m*K)	Magnetizati on	Hardness, HV	σ^{1000}/ρ , km	σ^{550}/ρ , km	σ_{bend}/ρ , km
1 (32K)	$\gamma+(\epsilon)+(Me_xC_y)$	7,7074	364	8,6	–	293	1,7	24	23,4
2 (35K)	$\gamma+(\kappa)$	7,3282	399	8,4	–	279	1,7	23,2	23,6
3 (36K)	γ	6,9552	405	8	–	434	1,7	24,2	27,5
4 (33K)	$\gamma + \kappa$	7,0181	376	7,2	–	447	2,9	23,8	-
5 (34K)	γ	6,9994	369	7,3	–	376	2,5	21,1	19,4
6 (38K)	$\gamma + \epsilon + \beta\text{-Mn}$	7,4643	454	15,3	–	204	1,8	9	24,3
7 (45K)	$\gamma+\epsilon(\text{marks})$	7,4774	427	9,5	–	130	2,2	13,7	14,6
8 (41K)	$\gamma+\epsilon+\beta\text{-Mn}$	7,6462	465	15,2	–	164	2	9,7	15,2
9 (44K)	γ	7,4041	417	9,3	–	127	2,5	12	15,1
10 (39K)	α	6,7191	441	11,9	++	285	1,0*	14	8,6
11 (40K)	$\alpha + \epsilon$	6,5151	426	9,9	+	345	0,8*	20,2	-
12 (42K)	$\alpha + \epsilon$	7,1033	445	12,8	++	272	1,0*	16,9	-
13 (43K)	$\alpha+(\gamma)$	6,6027	450	9,6	++	259	2,4	14,6	5,5

Experimental thermal conductivity definition shown within each group it is decreased with growth of the aluminum contents. Besides, the reason of lowering of thermal conduction is impurity dispersion on carbon atoms (and/or nitrogen) in high-carbon alloys (1st group) and the alloys microalloyed by nitrogen. Values of thermal conduction FeMn alloys with high aluminum content are similar to analogous values for classical austenitic CrNi steels. Change of manganese content in investigated alloys practically does not influence molar heat capacity and thermal conduction. Molar heat capacity of all alloys is decreased with increase overall alloying, and for γ -alloys of 1st and 2nd groups character of this decrease more expressed, than for α -alloys of 3rd group. Thermal conduction of all alloys is decreased with increase in total alloying Al+C+N, i.e. those alloying elements which deposit big distortions to crystal lattice. α -alloys have higher heat capacity and thermal conduction values, than γ -alloys.

Conclusions

1. TRIPLEX structure ($\gamma - \alpha - \text{carbides}$; $\gamma - \epsilon - \text{carbides}$; $\gamma - \epsilon - \alpha$) with controlled distribution of phases and determined level of mechanical and physical properties can be formed in investigated alloys through regulation of thermomechanical treatment schedules.
2. High-carbon high-alloyed as-cast Fe-Mn-Al-C-N alloys are well-hot-deformed up to 40-50 % of squeezing without cracking. Their

resistance for the hot deformation increases with the increase of the content of Al, C and N.

3. Warm processing (25 – 50 %) of as-cast Fe-Mn-Al-C-N alloys results to their well-plasticity (elongation was up 50 %) and high-strength (ultimate tensile stress was up to 1810 MPa). Their resistance for the warm deformation increases with the increase of the content of Al, C and N.
4. High concentration of Al (up to 15 %) and Mn (up to 25 %) causes significant decrease (up to 17 – 18 %) of the alloy density (comparing with common high-strength steels). Both thermal capacity and heat conductivity of these alloys decrease with the increase in total alloying by Al+C+N.
5. Investigated Fe-based alloys with high specific strength may be used (both as-cast and after deformation) as high-strength, heat-resistant and wear-resistant structural materials.

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CREATING INCENTIVES FOR TECHNOLOGICAL CHANGE: INNOVATION MANAGEMENT AND THE EU REGULATION OF ENERGY EFFICIENCY

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Abstract: *Technological innovations and change in highly regulated sectors such as the energy sector depend on decisions made by political actors in what is called a 'joint decision system'. Such systems comprise divergently constituted actors, varying from electoral bodies to expert committees to industry representatives. The problem with decisions made in joint decisions system is that they depend more often than not on the unilateral agreement between all the participant is the decisions. The presence of veto players in areas of divergent interests creates a 'joint decision trap': situation where suboptimal decisions are taken. This explains why even in areas such as energy efficiency where preferences among decision makers do not vary so much as in other areas, the EU regulation, creating incentives for technological change develops rather slow.*

Introduction

Energy efficiency has a key place among the measures of the EU energy policy. Higher energy efficiency means more competitive European economy, greater energy security and less impact on the environment. Energy efficiency plays a key part of the EU 20-20-20 by 2020 Action Plan that provides for the reduction of greenhouse gas emissions by 20 % compared to 1990, 20% share of renewables in energy consumption and 20 % reduction in primary energy consumption achieved by increasing energy efficiency. The policy has the following components:

- The establishment of minimum standards for „eco-design" of the 19 groups of products (Directive 2005/32/EC);
- The establishment of standards for energy efficiency of buildings (Directive 2002/91/EC and 2010/31/EU)
- The establishment of standards in the industry and transport (Directive 1994/94/EC, Directive 1999/94/EC).

In October 2006, the Commission adopted an Action Plan for Energy Efficiency, which was operational for a period of 6 years: from 2007 to 2012 (COM (2006) 545). Its purpose was to set in motion the process to achieve the 20 % reduction in energy consumption, as this identifies six priority areas:

- Requirement for dynamic energy consumption of products, buildings and services;
- Energy Conversion;
- Transport;
- Funding, economic incentives and pricing;
- Energy efficient and energy saving behavior of energy consumers;
- International cooperation.

Directives 2009/125/EC and 2010/30/EU further amended Directive 2005/32/EC establishing requirements for ecodesign for energy-related products and standards for labeling and product information concerning energy consumption. Finally, in October 2012, the EU adopted the Directive 2012/27/EU on energy efficiency which creates binding measures for energy efficiency in the public sector including energy audits, policy roadmaps, targets for renovation and energy efficiency in buildings, incentives for investments in heating, insulation and general energy neutrality.

Regulatory frameworks for technological change

a. Technology and sociotechnical change

Viewing technology as activities through which resources are transformed into output (Perrow 1970) is convenient if we wish to think about actors in the energy sector trying to optimize their performance in the settings of the regulatory regime. Energy producers decrease cost by investment in new generation technologies and buying cheapest energy resources. Industry wants cheap energy for greater competitiveness. Policy actors try to enact efficient rules to increase support and stay in power.

Users of technology and their environment create stable interdependencies distinguished as 'sociotechnical systems'. In sociotechnical systems technology becomes a symbol, an important

part of the material landscape (Lemonnier 1993). It becomes part of everyday life and important asset to the community. Thus we see the energy plants and wind turbine plants, for example, as important landmarks all over the world.

Sociotechnical systems underline the importance of technology and technological change. Technology is vital to societies' transformations. In Lewis Mumford's view, it is not an external driver of these transformations, but an integral part of them (Mumford 1967). Current world challenges such as climate change, depletion and increasing costs of petrol, energy prices and the security of energy supply are all intrinsically linked to technology. The technologies of the industrial revolution used coal to supply energy to the industry; burning fossil fuels led to the ever increasing of carbon dioxide and other greenhouse emissions in the atmosphere. Now, technology is viewed as the key factor in the mitigation of climate change impact on the planet and provision of cheap, reliable and secure energy.

Energy efficiency stays at the center of the global energy issues. First, it helps fight global warming by emitting less greenhouse gasses. Second, it adds to the competitiveness of the economy by decreasing the amount of energy consumed for a unit of production. Third, it limits the dependence on energy imports thus increasing economic and political freedom. Therefore, energy efficiency technologies are important in the same sense as the steam engine, the locomotive, the automobile, the computer: they are a key to a transformation of the whole sociotechnical system.

b. Technological and policy regimes

Sociotechnical systems operate within the rules and institutions of the society. These rules constrain human behavior, shape interactions between economic and policy actors, reduce uncertainty and create incentives for development and growth (North 1990). Within the institutional settings the sociotechnical systems create stable forms of interactions defined as 'technological regimes' (Kemp et al. 1994). Technological regimes define the rules, standards and practices of production processes, industry standards for the use of technology and development of innovations. The 'efficiency' of the regime: the way incentives are embedded in rules and practices, determines the quality and quantity of the innovations that are created and adopted in the society. Thus, it is important that these regimes are 'efficient' enough so that they contain enough incentives for creation and adoption of innovations.

Policy regimes, on the other hand, consist of formal and informal networks of interdependent policy actors negotiating and agreeing on decisions, often in forms of 'package deals' which include several different issues at once so that deals and concessions are more easily made. In such regimes (the European council is a prime example) bargaining power and the level of conflict often determine the outcome of the negotiations and the form and matter of the decisions made. Thus, as with technological regimes, the 'efficiency' of the policy regime is important for the outcome of the bargaining, decisions and outcomes for both policies and technology.

The most important feature of these regimes is the self-interest of the parties involved. Industries and policy actors operate in competitive environment where the rules of economic and political markets dictate what actions are feasible and what not for survival and growth. Thus participation in technological and policy regimes is voluntary and any actor may choose to exit and act unilaterally if his self-interest dictates so. Violations of industry standards and norms of political behavior occur often even within the highly developed setting of the western world. Globalization creates even more pressure for violation of the rules and standards as industries' exit options are ever more cheap and available.

Good example for such pressures is the carbon leakage: the incentives for the industry to move production away from strict regulation on emissions and energy use to places where energy is cheap and regulation is not so strict. Carbon leakage not only negates the efforts for emission reductions, it creates a state of affairs where old technologies are still used for the benefit of lower cost even if they are harmful for the environment and may lead to unwanted economic and social consequences in the countries the industry is move from. Thus the creation of an 'efficient' incentives structure within technological regimes that lead to creation, adoption and diffusion of technology is important for solving problems, development and growth.

Innovation management as a cooperative game

Can the interaction between industry and policy actors be represented using the analytic tools of game theory? When participants in a decision making system take their decisions sequentially the interaction between them can be represented as a continuous game. Its analysis, then, requires finding Nash equilibria for each sub- game and will be complicated if, for each sub- game to more than one such equilibrium. The biggest problem of this analysis, however, would be to ignore the specific circumstances of the players in the representation of energy policy which not only interact with each other but also have some control over the environment in which they interact.

Possibility of recurrence of the interactions and subsequent changes in the behavior of the players could in principle lead to an efficient result in games such as prison dilemma and , indeed, of all collective dilemmas. The Folk theorem (Folk Theorem) gives an evidence of such cooperative behavior, although this has not been formally proven. What changes the behavior of the players furthermore, is the possibility of "intelligent design" of the institutional setting in the a series of interactions take place. If the political actors are involved in a non-cooperative game, they would have the opportunity through 'mechanism design' to coordinate their actions towards achieving a collective goal (Hurwicz 1973). Such coordination is a game in itself, and different strategies are themselves rules by which the game is played at least one of the participants in the game. Allocation of limited resources is a typical example of mechanism design and the tendering - for example for telecommunication frequencies (Binmore, Klemperer, 2002) . The problem with this conceptual possibility , however, is the inability for the individual preferences to be ordered as a meaningful group preferences as shown by the Arrow's impossibility theorem (Arrow 1951). Thus, for various classes of interactions - from elections to markets - the aggregation of the preferences of the participants is not a realistic outcome.

But what can be said if the participants in a game can form coalitions? First, the negotiation process is usually accompanied by transaction costs, which are the greater, the more different are the preferences of the participants. They can be minimized, however, if the negotiators reach preliminary agreements on the implementation of commitments and of the production and the distributive dimensions of the agreement (Scharpf 1997 , 117-119) . In the first case, this means that the participants have to fulfill their obligations even if their failure to do so do not incur direct loss for them (for

example, if the benefits to a participant does not depend directly on its contribution) . In the second, it means an acceptable distribution of costs and benefits of the agreement. What immediately stands out here is the fact that the institutional environment is the key to how the players will address these problems. If the institutional environment has the means to enforce the sanctions for any breach of the agreement, this could deter a self-interested player who wishes to unilaterally escape from fulfilling the obligation. In addition, there may be mechanisms to compensate those affected by a decision or possibly negotiation process include package deals whose elements are meant to offset the high cost absorbed in a particular sphere. In such a situation, an agreement between the political actors with different preferences is possible . But the provision of such institutional capacity in the first place is a legitimate goal for the participants in the negotiation process, or at least some of them.

Going back to the energy efficiency regulation and taking into account the above considerations, we can see how the creation of the institutional regime reflects the desire to achieve a 'mechanism design' to ensure achievement of the desired collective objectives: cheap and secure energy and economic prosperity. In addition , it could be said that the regulatory regime reflects the specific preferences of the leading Member States - France and Germany (Garett 1992). Establishment of the internal market, launched in mid 80s of last century occurs in the shadow of the collective need to increase economic growth. This led to the increase of the role of the Commission which was authorized to monitor compliance with rules of the internal market.

One important note is in order here. Intentional mechanism design does not fully reflect the historical development of the regulatory regime because in practice the creation of the common energy policy did not fully reflect the preferences of the Member States that participate in it. This development is a rather unexpected consequence of the construction of the 'mechanism' of the Internal market of the EU, because it is through this mechanism that building the overall energy market began. So perhaps to illustrate this process the more flexible metaphor 'intelligent design' is in order, which in this context simply illustrates a particular institutional environment for the status, the rights and obligations for the participants in a given regime, and from the moment of its creation it began to live its own life and form its own look.

Conclusion

Technological innovations and change in highly regulated sectors such as the energy sector depend on decisions made by political actors in what is called a 'joint decision system'. Such systems comprise divergently constituted actors, varying from electoral bodies to expert committees to industry representatives. When such actors join in finding a cooperative solution for common problems? The above analysis shows that some preconditions are important. First, there must be serious problems that affect all participants. Second, the institutional setting in which interaction take place and regulatory regimes are created must favor cooperative solutions. Thus, there must be incentives for cooperative behavior even before the bargaining begins. Third, the self-interest of the economic and political actors must be compatible enough so that the negotiations would not break up easily.

In the case of the energy efficiency regulation all three conditions are in order, thus setting the stage for the creation of incentives for energy savings and more efficient generation, transmission and distribution of energy. Energy saving technology now is a familiar sight in world landscape with house insulation, energy use labels, energy saving light and heating devices all over. Such change could not occur if all decision makers: from industry giants to single households were left to their own devices. It happened through the process of intentional creation of incentives by economic and policy actors involved in cooperative bargaining that can be represented as

a cooperative game. This game, furthermore, could not yield an efficient solution without the favorable institutional setting of the European Union, where the Commission acts as agenda setter and the European court – as guardian of the agreements.

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USE OF SCIENTIFIC APPROACHES AND METHODS FOR PERFORMANCE APPROVEMENT OF SAFETY MANAGEMENT SYSTEMS IN RAILWAYS

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Abstract: Recently, the issue of safety has not been whether or not Safety Management Systems are necessary to secure a high level of operational safety in railways but if they could eventually be improved. The answer is yes and that improvement can be done on the basis of well known (and adapted to the problems of safety) scientific approaches and methods. In other words, safety understanding will be developed into a new stage - Modern Safety Management System. The present paper discusses the possibilities for the introduction of some scholarly methods into safety management in railways.

Keywords: RAILWAY OPERATING SAFETY, SAFETY MANAGEMENT SYSTEM, BAYESIAN NETWORK

1. Introduction

The understanding of railway operational safety and its primary role for securing quality of the overall transportation process has evolved over the past several decades. The process of evolution started at a stage when safety was identified only as the number of incidents (accidents) which occurred within a given period. Railway safety experts usually call this stage the traditional approach to safety understanding. This initial attitude to safety is characterized only by incident (accident) reporting, spontaneous (unplanned) inspections, design and enrichment of operational regulations on the basis only of accident consequences, poor level of awareness, separate examination of the human factor, equipment and technology, etc. The second stage of safety understanding is marked by evolution of the elements (separately or in combination) of the first stage, for example: complex analysis of the relation between staff and equipment, more comprehensive and developed on the basis of consistent analysis rules, increasing role of personal liability, planned supervision and increasing supervisor's role, etc. The third stage of safety understanding is called Safety Management. Safety Management is based on a system-based approach that stresses the interactive nature and interdependence of external and internal factors in a structure (for instance: railway undertaking). In this connection, all written procedures and regulations, operating (management) logic and company's strategy for decision-making is named Safety Management System (SMS). Recently, the question has not been whether or not Safety Management Systems are necessary to secure a high level of operational safety in railways but if they could eventually be improved. The answer is yes and that improvement can be done on the basis of well known (and adapted to the problems of safety) scientific approaches and methods. In other words, safety understanding will be developed into a new stage - Modern Safety Management System. The present paper discusses the possibilities for introduction of some scholarly methods into safety management in railways.

2. Fundamentals of SMS

2.1. Background

The idea of a Safety Management System is inextricably connected with the concept of system safety. This concept itself has a long history beginning in the late 1950s when it was recognized as a separate scientific discipline. Prior to the 1950s, designers, engineers and managers relied mainly on a fundamental method of solving safety problems known as the *trial-and-error method*. Initially this simple approach gave a modest contribution towards the achievement of safety design. But with the growth of complexity of systems, this approach began to be unsuitable for qualitative decision-making process in the field of safety. The primary reason for this was the increased sensitivity of society regarding safety. The old model of creation of safety rules after a

technical failure, incident or accident was no longer able to give enough positive results to prevent the future occurrence of similar failures or accidents. A new approach was necessary for better results in prevention.

Thus, *trial-and-error approach* gradually developed into a *system-based approach* of the attitude to safety. System-based approach to system safety considers safety problems in their entirety and its specific characteristic can be summarized as: *instead of waiting for something bad to occur it is better to take action to prevent this occurrence*.

All the above apply to a variety of industries including railways. It could be said that the increased complexity of railway technical and technological systems played the role of a catalyst for the origin, gradual adoption and present utilization of the concept of system safety in railway industry. Nowadays, the system safety approach is extensively used by a variety of railway undertakings and its practical realization is known as Safety Management System.

2.2. Pillars of Safety Management in railways

In order to illustrate the possibilities for the utilization of scholarly approaches and methods in design and functioning of a railway SMS, it is firstly necessary to define its nature and foundations. The next three items form the basics of the concept of Safety Management System:

-Key definitions:

-**System.** The term *system* is mentioned in [1], [7] and [8]. But from the point of view of railway technical exploitation and operational management, the following definition is probably more accurate: *A railway system is a combination of people, procedures and/or specific equipment all functioning within a specified working conveyance to accomplish a specific task or set of tasks for conveyance of people and commodities* (adapted to [6]). A railway undertaking (company) could be considered as a *technological system* including a variety of technical objects (also called *technical systems/subsystems*: vehicles, specific equipment, etc.), natural resources, people (designers, managers, operators, and customers), scientific and technical knowledge, regulations, norms of culture and behaviour, etc.

-**Hazard.** This is a situation that can occur within the transportation process capable of causing harm, injury, death, and/or damage.

-**Risk.** According to [2] risk is the probable rate of occurrence of a hazard causing harm and the degree of severity of that harm.

-**Safety management.** Application of engineering, technological, economical and management principles, criteria, and techniques to optimize the operating process of transportation on a

level where all potential risks are tolerable in line with predefined railway authority requirements.

-Principles and related conclusions:

-Every man-machine system entails some kind of risks (nothing can be perfect). As a matter of fact, whatever the railway undertaking (Carrier or Infrastructure operator), it consists of a variety of subsystems which are usually a complex mixture of man-machine systems and could be a source of risk. Therefore, only a qualitative, profound and system based analysis will identify risks and assess their elements, probability of occurrence and possible consequences.

-Identified and assessed risks do not require managerial confusion or relief (no need of prejudice). It is well known that within transportation process total absence of risks is practically impossible, a fact that should not be taken for granted or as source for panic. Therefore, only a reasonable and well-balanced identification, monitoring and controlling of risks will lead to an adequate response (in compliance with company's features, knowledge and experience about safety, regulations, etc.) to whatever internal or environmental changes influencing the operating process.

-There are no obvious safety issues within an operating process, just engineering, technological and managerial ones which could cause serious mishaps (nothing can be absolutely obvious). Therefore, It is very important to define clear purposes regarding subsystems to be analysed (including their attributes, components interrelations, role in the overall operating process, inherent potential risks, etc.) and employ appropriate scholarly analytical tools (econometric, statistical, probabilistic, simulation, etc.).

-Whatever safety issue leads to the necessity for solution (mitigation measure), that can never be the best, just optimal. Therefore, decision-making needs to be put in place in order to achieve a reasonably practicable option of possible solutions.

-Most events and conditions influencing safety have a stochastic and unique nature. Therefore, a knowledge based approach to decision making with permanent involvement of operating staff in it is very important in safety management.

-Hazards may happen any time (and also many times) and in transport industry they usually impact not only the system where they occur but others (other companies, local people, etc.). Therefore, continuous efforts for safety improvement with mutually beneficial results are needed.

-Basic components:

-Safety Policy - It is company's commitment that safety is a key element of the entire operating process. This commitment is usually in form of written document from highest level of management and should be circulated to all operating staff. The safety commitment has three elements: design and future improvement of SMS (including all company's rules, procedures and standards), encouragement of the staff acting on all levels of the operating process and ensuring all needed resources are available to meet safety requirements.

-Safety encouragement - It is a company's duty to promote the right understanding of safety at all levels of technical exploitation. It includes: safety behaviour (safety culture), training of the staff regarding structure and requirements of SMS and the exchange of knowledge (communication).

-Risk management - This is an analytical procedure used to make decision regarding the nature of potential risks and the necessity for their reduction, involving the following main subtasks: hazard identification, risk assessment, defining and implementation of mitigation measures.

-Safety monitoring - It is a general and permanently implemented procedure to ensure that a railway undertaking follows

the defined safety policy. It includes: company's scheme of periodical audits (internal or/and external) and procedure of corrective actions.

3.Possibilities for monitoring of SMS components with utilization of scholarly methods

The achievement of a safe transportation process is a very important task. At the same time even with well-established and good working SMS, this is a complex requirement, not easily achieved. The main reason for that is that a variety of processes and events typical for the above-mentioned components of SMS are characterized by complexity, uncertainty and ambiguity. A number of scientific approaches and methods exist that could be successfully utilized in SMS design, implementation and further improvement. The application of a very popular analytical method to improve the functioning of SMS will be presented within this section.

3.1.Bayesian network relevance to SMS

3.1.1.Background

Bayesian networks (also known as Bayesian belief networks) are probabilistic graphical models that make it possible to arrive at a decision regarding the sequence and interdependence of defined events at the conditions of uncertainty and ambiguity [3], [4], [5]. A Bayesian network consists of nodes (vertices) and arcs (direct edges). The nodes $X = X_1, \dots, X_2, \dots, X_n$ of the network represent random variables (or events) whilst the arcs describe their causal relationship. In other words, the arc $X_i \rightarrow X_j$ represents a statistical dependence between events X_i and X_j , that is: the first event (also named *parent event*) can cause the second one (also known as *child event*). Due to the fact that an event may have some "parents", a Bayesian network can be deemed as a mixture of "descendant" sets (sets of nodes that can be reached by a direct connection from the considered node) and "ancestor" sets (sets of nodes from which the considered node can be reached by a direct connection). A basic property of Bayesian networks is their acyclic design - there is no causal feedback in their structure (the graph does not involve nodes which are their own ancestor or descendant).

Each event (variable) in a Bayesian network is characterized by a probability set (table). For a child event, the table consists of some conditional probabilities covering all combinations of states of an event's parents. Depending on the number of parents the probability tables can dramatically increase.

Events without parents have simpler probability tables consisting just initial probability distribution.

The design of a Bayesian network encompasses two basic stages:

-Definition of consequence (hypothesis) events. These are events for which the investigator wants to know the probability distribution allowing him to make a respective solution.

-Definition of initial events. These are events giving evidence (initial) information about the process under consideration.

-Definition of intermediate events. These are events providing additional information regarding the process under consideration.

-Graphical design of the network. Construction of the network is made by connection of events (arcs) having logical relationship (in the context of the investigated process). It is very important to follow causality direction.

-Constructing the probability tables. Tables can be filled by using subjective probabilities (on the basis of expert's knowledge), statistical methods and gathered data, simulation, etc.

-Reasoning. Depending on the analysis Bayesian networks can be used for two types of reasoning (conclusions):

-Top-down reasoning (follows the direction of the network arcs) – predictive reasoning from the information about causes to the beliefs (expressed by conditional probabilities) in effects.

-Bottom-up reasoning (follows the opposite direction of the network arcs) – diagnostic reasoning from consequences to causes

3.1.2. Feasibility

The ability to make effective SMS decisions largely depends on the presence of sufficient information about different operating situations. Unfortunately, due to the essence of the transportation process, it is almost impossible to gain as much reliable information as safety managers would like to have. Therefore, an appropriate analytical tool used to handle uncertainty (basic problem for an effective decision-making) is to be used. Due to the fact that Bayesian networks use probability to represent uncertainty and ambiguity (and in such a way the respective operating scenarios connected with them) they are a very good example of such an analytical tool.

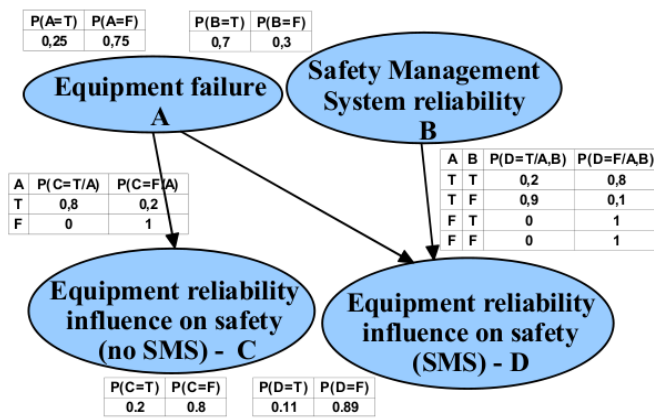


Fig.1. Exemplary Bayesian network

There are lots of possible applications of Bayesian networks within the procedures of implementation of SMS. Let us consider a simple example that illustrates some of the characteristics of Bayesian networks and their specific feasibility in railway SMSs (Fig.1). The example describes the influence of SMS over transportation process safety. More specifically, it considers railway technical equipment reliability and its impact on safety in two possible scenarios – with and without SMS – of the railway undertaking. Furthermore, the network takes into consideration the SMS reliability that can be defined as its possibility to encompass all possible safety issues (risk assessment, scope of safety rules, adequacy of procedures, etc.). So, in this operational diagnosis example, we might ask whether and to what extent SMS presence (and its efficiency) mitigates the equipment imperfection. All network variables (events) are binary, i.e.: they are either TRUE (denoted by “T”) or FALSE (denoted by “F”). For instance: equipment reliability is described by event A - “equipment failure” with probability of occurrence $P(A=T)=0.25$, such as SMS reliability is represented by event B - “SMS failure to detect and prevent an equipment failure from developing into a mishap” with probability of occurrence $P(B=T)=0.3$. Conditional probability tables describing all possible scenarios of dependence between events are shown beside each node. Following the network topology and quantifying the relationship between connected events (by using conditional probability distribution about each one of the nodes) it is possible to determine the final events (effects). In the present example they are events C and D. There are two scenarios

of equipment reliability influence over safety and it is very easy to notice the effect of SMS. The presence of a well-established and properly working SMS (within the operating process of a given railway undertaking) helps to diminish almost two times the impact of equipment over operating safety represented by the probability of accident occurrence $\rightarrow P(C=T)=0.2$ and $P(D=T)=0.11$.

The example above of Bayesian network can be deemed as a causal model of relationship between some predefined safety attributes and their strengths. Similar models could be developed regarding many safety management problems and could successfully be used to implement qualitative decision-making.

3.2. Using simulation in Bayesian networks

As it is explained above, the inference through Bayesian network relies on a set of probability tables representing uncertain events. Sometimes, there is no need to compute the exact value of the unknown probability but only its approximate assessment (which could be improved later by using supplementary computing resources). That could be done by stochastic simulation and such an approach is applicable in safety management where a decision-maker must urgently respond to the occurrence of specific events (changes) within operating environment. Thus, the manager would have permanent knowledge (although not too precise) about the specifics of the operating environment. This approach will be illustrated in the following example.

Let us have a Bayesian network describing a given scenario of accident occurrence B caused by two causes A and C (Fig.2). Probabilities of occurrence of causes A and C which are under consideration regarding the investigated type of accident are $P(A=T)=0.75$ and $P(C=T)=0.25$. The conditional probabilities of event B are also depicted in figure 2. As a matter of fact, they represent all possible scenarios of accident occurrence B as a result of occurrence (or not occurrence) of cause A and/or cause C. The diagnostic reasoning of constructed in such a way Bayesian network allows obtaining probability of occurrence of cause A given that accident B has not happened - $P(A=T/B=F, C=F)$. In other words, this is the probability of occurrence of cause (causal factor) A which is under investigation within the operating process of transportation. The diagnostic reasoning could be implemented by simulation following the next algorithm involving three main steps:

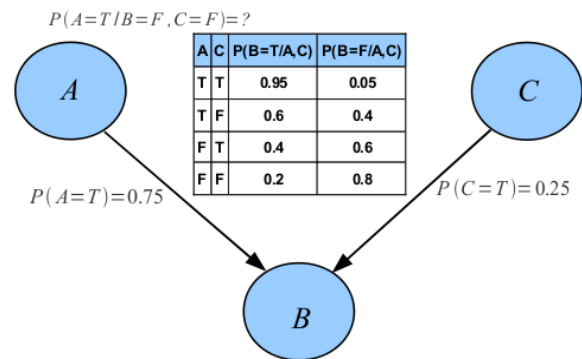


Fig.2. Accident scenario B with causes A and C

Step 1: Simulation of event A following previously predefined prior probability - $P(A=T)=0.75$.

For this purpose a random variable $R_A \in [0,1]$ is generated. Each value of R_A as a single representative of event A has to be compared to prior probability $P(A=T)$. If $R_A < 0.75$ event A can be considered as TRUE (A) otherwise as FALSE ($\neg A$). The simulation process regarding event A is shown in figure 3.

Step 2: Simulation of event B.

Depending on the results connected with the first step of simulation, the respective conditional probability of event B has to be chosen for continuation of the simulation process following the same approach as this on step 1, namely:

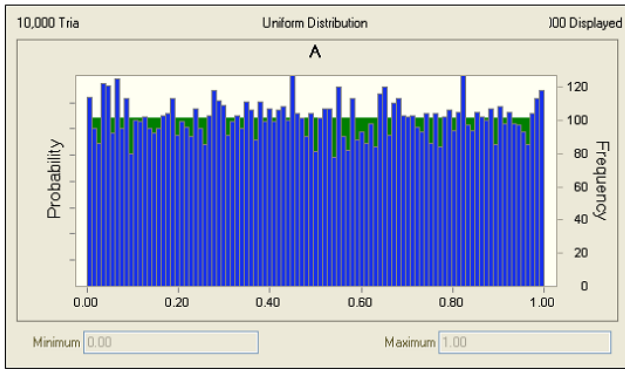


Fig.3. Simulation of event A

-If after the first step $A = TRUE$ then a random variable $R_B \in [0,1]$ is generated and compared to conditional probability $P(B = T / A = T, C = F) = 0.6$. If $R_B < 0.6$ event B can be regarded as TRUE (B) otherwise as FALSE ($-B$).

-If after the first step $A = FALSE$ then a random variable $R_B \in [0,1]$ is generated and compared to conditional probability $P(B = T / A = F, C = F) = 0.2$. If $R_B < 0.2$ event B can be regarded as TRUE (B) otherwise as FALSE ($-B$).

The simulation process including steps one and two should be fulfilled many times (K) and each iteration of implementation increments two counters - $K_1 = K_{A=TRUE, B=FALSE}$ and $K_2 = K_{A=FALSE, B=FALSE}$ with one, that is..

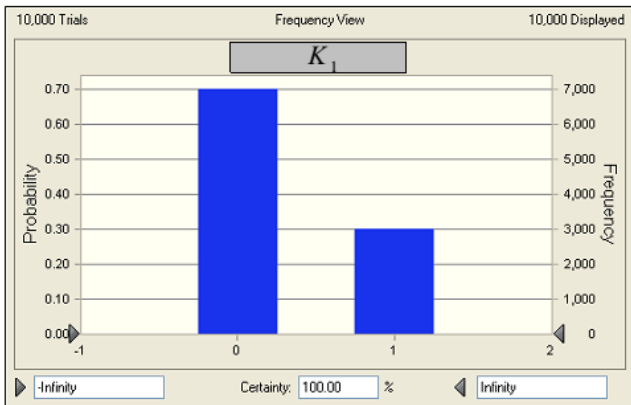


Fig. 4. Estimation of parameter K_1

- $K_1 = K_1 + 1$ if $A=TRUE, B=FALSE$;
- $K_2 = K_2 + 1$ if $A=FALSE, B=FALSE$.

The ratios K_1/K and K_2/K represent probabilities $P(B = F)$ and $P(A = T \wedge B = F)$. Having their values and by the usage of conditional probability formula the obtaining of probability $P(A = T / B = F, C = F)$ is very easy to calculate as the ration $K_2/K_1 = 0.66$. The results about parameters K_1 and K_2 are shown in figures 4 and 5.

4. Conclusion and Discussion

The successful management of operational safety in railway industry requires understanding of railway undertaking as a complex system. Such a system could never be designed perfectly and every constituent of it can be subject to failure - technical equipment, operating staff, procedures and rules, etc. System failures entail incidents which are usually considered as normal to occur (it is impossible to absolutely prevent them from occurring). At the same time, serious ones (accident) could and should be prevented and that can be done by implementing certain measures, e.g. company's knowledge of incidents. On this basis and by the usage of appropriate scholarly approaches and methods, the risk management regarding incidents and serious accidents becomes not only possible but extremely effective.

The present article demonstrates that Bayesian networks are applicable in designing and functioning of Safety Management Systems of the railway undertakings. The possibility to manage reasoning and decision making under uncertainty is their main advantage. It all makes them appropriate tools for analysis of

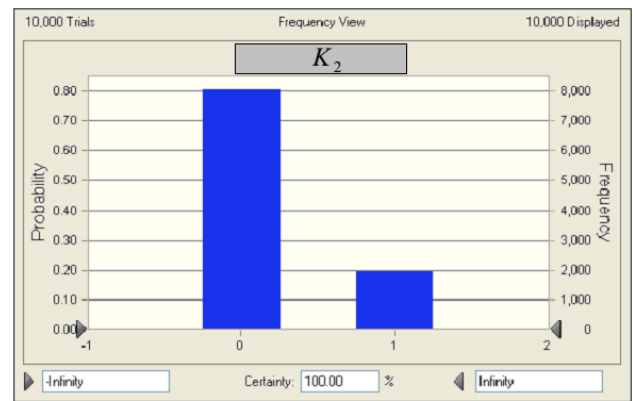


Fig.5. Estimation of parameter K_2

interactions and relationships characterising a railway undertaking which under certain conditions could turn into causal factors of accidents, e.g.: organizational deficiencies, operating environment influence, etc. Due to their simplicity to use, applicability and comprehensive results, Bayesian networks will become more popular analytical tool within all components of railway undertakings' SMSs.

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DIAGNOSTICS AND MODELING OF COMBUSTION ENGINES WEAR AND DEGRADATION PROCESSES

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Abstract: The paper deals with ways of applying mathematical methods to evaluate the result of tribodiagnostics related to vehicle combustion engines. The idea is based on a discriminative analysis that makes possible to describe one qualitative parameter (complex technical state) by means of several quantitative parameters (i.e. quantity of diagnostic parameters). The results have been verified by means of considerable statistical data of T-3-930 engines made in the Czech Republic which are used in ground vehicles.

Keywords: WEAR, TRIBODIAGNOSTICS, QUALITATIVE AND QUANTITATIVE PARAMETER, COMPLEX TECHNICAL STATE

1. Introduction

Generally, wear depends not only on the friction character (rolling or sliding) but also on a complex physical-chemical process occurring on the sliding surfaces of a tribological unit. An external undesirable product of the friction system action is a very wide range of wear particles. From the diagnostic point of view, it is important that these particles carry nearly comprehensive information about the mutual connection among individual elements of such a system, that is, what the conditions for production of the particles in individual friction couples are. A combustion engine is characterized by simultaneous contacts of many friction couples and, thus, also by simultaneous production of wear particles at all of these points. The problem is, on the basis of number, shape, size, or coloration of the particles, to determine what tribological processes are in progress in the engine. Wearing dynamics can be evaluated according to:

- material composition of particles,
- intensity of particles production,
- distribution of particles' size groups,
- morphology and shape of particles' surface features, etc.

Generally, the wear products can be categorized as follows:

Adhesive particles (rubbing wear particles)

These are "one-dimensional" particles, whose length and width are approximately equal, at 5-15 μm , but are only 0,25-0,75 μm thick. These particles are characteristic for wear of steel components therefore they have very good magnetic characteristics. During the ferromagnetic analysis, these characteristics can practically always be recorded. Their genetic origin is in the Beilby layer, from which they gradually spread and are washed off by the lubricant. Their number and especially their size characterize the adhesive wear intensity.

Abrasive particles (cutting wear particles)

They always characterize an improper mode of engine operation. From the tribo-technical point of view two origins of abrasive particles may be indicated:

- a) – Action of a heterogeneous particle between friction surfaces results in strong surface scratching, tribological mode changes, and rapid wearing of the friction surfaces. The abrasive wearing has its origin in, for example, siliceous powdery particles that leak into the engine through insufficiently tight of air filters.
- b) – Penetration of a harder material of the friction couple into a softer one. The probability of forming particles in this way increases when friction couples with a considerable difference in their surface hardness are contacting.

In any case, abrasive particles are of a characteristic of a "micro-cut" or of a coiled "thin wire" shape. The shape considerably differs for those abrasive particles that infiltrate into

the engine after a partial or complete disassembly, that is, during running-in mode (cutting wear). They are shaped into crescents or swords with sharp protrusions on their ends. Generally, the size of abrasive particles ranges in the interval of 50-300 μm with a very short thickness of 0.25 μm , Fig. 1.

Spherical particles (spherical debris)

They belong to the main types of particles originating in fatigue wear of a rolling kind. Generally, they originate in consequence of Beilby layer fatigue on internal or external surfaces of bearings. The spheroids' dimensions are relatively short $\varnothing 2 - 5 \mu\text{m}$. In the Ferro scope lens, they appear like little black points; with better magnification, a polished surface with light reflection in the center is evident. The presence of these particles on a ferrogram signalizes an ongoing failure of anti-friction bearings. It has been verified by experiments that one rolling element is able to produce 6 – 7 million of spheroids before a failure occurs.

Laminar particles

Most often originate as a consequence of redistribution processes in lubricating systems. Repeated flow of oil and, therefore, also flow of particles through the system results in particles' plastic deformation (for instance, between a rolling element and a ring path). Rolling out the spheroids and other tri-dimensional particles results in thin flat laminas of minute thickness. Their length ranges from interval 40 to 250 μm and their width from 10 to 50 μm . Particles are characterized by a plain surface and irregular edges. As a rule, the presence of these particles is attended by the presence of spheroids; in these cases, the process of a gradual failure of the anti-friction bearing has begun.

Fatigue particles

They characterize the most common failure of tooth wheels. These are tri-dimensional particles with a comparable length, width, and thickness. The particles' surface is irregular, scratched with irregular sectioned edges. Dimensions of these particles fluctuate from 10 to 150 μm . Fatigue particles can further be divided into two groups:

- a) The "chunky" (micro-prism) type has an irregularly rugged surface and a size of 10-80 μm ; on the surface, they usually have secondary originated inclusions.
- b) The "scuffing" (high-temperature abrasion) type comes up on the teeth sides of tooth wheels during high pressure and temperature, Fig. 2. The particles' material is usually thermally affected, which is indicated by particles' coloration of distemper tints.

Abnormal particles (severe wear particles)

The extreme and breakdown wear particles that originate with seizing or a strong abrasion. They arise from mechanical deterioration of the Beilby layer under the action of an excessive load. In the touch-point of friction surfaces, this layer does not have

the necessary loading capacity and is scratched off. The abrasion rate is so high that the Beilby layer's restoration is impossible. During the diagnostic analysis, it is then impossible to register any adhesive abrasion particles that are replaced by tri-dimensional particles, always with a characteristic sharp edge and dimensions of 30-70 μm .

Non-ferrous particles

Their appearance may be similar to abnormal particles (severe wear particles), especially because of their shape and size. They always differ in their coloration and magnetic features. They originate as a result of contacting steel and nonferrous metals alloys during the adhesive mode of abrasion.

Iron oxides – magnetite Fe_3O_4 originates under high temperatures and pressures, mainly owing to insufficient lubrication of the friction surfaces. The surface of these particles is black, plain, and of a shingle character; the size of these particles fluctuates around 5 μm . The high-temperature oxides presence relates to abrasion of the materials made of a high-strength steel or a bearing steel. Alpha-hematite Fe_2O_3 signals corrosion of the machine function surfaces by action of water. Pink or red hematite particles can be recorded by analyses of samples taken during the running-in mode of engine operation.

Corrosive and other particles

During tribodiagnostic analyses, the presence of secondary originated non-metallic particles can also be recorded, except for metallic abrasion. Dust particles – small spherical or prismatic particles – silicates with a size of up to 30 μm . They are translucent and clear. Tribopolymers – are shaped into spherical particles or tiny cylinders in the amorphous form. The tribopolymers core is always composed of submicronic steel particles. Organic substance of the particle can be dissolved with an appropriate solvent or by heating it at more than 300°C. Fibers mainly originate from filtration materials. Cotton fibres are ribbon-like in shape; synthetic fibres are straight, with conspicuous luminous refraction on their edges.

Stated characteristics of the most important categories of particles signal the fact that there are two origins for particles indicated:

1 – Primary particles – generated directly by the friction couples. They characterize directly the abrasion mode according to generally known findings.

2 – Secondary particles – originate from a transformation of primary particles after repeated passage through the system. The relative rate of presence of primary and secondary particles depends on several factors, for instance, on the lubricating medium's volume, number and efficiency of oil filters in the system, efficiency of other processes of particles separation from the system, real thermal and mechanical load of the engine, number of tribological units, the type of lubricating oil used, etc.

The difference in effect of factors mentioned during evaluation of individual engines requires separate monitoring of each type and design type of the combustion engine.

For evaluation of the wear mode of machine groups (engines, gearboxes, etc.), in practice, two basic strategic approaches are used:

- 1 – trend evaluation of the wear mode using time series.
- 2 – multidimensional statistic monitoring and its evaluation.

Specific features characterize both of these approaches, and it is impossible to consider one as absolute and exclude the other one.



Fig. 4 Strong cutting wear steel particle, so-called two-point abrasion. Harder member of the friction pair penetrates into softer member of friction pair and separates chips from it. Magnified 1000 x.



Fig. 5 Ferrogram from oil diesel engine. Spheroid always indicates the development of fatigue crack. Magnified 1000 x.

2. Trend evaluation of the wear mode

During normal engine operation, a balanced concentration of the wear products develops in the lubricating medium. This means that the concentration speed of various origin wear products equalizes with the speed of mechanisms removing the wear products from the lubricating medium. Removal of these wear products is carried out mainly by filtration and sedimentation, followed by loss of oil from the system and chemical reactions. Owing to the complexity of the problems related to reactive kinematics of organic ingredients contained in the lubricant and generated here as a consequence of chemical reactions for the duration of lubricant exploitation, it is impossible to obtain the data needed for reactive kinematics calculation. The balance equation expressing the substances balance between inflow of wear products from the friction points of the system into the lubricant and their decrease owing to the action of individual decreasing mechanisms can be derived from a deterministic model Fig. 3 and Fig. 4. The basic differential equation expressing the dynamic balance in the model under consideration is:

$$V \cdot c + m \cdot dt - c \cdot f \cdot p \cdot dt - c \cdot Q \cdot dt = (c + dc)(V - Q \cdot dt) \quad (1)$$

where

V ... oil volume in the lubricating system (dm^3),

c ... concentration of wear products in lubricant medium at the time t (mg/dm^3),

f ... total coefficient of wear products decrease (mg/s)

p ... oil quantity delivered to the engine friction points (dm^3/s),

Q ... oil loss volume (dm^3/s).

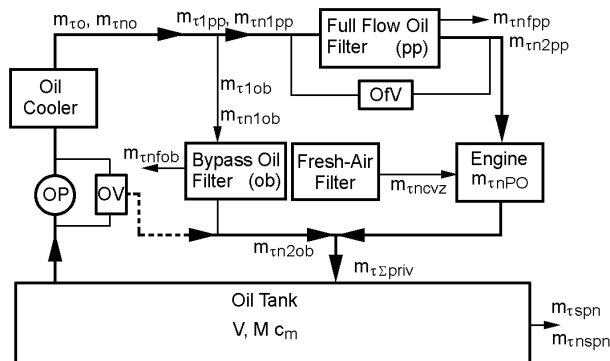


Fig. 9 Lubricating oil system of combustion engine.

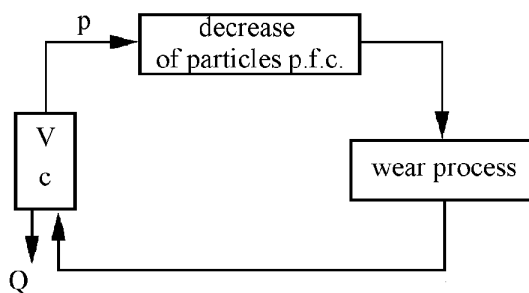


Fig. 10 Diagram showing the process of production and decrease of wear products in the lubricating system of a combustion engine.

The instantaneous volume of lubricant V varies during the time as a result of loss of lubricant in the system (caused by leakages, burning, etc.) according to the relationship:

$$V = V_0 - Q \cdot t \quad (2)$$

where

V_0 ... initial lubricant volume at the beginning of the given time period.

The loss coefficient f represents generally all the loss mechanisms acting inside of the considered system (that is, filtration, sedimentation, chemical reactions, etc.).

Wear products' generation speed m represents dynamics of the wear process (degradation), which varies in time. The general expression for this change is usually stated in linear dependence on the time t :

$$m = m_0 - a \cdot t \quad (3)$$

where

m_0 ... initial speed at the beginning of the time period,

a ... acceleration.

To enable the solution of the equation and to determine the resulting relationship for calculation of the speed of wear products generation, the following simplifications are recommended:

- in the given time period between two sequential sampling values, the m and Q are considered to be constant,

- the value of the coefficient f is estimated on the basis of oil filters' pervious action and the speed of wear products' sedimentation.

In the case of products of oil degradation reactions, the loss coefficient is not considered because as K matter is to determine the concentration of relevant substances dissolved in the lubricant.

After substitution for V according to the relationship (2), modification and dereliction of the expression of the second order (i.e. $Q \cdot dc \cdot dt$), the equation transforms to the form:

$$(m - c \cdot f \cdot p) \cdot dt = (V_0 - Q \cdot t) \cdot dc \quad (4)$$

which can be further modified as

$$\frac{dt}{V_0 - Q \cdot t} = \frac{dc}{m - c \cdot f \cdot p} \quad (5)$$

After integration in the limits c_1 to c_2 for c , t_1 to t_2 for t and after the final modification, we will get the final relationship for the mean speed of wear products generation:

$$m = \frac{(c_2 - c_1 \cdot e^A)}{1 - e^A} \cdot f \cdot p \quad (6)$$

$$A = \frac{f \cdot p}{Q} \cdot \ln \left(\frac{V_0 - Q \cdot t_2}{V_0 - Q \cdot t_1} \right) \quad (7)$$

However, during operation of real combustion engine vehicles, the lubricating medium is continuously refilled, and thus the calculation of m is correspondingly more complicated. After each oil refilling by the volume V' to the original volume V_0 , the original concentration of wear products c changes to c' :

$$c' = \frac{c \cdot V}{V + V'} \quad (8)$$

During the number of n constant time cycles and the number of a refilling with a constant volume of oil to the V_0 and on all of the premises mentioned above, the main speed of wear products generation can be calculated according to the relationship:

$$m = \frac{(c_n - c_1 \cdot B^{2n-1} \cdot e^A)^n \cdot (1 - B \cdot e^A) \cdot f \cdot p}{(1 - e^A) \cdot (1 - B^2 \cdot e^A)} \quad (9)$$

where

$$B = \frac{V_0 - V'}{V_0} = \frac{V_0 - Q.t}{V_0} \quad (10)$$

However, the stated theoretic calculations must be applied to conditions of factual operation of vehicles with combustion engines. To deduce appropriate conclusions and to describe long-term trends of monitored indices developments, it is necessary to determine their trend, that is, to replace the progression of empirical values with a progression of values without a random fluctuation and, thus, to equalize interval time series using a suitable method. For equalizing time series, an analytic equalizing is frequently used in technical routines. This equalizing consists of describing the course of given time series by a simple theoretic and analytic function of the type $y = f(t, b)$ where t is a time variable and b represents a vector of unknown parameters. In principle, this is a simple regression where the time series index features a dependent variable and time (time variable) an independent variable. To determine the “best” values of parameters, the minimum of sum of deviations (residua) squares of the measured and calculated magnitudes of a dependent variable is used as a regress criterion in technical routines most often.

$$U = \sum (y_i - Y_i)^2 = \min \quad (11)$$

Where the function U is called the objective function, which is minimized during the calculation of parameters.

As the whole progression of nonlinear dependences can be transformed using an appropriate transformation to a linear dependence, the linear regression method is used most often

$$y = (b_1 \pm s_{b1}) + (b_2 \pm s_{b2})t \quad (12)$$

Coefficients of the regression linear equation will be determined providing that partial derivations of the objective function U must be zero; then, by solving them, the estimations will be obtained

$$b_1 = \frac{(\sum y_i - b_2 \cdot \sum t_i)}{n} \quad (13)$$

$$b_2 = \frac{\sum t_i \cdot \sum y_i - n \cdot \sum t_i \cdot y_i}{(\sum t_i)^2 - n \cdot \sum t_i^2} \quad (14)$$

The trend value, as a criterion for serviceable condition of the engine and its lubricant medium, respectively the upper or lower limit of the interval of gradient of regression line reliability can be then considered.

$$L = b_2 \pm s_{b2} \cdot t_\alpha \quad (15)$$

and parameters of the line

$$s_{b2} = \frac{S_{y,t} \cdot n}{\sum t_i^2 - (\sum t_i)^2} \quad (16)$$

$$S_{y,t} = \sqrt{\frac{U}{n-2}} \quad (17)$$

where

s_{b2} ... standard deviation of the coefficient b_2 ,

t_α ... critical value of the “Student division” for selected level of importance,

$s_{y,t}$... standard deviation characterizing scattering of outcomes along the given regression line.

3. Multidimensional statistical evaluation

Modelling of stochastic magnitudes characterizing a real condition of equipment is an important element in tribotechnical diagnostics application. Besides the trend approach, the probability model can also be used. Such a model enables us to define one qualitative variable u by means of several quantifiable parameters $X_1, X_2, X_i \dots X_p$. The primary set, as well as the informative selection which represent the primary set, are subsequently resolved into several groups (generally “ k ”). Individual groups have to correspond to variants of the variable “ u ”. A priori probability of belonging to groups is

$$\pi_h \approx P(A_h), h = 1, 2, \dots, k, \quad (18)$$

where

π_h ... probability of belonging to the group of number h

$P(A_h)$... probability of the event A_h and it can be estimated according to the informative selection structure.

$$\pi_h = \frac{n_h}{n}, \quad (19)$$

where

n_h ... the number of elements in the group h ,

n ... the number of selection elements.

After carrying out multidimensional observations “ x ” a-posteriori probability can be determined using the Bayes formula:

$$P(A_h / x) = \frac{\pi_h \cdot f_h(x)}{\sum_{h=1}^k \pi_h \cdot f_h(x)}, \quad (20)$$

where

$P(A_h/x)$... conditional probability of the phenomenon A_h/x ,

$f_h(x)$... conditional density of probability of the complex of “ p ” considered variables for $h = 1, 2, \dots, m$.

f_h ... vector of coefficients in the h^{th} group,

x_i ... vector of measured values.

To categorize unknown elements, it is necessary to provide for a decision-making rule for their classification within individual groups. The selection area is divided into “ k ” not-overlapping classification areas. Each element is categorized into such a group where the a-posteriori probability will be maximal, and, simultaneously, the incorrect classification probability will be minimized. The total probability of incorrect classification can be described by the equation

$$\omega = \sum_{h=1}^k \pi_h \sum_{h' \neq h}^k P\left(\frac{x \in \varphi_{h'}}{A_h}\right) = \sum_{h=1}^k \pi_h \sum_{h' \neq h_{\text{opt}}}^k \int f_{h'}(x) dx \quad (21)$$

where

ω ... total probability of incorrect classification

$\varphi_{h'}$... area into which the object is incorrectly classified

For objects classification, it is sufficient to search for the group where the numerator in the Bayes formula (20) is maximal, because the denominator is common for all groups.

$$\psi_h = \pi_h \cdot h_h(x) \quad (22)$$

By expressing the probability of multidimensional normal classification by logarithmic calculation and omission of the addends, which are common for all of the groups, we obtain a quadratic discriminative score

$$\psi_h^{(Q)} = x' \cdot \varphi_h \cdot x + v_h \cdot x + \rho_h \quad (23)$$

with a matrix of quadratic form

$$\varphi_h = \frac{1}{2} \cdot \sum_h^{-1} \quad (24)$$

a vector of linear coefficients

$$v_h = \mu_h \cdot \sum_h \quad (25)$$

and a constant

$$\rho_h = 1n\pi_h - \frac{1}{2}1n\left|\sum_h\right| - \frac{1}{2}\mu_h \cdot \sum_h^{-1} \cdot \mu_h \quad (26)$$

where

$\Psi_h^{(Q)}$... quadratic discriminative score,

x' ... line vector of values,

x ... column vector of values,

φ_h ... quadratic form matrix in group h ,

$\sum_h^{-1}$... inverse matrix to covariant matrix in group h ,

v_h ... vector of linear coefficients in group h ,

μ_h ... vector of mean values in group h ,

ρ_h ... quadratic discriminative constant of the group h ,

π_h ... a posteriori probability of belonging to the group h ,

$|\sum_h|$... determinant of covariant matrix of the group h .

If another condition of covariant matrices correspondence is observed, discrimination can be performed by means of a linear discriminative score.

$$\psi_h^{(L)} = \alpha_h \cdot x + k_h \quad (27)$$

with a vector of coefficients

$$\alpha_h = \mu_h \cdot \sum_h^{-1} \quad (28)$$

and a constant

$$K_h = 1n\pi_h - \frac{1}{2}\alpha_h \cdot \mu_h \quad (29)$$

where

$\psi_h^{(L)}$... linear discriminative score in the h^{th} group,

α_h ... vector of coefficients in group h ,

K_h ... linear discriminative constant (constant of the h^{th} group).

$\wedge$... over π_h it indicates the choice probability of belonging to the h^{th} group.

$\bar{\mu}_h$... vector of mean values in the h^{th} group.

The discrimination efficiency can be verified by means of substitution that is application of discriminative classification on a selective set and percentual expression of incorrectly classified objects.

4. Results and discussion

The above methodology of evaluating multidimensional diagnostic signals has been applied to objective evaluation of results obtained by means of ferrographic analysis. Four basic groups of engines were indicated, as follows:

1. Current wear - this group involves all the states characterized by absence of increased quantity of inadmissible particles.

2. Limit wear - this group is characterized by the presence of particles of an inadmissible type. Such an engine needs intensive examination.

3. Critical wear - this group involves an engine threatened by a serious defect of some part within the engine. Further operation of such an engine should not be allowed with respect to technical and/or economical viewpoints.

4. Running - in mode - this group is characterized by the phase presence of particles typical for this and inadmissible in other phases of the engine operation.

All the modes of wear are modelled, according to the number of types of particles present in oil samples. It is known in advance what kind of engine they come from. The results are compared by considering the number of particle types in a 1 ml oil sample, used for preparation of the ferrogram. During analysis of the ferrogram, nine particle types were detected:

1-Cutting wear particles, 2-Laminar particles, 3-Fatigue particles, 4-Spherical debris, 5-Severe wear particles, 6-Corrosive particles, 7-Oxide particles, 8-Non-ferrous metallic particles, 9- Others.

For every particular group, the mean values of the number of particle types were determined and numbered as shown in Table 1. Using these mean values in compliance with Eq.(27) a parameter can be formed called the complex ferrographic parameter F . The parameter makes possible to describe the dependence of a latent implicit parameter of the current state of the engine wear by means of vector of measured values, i.e., number of particular types of particles (29).

Based on results of the selective set, the complex parameter can be written in the form:

$$F_h = f'_h \cdot x_i - K_h \quad (30)$$

where

F_h ... values of the parameter F in the h^{th} group.

The vector of coefficients is an element, which involves internal coupling of selective statistical sampling. It is based on the relation:

$$f'_h = x_h \cdot V^{-1} \quad (31)$$

where

V^{-1} ... inverse of covariation matrix of the selective set.

The constant in Eq. (30) involves first of all the demands on vector ranging in accordance with a reselected criterion, i.e.:

$$K_h = 1n\pi_h - \frac{1}{2}f'_h - x_h \quad (32)$$

In the above procedure, Eqs. (30) - (32), a selective set of oil samples has been worked out. For predestinated groups there were particular parameters numbered as shown in Table 2. Any unknown vector of measured values can be assigned to one of the indicated groups. This means it will be placed in the group of maximum parametric value.

Applying the ranging criterion to the original selective set, the quality of the assigning method and the quality of the description of particular indicated groups of engines can be evaluated. From the total number of samples (106) involved in the selective set, 98 samples were evaluated correctly, i.e., full compliance with the actual state of the engine, known before. Standard deviation of determination of the technical state of the engine is about 7,6 %. The standard deviation of each particular group is given in Table 3. Higher values of the relative standard deviation in the IVth group (running-in mode) are closely connected with poor knowledge of

the course of tribological phenomena during running in of engine T3-930. To decrease this value it is necessary to consider a larger statistical set formed to describe all the indicated groups with the same validity. The above method of evaluating ferrographic analysis is suitable for a large number of ferrography users. It is rather difficult to count particular types of particles, but the counting is defined precisely and the results obtained are unambiguous. Once the ferrosopic evaluation of the ferrogram has been mastered, there is no other difficulty in using the above method. The group characteristics specified is valid for the T3 - 930 engines. When dealing with an engine of another type, it is necessary to verify the validity by further research. An important factor to note is that the decisive feature for assigning an element to a certain group is not the value of the parameter F, but the maximum value of the parameter. This is the difference in application of discriminative analysis in comparison with applications published in the open literature.

Table 1: Vectors of mean values in particular groups.

Type of Particle Code	MEAN VALUES OF NUMBER OF PARTICLES IN GROUPS			
	CURRENT [pcs/ml]	LIMIT [pcs/ml]	CRITICAL [pcs/ml]	RUNNING-IN [pcs/ml]
1	1.560	4.539	6.979	5.426
2	1.501	3.934	6.548	0.917
3	0.737	3.207	6.827	1.170
4	1.208	3.238	5.110	0.629
5	0.486	2.543	5.117	1.046
6	0.971	2.508	4.102	2.510
7	0.489	2.533	5.681	0.719
8	1.809	4.005	5.636	0.464
9	0.789	2.649	5.100	1.874

Table 2: Ferrographic Characteristic of Groups.

Group Parameter	Vectors of Coefficients $f_{i,h}$ and Constants of Groups K_h			
	Current	Limit	Critical	Running-In
1	0.718	1.350	0.632	2.067
2	0.609	0.771	0.600	0.031
3	-0.839	1.236	-0.206	-1.175
4	0.703	1.179	0.644	-0.172
5	-0.787	-0.489	-0.501	-0.416
6	0.405	0.352	0.598	1.395
7	-1.175	-1.703	-0.553	-1.738
8	1.171	1.715	0.900	0.370
9	0.029	-0.135	0.459	0.876
K_h	1.921	5.425	7.195	6.696

Table 3: Standard Deviation of Groups.

GROUPS	I	II	III	IV
S_d (%)	6.35	8.33	8.33	14.30

5. Conclusion

The considerably simplified model presented here enables applications of multidimensional classification of particular ferrographic (or other) oil analyses and shows the utilization possibilities of this method for interpretation of tribodiagnostic check-up results. However, the practical exploitation depends on particular tasks to be solved. The trend evaluation performs a methodical function during evaluation of tribodiagnostic measuring results. But interpretation of results still depends on the qualifications of the expert who can judge individual changes, their size, and deviations from normal state. These facts somewhat complicate putting tribodiagnostics into practice, because reliable results depend on the qualifications and experience of the expert.

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PROACTIVE MAINTENANCE OF MOTOR VEHICLES

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Abstract:

In this article the author describes particular maintenance systems used in the past, some of which are used also at present. The basic maintenance systems include maintenance after use, preventive maintenance with predetermined intervals, and conditioned-based preventive maintenance - predictive maintenance. The current trend in the field of vehicle maintenance tend to continuous monitoring of their actual status. By the help of a vehicle monitoring in use, it is possible based on current operating parameters to determinate the technical condition of the vehicle parts. Ideally to prevent the failure or damage of groups of vehicle. Tracking of vehicles in use can be effected through the telemetry. Telemetry is a technology that allows remote measurement and reporting of information.

KEY WORDS: PREVENTIVE MAINTENANCE, PROACTIVE MAINTENANCE, PREDICTIVE MAINTENANCE, TELEMaintenance, ON-BOARD DIAGNOSTICS.

1. Introduction

Quality and reliability control and the choice of optimal maintenance methods cannot be realised at present without properly functioning technical diagnostics. Thanks to the use of technical diagnostics, the maintenance itself has reached a new level which in a sense may be labelled as a completely new, generation different maintenance system.

Technical literature provides a number of definitions of "maintenance", more or less influenced by their authors or by the A vehicle is either in usable or unusable condition. Our aim is to maintain the vehicle in usable condition, which means to prevent its failures and limiting condition. This aim shall be achieved upon the lowest vehicle life cycle costs possible while keeping inherent reliability of the vehicle for the whole operating time. This is manifested in particular maintenance systems since the 1930's until the present, which is shown in Figure 1. In general, maintenance system approaches may be divided as follows:

force of a norm upon which they are based. For the purpose of this article, the following definition according to [1] is used: "Maintenance is a combination of all technical, administrative, and managerial activities during a life cycle of an item aimed at maintaining the item in condition, or returning it to condition, in which it can perform a required function."

2. Development of maintenance approaches

1. Corrective maintenance system.
2. Preventive maintenance system – schedule based.
3. Preventive maintenance system – condition based:
 - a) Predictive maintenance system.
 - b) Proactive maintenance system.

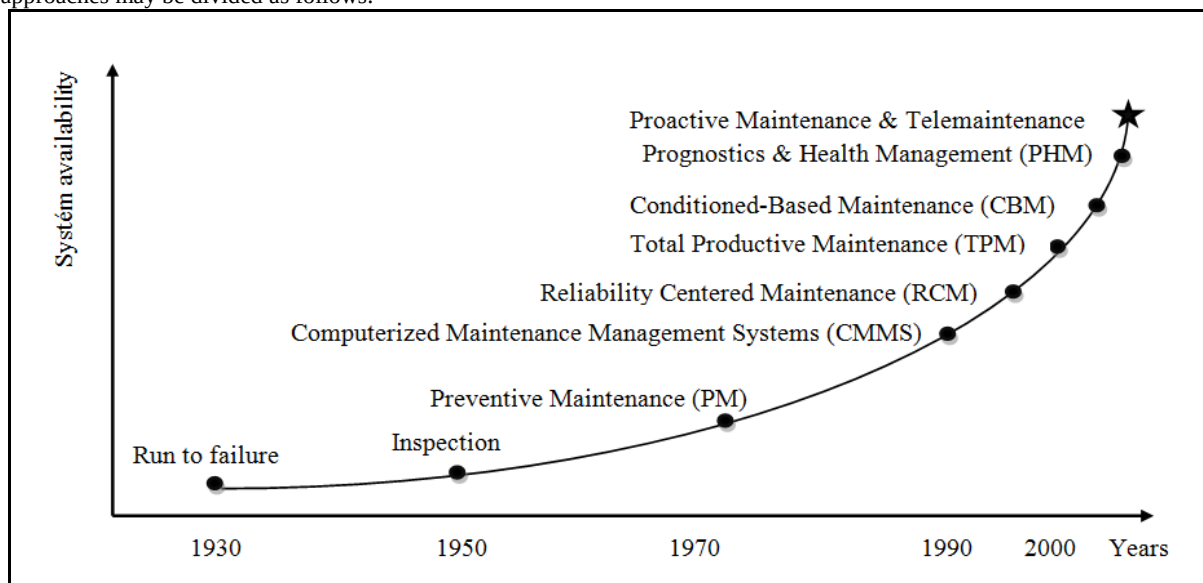


Fig. 1. Development of maintenance approaches since the 1930's [3]

2.1 Corrective maintenance system

This maintenance system represents the lowest level of the maintenance approach. It is maintenance performed after failure condition has been detected and aimed at bringing the item to condition in which it can perform required functions of the given equipment. In practice this means that the equipment is operated without supervision for its whole durability and maintenance is performed only when a failure occurs. In this case repair costs are high, including loss due to the vehicle being out of operation.

Corrective maintenance (1st generation maintenance) may be applied to simple and cheap machinery in which 100% backup and

prompt repair or replacement may be provided. This type of maintenance is obviously suitable only in these cases:

- The broken part may not be repaired or is not worth repairing.
- The machinery is cheap compared to maintenance costs.
- The part replacement is very fast, technically feasible and economically acceptable.
- No other maintenance method is possible to be performed.

In later years, corrective maintenance started to be completed with so called **Inspection**, the aim of which is to verify the compliance by measuring, monitoring, checking or comparing significant characteristics of the vehicle performed during the primary failure removal.

2.2 Preventive maintenance system with predetermined interval

This system is still frequently used since in principle it comes from the theory of reliability. Upon theoretical reliability and practical experience from a similar technique fixed time intervals are set for performing the “service maintenance”, it is so called “schedule-based maintenance”. Preventive maintenance is maintenance performed in predetermined intervals or according to specified criteria, and aimed at reducing the probability of failure or degradation of the item operation. [1].

An advantage of this system is the prevention of failure and thus reduction of corrective maintenance costs. However, preventive maintenance costs will increase. The aim is to keep the maintenance costs as low as possible. In practice the total maintenance costs are relatively high, but in the overwhelming majority of cases lower than for “corrective maintenance”. Another advantage is even distribution of costs in time, and the fact that costs incurred by a vehicle dropout are lower and mostly planned in advance.

A fundamental drawback of scheduled maintenance is the fact that the period (maintenance interval) is often shortened due to the reduction of failure risks and the action is performed on a vehicle which does not exhibit wear signs. Therefore maintenance costs increase and actions performed reduce planned durability of the vehicle. It is true that every useless dismounting and mounting of a part or assembly, or disassembling and assembling the whole vehicle, changes distribution of clearances and brings further unknown static and dynamic loads to the run-in vehicle. This leads to its increased wear and fatigue damage occurrence.

This maintenance system was gradually developed and completed in order to achieve maintenance costs reduction and keep inherent reliability of the vehicle. Higher efficiency was achieved by introducing so called “**Computerized maintenance management system - CMMS**” which leads to significant improvement of the maintenance efficiency by making information on performing individual types of maintenance more available [2].

The schedule-based preventive maintenance system was further completed with so called “**Reliability centred maintenance – RCM**”. This method is based on a systematic approach for the identification of purposeful and effective tasks of preventive maintenance which are performed in compliance with a specific set of procedures for determining intervals between the maintenance tasks. The aim is to improve overall safety, availability, and efficiency of the operation. It is also based on monitoring the total vehicle life cycle costs.

Further improvement of the schedule-based preventive maintenance system brings so called “**Total productive maintenance – TPM**”. The performance of each organisation depends especially on work organisation, utilisation of basic equipment, and qualification level of its employees. To achieve maximal performance the organisation must utilize optimally the vehicle productivity. In terms of losses, the vehicle maintenance represents a significant area where productivity should be increased and resources for cost reduction

sought. TPM utilizes abilities and skills of all employees with the aim to significantly reduce downtimes of vehicles and individual losses in their usage. On this account, organisations are strongly advised to use this progressive approach [3].

2.3 Preventive maintenance system – condition based

Technical condition based maintenance was gaining importance in past decades with the expansion of technical diagnostics. It is preventive maintenance comprising of monitoring performance or parameters and of consequent measures. Its main benefit resides in consistent removal of failures. Particular worn parts and parts or whole assemblies in the risk of failure are repaired or replaced optimally in advance. Thus failure occurrence is prevented. This technical condition-based maintenance system may be divided to:

- a) Predictive maintenance
- b) Proactive maintenance.

ad a) Predictive maintenance

This is condition-based maintenance performed upon a prediction derived from an analysis and evaluation of significant parameters of the item degradation. An action is performed on the item only when it is technically and organisationally justified sufficiently enough to maximally exhaust technical durability of the critical part, and at the same time unexpected accident was prevented. In other words, this is maintenance residing in a statement that only that is necessary to be repaired on the item and only then if it is indispensable. The maintenance itself is based on periodical evaluation of technical condition. Maintenance mechanisms applied to the vehicle allow yielding information on the change of technical condition of monitored parts. Such information is processed with the aim to estimate remaining durability, and thus to commence the process of a technical action (remedy). For monitoring signs of developing damages “Condition Monitoring”, usage of specialised instruments is required, designed for collecting and evaluating information. These instruments utilize so called technical diagnosis. The equipment is to be monitored and evaluated constantly, or at least periodically.

Costs of the maintenance itself are several times lower than in the previous alternatives. The vehicle downtime for the time required for preventive maintenance is usually negligible in comparison with corrective maintenance. However, initial costs of purchasing the diagnostic systems are relatively high. Therefore it is necessary to consider whether these costs of purchasing the technical diagnostics instruments together with maintenance costs will/will not be higher than maintenance costs without using technical diagnostics [8].

ad b) Proactive maintenance

Proactive maintenance is considered another higher level of maintenance. It is completely based on the previous predictive maintenance which it further improves so that its basis is the utilization of more complex technical diagnostics. Basically it is the top current version of predictive maintenance based upon actual condition of the item operated. It is analysed in detail in the following chapter.

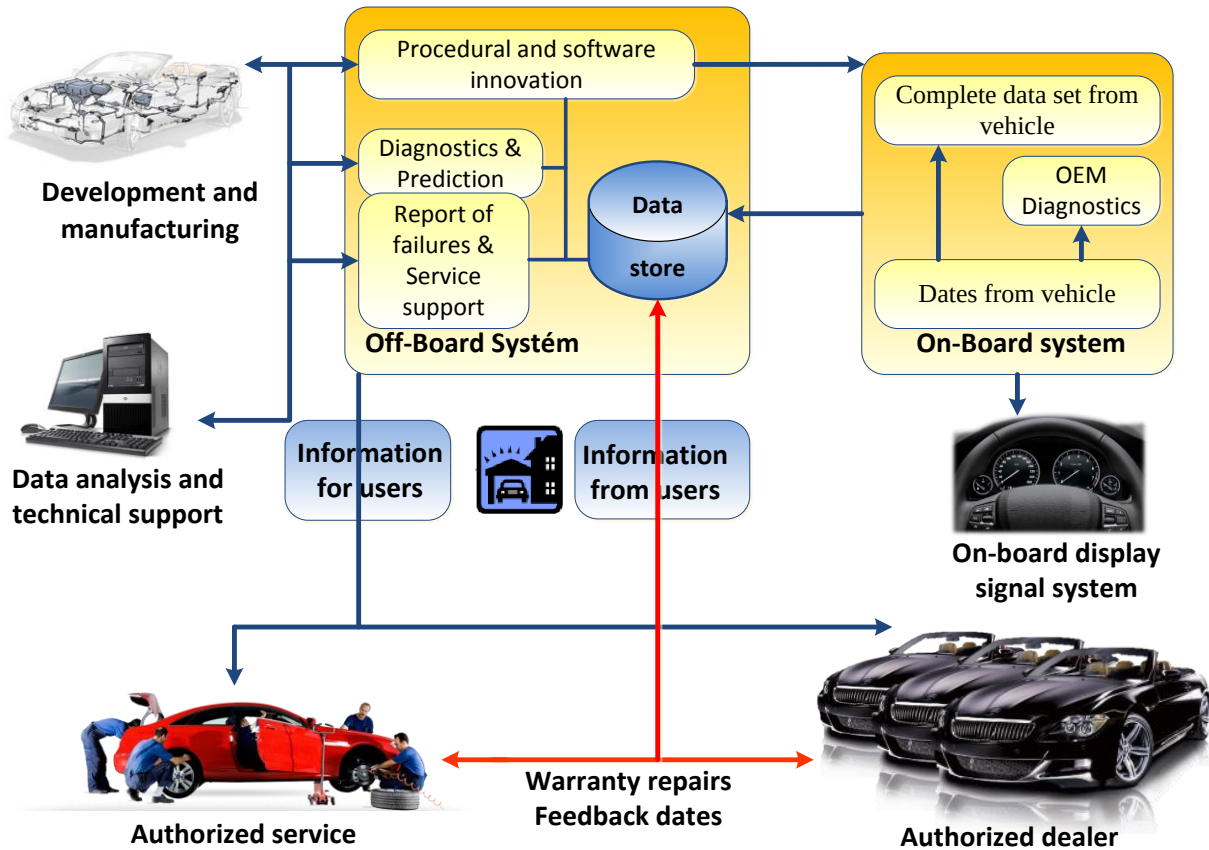


Fig. 2. Design of predictive maintenance

3. Results and discussion - Proactive maintenance system

One of the latest trends in maintenance systems is proactive maintenance completed with so called “telemaintenance”. The proactivity is manifested also in the fact that new vehicles are designed with respect to an easy access to their integral diagnostics. Possible connection of diagnostic systems, location of sensors and measuring spots for monitoring vibrations, temperatures, lubricant sampling and detection of other selected parameters should be considered during the vehicle design.

Proactive maintenance arose from the predictive maintenance type as a reaction especially to long-term findings that a certain group of failures repeats periodically upon clear causes. Known causes include mainly the following:

- Incorrectly organised maintenance work.

- Incorrectly performed maintenance (technical operation in the vehicle).
- Unqualified operators and maintenance personnel [3].

The proactive maintenance type is aimed at keeping inherent reliability of the vehicle on an acceptable level. As a source of information technical diagnostics is utilized. The main objective of proactive maintenance is:

- Further reduction of maintenance and operational costs.
- Prevention of failure occurrence and thus extension of an interval to preventive maintenance, meaning extension of the vehicle durability.
- Statistic control of accidental and systematic influences affecting the vehicle operability [3].

Proactive approach means not only monitoring and evaluating the vehicle condition, but especially performing such actions that prevent or at least postpone damage occurrence.

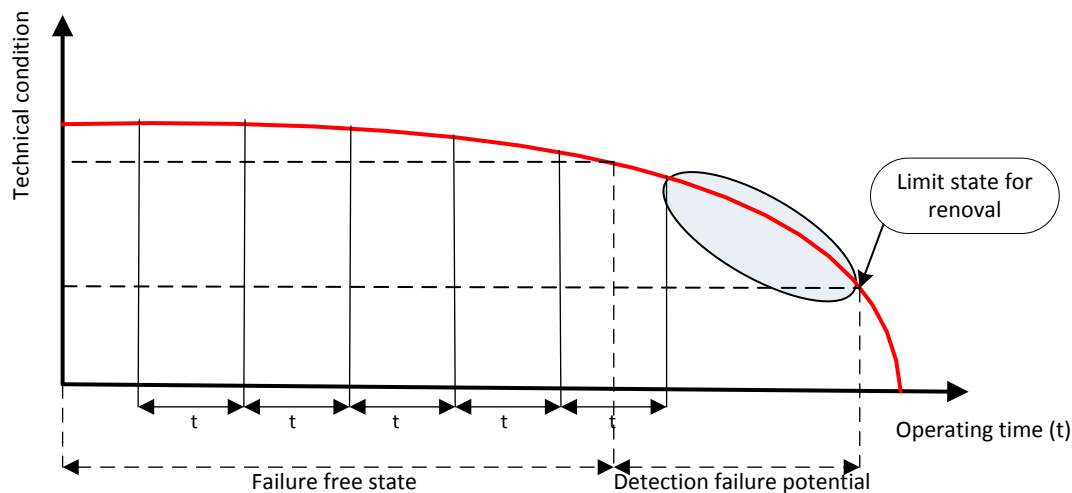


Fig. 3. Machine components technical condition of dependence on operating time

On-board diagnostics OBD is a label for diagnostic system installed in the vehicle system to ensure the control of exhaust emissions, which must be able to indicate failure and probable causes using the fault codes stored in the control unit memory. The aim is to ensure OBD standards throughout the life of your vehicle minimal amount of exhaust emissions [7].

The OBD II is characterized by monitoring these parameters to emissions:

- a) monitoring the lambda sensors,
- b) monitoring the fuel system and the air supply,
 - fuel injection pressure,
 - ignition advance,
 - intake air temperature,
 - intake air quantity,
 - absolute pressure in the intake pipe,
- c) monitoring the effectiveness of the catalyst,
- d) monitoring the exhaust gas recirculation,

Other parameters monitored:

- e) standardized output operational data,
 - vehicle speed,
 - engine speed,
 - coolant temperature and oil etc.,
 - engine oil pressure,
- f) monitoring of braking systems (ABS, ASR, ESP, etc.),
- g) monitoring of safety systems - airbags and anti-theft,
- h) monitoring of transmission (mostly automatic),
- i) condition of brake pads,

- j) condition of brake fluid,
- k) condition of the spark plugs,
- l) monitoring of active chassis - control wheels, suspension settings etc.,
- m) condition of accumulator battery and wiring,
- n) monitoring of engine oil quality.

The OBD system must be equipped with control lamp errors - MIL (Malfunction Indicator Light).

Detecting the state and quality of the engine oil is one of the newest ways using internal sensors. These are mounted directly on the engine. The measured data are transmitted using the CAN bus of the vehicle and then evaluated using the OBD II [9].

Sensors detect oil quality:

- amount of oil,
- temperature of oil,
- index TBN (Total Base Number) - measuring ability to neutralize acids - affects the oxidation and corrosion, oiliness and viscosity,
- dynamic viscosity of oil - η ,
- specific density of oil - ρ ,
- for diesel engines soot content in oil,
- water content in the oil,
- electrolytic conductivity - G , measures the concentration of salts and acids,
- permittivity - ϵ_r .

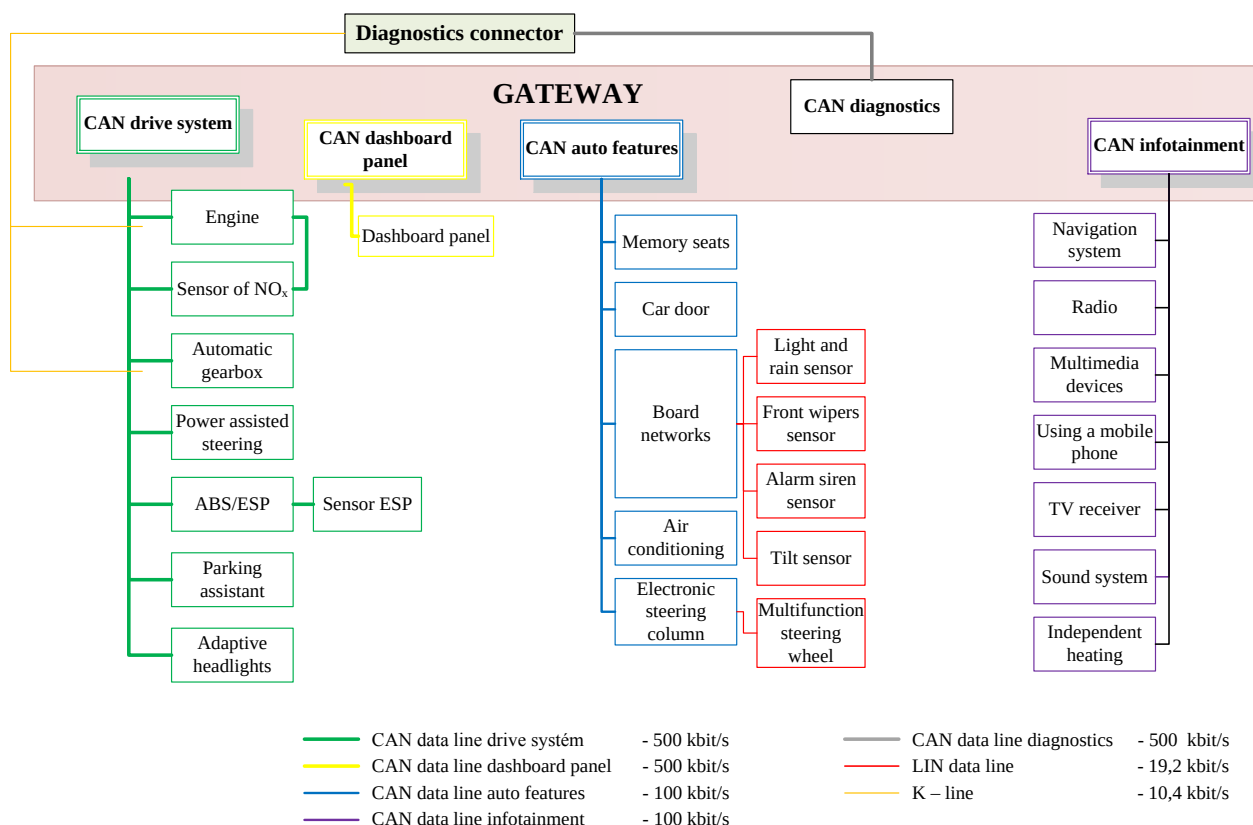


Fig. 4. Electric scheme for OBD vehicle

Predictive and proactive maintenance systems are based on information obtained from vehicle sensoric networks, which are inherently installed in vehicle. Therefore emphasis is put on installation of sensors in vehicles subsystems and also on their connection in backbone network with the intention to obtain efficiency of whole electronical vehicle diagnostics. CAN, LIN and other buses are already used for these purposes. One of the biggest requirement on OBD (on board diagnostics) is the creation of Gateway with single output diagnostics connector (Fig. 4).

The latest trend in the maintenance area is so called "telemaintenance", which may be explained as remote-controlled

maintenance employing the proactive maintenance principle. In some publications, the term "Remote Diagnostics & Maintenance (RD&M)" is used [5]. It is based on wireless transmission of technical data about the vehicle. The main field of its utilization is in companies specializing in long-distance transportation and also in military environment. This method enables on-line monitoring of parameters upon sensors integrated in the vehicle and wireless transmission of the information to a remote computer. This is utilized especially for securing missions in a foreign territory.

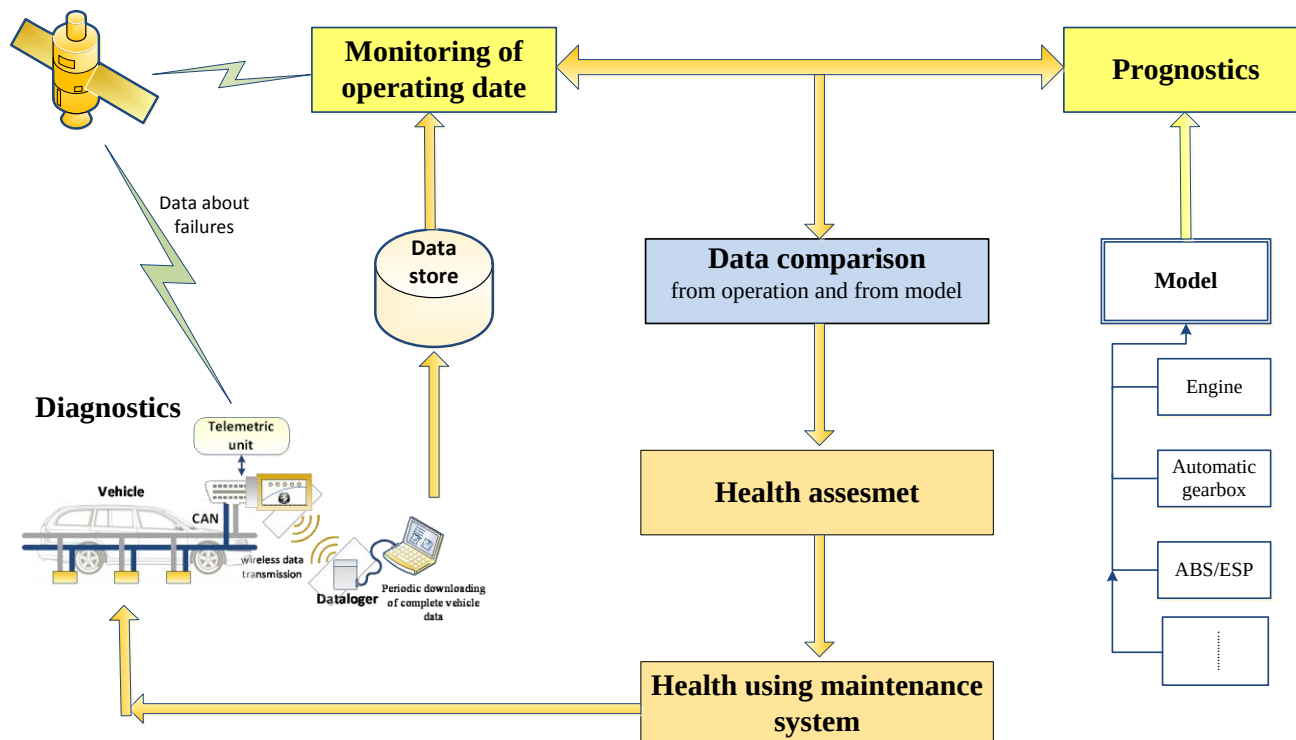


Fig. 5. Design of proactive maintenance with telemetry

Complete output data obtained from vehicle bus can not be transmitted using wireless monitoring. This is caused mainly by limited capacity of wireless connection on long distances. Therefore it is recommended to transmit just selected important data, mainly failure reports. Another data obtained from vehicle bus should be recorded from vehicle datalogger into computer memory and subsequently used to create analysis and prediction modeling.

Telemaintenance may be divided to the four following levels:

1. Diagnosed vehicle with a driver.
2. Support logistics centre where a computer processing the diagnostic information is located.
3. Experts performing the maintenance on the vehicle.
4. Vehicle manufacturer who supplies a technical database including drawings and technological procedures for maintenance [3].

Proactive systems are characterised by complete OBD and also by subsequent vehicle data transmission. Transmission of data can be executed by loading complete datalist in periodic intervals or by on-line data transmission. One of the most modern way is the usage of long distance transmission of selected data. These systems are applied in big transport companies and also in army conditions. Except of these requirements there is also an effort to create individual prediction models of single machine parts. Possible proposal could be seen in figure 5. These models are based on monitored data obtained from vehicle buses. Data are taken during vehicle operation. Afterwards there is a possibility to compare obtained data with true values and define real TS (technical state) of vehicle subsystems subsequently. Apart from defining the real TS, we should be capable to predict time period to service control, TTL (total technical life of vehicle) part alternatively. This could cause reduction of maintenance costs, operation and costs caused by vehicle temporary shutdown. The costs for acquisition are higher contrarily. Decisive criterion should be total LCC (life cycle costs).

4. Conclusion

The purpose of this article is to introduce to the reader the development of particular maintenance approaches since the beginning of the 20th century to the present. It includes advantages and disadvantages of performing maintenance after use, preventive maintenance with predetermined interval, predictive maintenance and proactive maintenance. The final part brings a new approach to maintenance based on on-board diagnostics, which is on-line testing

of diagnostic signals and their wireless transmission to the telemaintenance logistics centre.

The unified diagnostic systems for reasonable application of telemetry have to be introduced. It is also necessary to use unified CAN BUS. These issues should be already solved in acquisition phase. With regard to previous experiences, I would consider to unify all those components and systems into common control unit including single OBD connector for data transmission for subsequent analysis.

Using telemetry, which can be described as the wireless data transmission into logistic centres, with which is possible to analyse obtained data about technical state of vehicles in real time. The vehicle maintenance can be executed on the basis of comparison of obtained data and data recommended. These workshops should have possibility to contact crew of vehicle in order to give them advice about solution of the problem

Implementation of maintenance system based on telemetry enables cost reduction of proper realization of maintenance, on the other hand their purchase cause higher acquisition costs of vehicles and related portable wireless devices. Except the lower maintenance expenses, this access bring also the complete overview of general operation of all in this way equipped vehicles.

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COMPARISON OF THE FRICTION COEFFICIENT FOR SELECTED CAR SUSPENSIONS ELEMENTS

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Abstract: This paper presents values comparison of friction coefficient inside ball joints depending course given by the vehicle, period of exploitation and the vehicle brand. Friction coefficient were defined on the contact surface between steel ball joint pin and the ball joint seat made from plastic covered by PTFE. For the selected working pair of the elements comparison of friction coefficient in load function are done. The preform of the measurements methodology and the test bench are additional show in the paper.

Keywords: BALL JOINT, FRICTION COEFFICIENT, PIVOTING FRICTION, STRING.

1. Introduction

The set of phenomenon's in the contact area between two bodies in the rest, or moving towards oneself friction is called. As a result of these phenomena's resistance of motion are arises. A lot of kinds of the friction are distinguish. It is possible to distinguish diversity of friction conditions types inside the working pairs (figure 1).

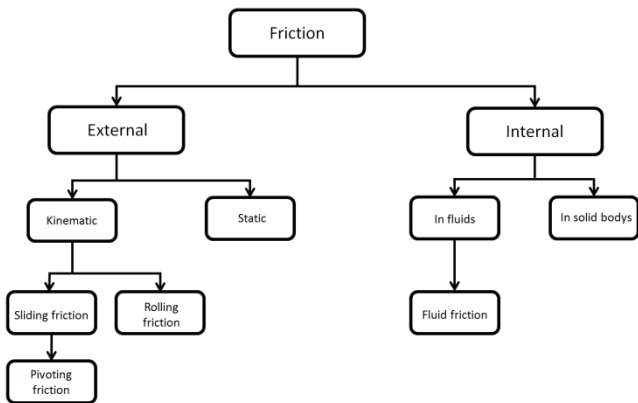


Fig. 1 Types of friction.

The machines constructors try to eliminate friction dry, replacing it more advantageous fluid friction. Because co-operating surfaces are not ideally smooth, on the top of irregularity of surface could be condition of dry or boundary friction and cavities are fill by lubricant. In such conditions the friction in the rough contact surfaces is the mixed friction.

2. The pivoting friction

One with special cases kinetic sliding friction is pivoting friction.

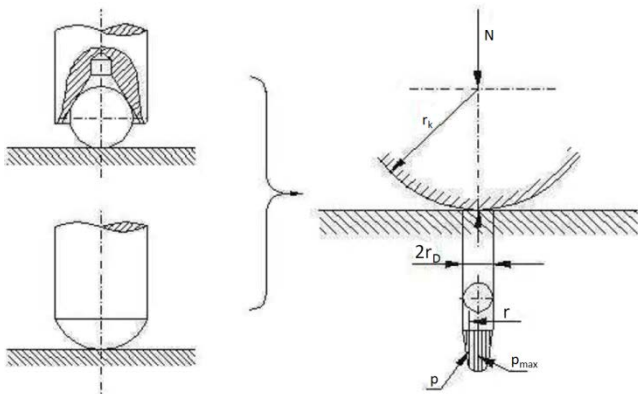


Fig. 2 Model of the bearing type spherical cap on plate; p - Hertz pressure, p_{max} - Hertz pressure max.

$$p_m = \frac{1}{\pi} \sqrt{\frac{6 \cdot N \cdot \frac{1}{r_k^2}}{\left(\frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2} \right)^2}} \quad (1)$$

where: ν - Poisson ratio, E - Young's modulus, N - axial force, r_o - contact radius, r_k - sphere radius.

Pivoting friction is created by continuous rotary motion or gyroscopic motion around normal in the point of contact between two co-operating surfaces. In the paper try analyzed pivoting friction conditions for flat surface – spherical cap model type (figure 2).

3. Research object

Moveable connection (kinematic pair) enabling the rotatory oscillate movement of the one connected component in relation to the second element are ball joint named. The axis pass through the ball joint, round which takes the place the turn of wheel in moment of turn the steering gear of vehicle by driver. Additionally the ball joint enable the angle deflection and transmit the shearing and longitudinal forces (along the ball joint axis). Because in the time of work ball joints performs swing-rotational movement, they are lubricated by solid oil by grease nipple or by graphite grease when the ball joint construction are knead by machinery in housing. Build and description of main components of ball joint shows figure 3.

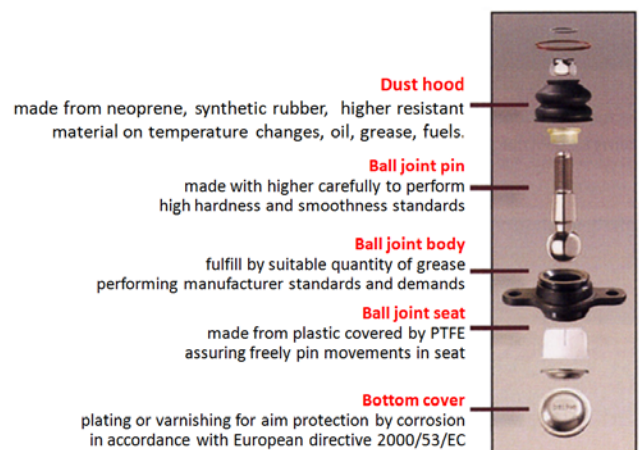


Fig. 3 Build and description of the of ball joint elements [1].

The ball joints construction approach to minimize friction by polishing the pin of ball joints. The grease used inside and pin additionally covered by teflon are also contributed to smooth working and for fast reaction time. Dust hood are mainly made from neoprene (CR), which characterize protection to temperature changes, oil and fuel conditions and protection to variable weather conditions. Nylon insertion inside nut prevents forming among pin

and nut corrosion inside, as well as makes impossible coming unscrewed nut. The most often ball joints defects are: get inside water, sand and other foreign matter are result of faster wear mates elements in ball joints are effect of splitting rubber cover [2].

4. Test bench for determination friction coefficient

Figure 4 shows the test bench for determination friction coefficient by the string twist angle measurement.

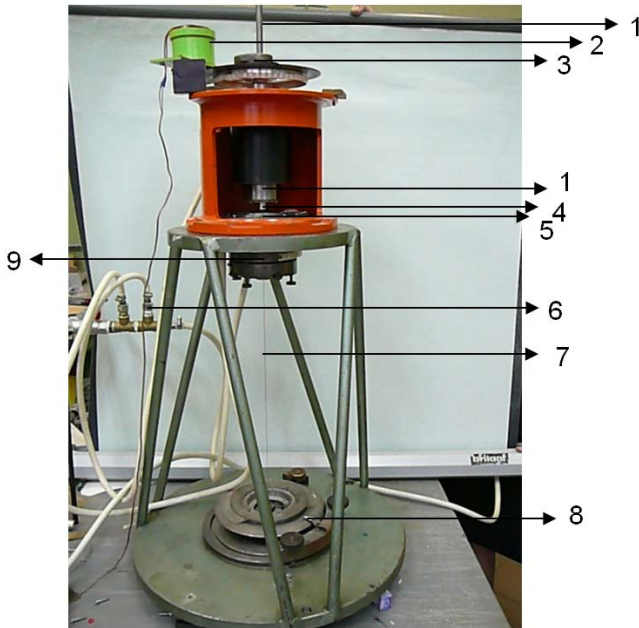


Fig. 4 Test bench for the friction moment and friction coefficient for the frictional pair ball joint – spherical cap; 1 – shaft, 2 – electric motor, 3 – weights, 4 – ball joint, 5 – tested ball joint, 6 – compressed air supply, 7 – string, 8 – disc to read the angle of torsion, 9 – aerostatic table [3].

The test bench are built from two cylindrical radial bearing and axial bearing. Drive from electric motor (2) are transferred between belt transmission on the shaft (1) which ended by the ball joint. The load of the researched friction pair is change by add weights (3) on the shaft (1). The tested ball joint (5) is placed on the aerostatic table (9) which is connected with string measurement (7). The second end of string is mounted to the table (8) which is used to twist string angle compensation. The angle of compensation is read from the scale plotted on the table (8).

5. Calibration of the strings

String patterns on a special measuring instrument bearings aerostatic (figure 5,6), placed on a table to eliminate external vibrations from the environment. Aerostatic fed bearing pressure of 10 bars. In order to obtain the actual value of the angle of torsion measurements made over ten series of successively burdening string weights G (figure 5) with a mass of about 2 g, 4 g, 6 g and 8 g (accurate mass values are given in the tables of measurement data). The arm weights of force was 50 mm. In this way data to calculate the torque and removal characteristics of the studied strings. The calculation results are presented graphically in charts 5 and 6 respectively for the strings 1 and 2. Constant strings calculated from the following equation.

$$k = \frac{P \cdot r}{\varphi} \quad (2)$$

Where k – constant of string, P – loading force, r – arm of a force, φ – torsional angle.

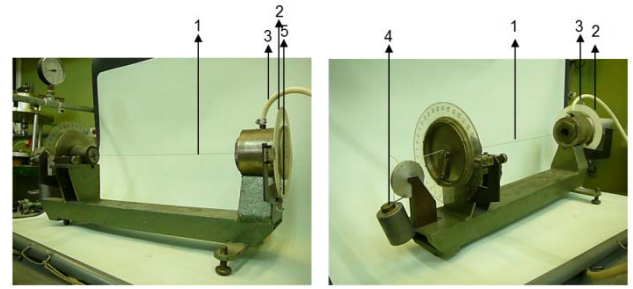


Fig. 5 The scheme of test bench for string calibration: 1 – string, 2 – disc for read torsional string angle, 3 – aerostatic bearing, 4 – weight for string load, 5 – the place for weights position.

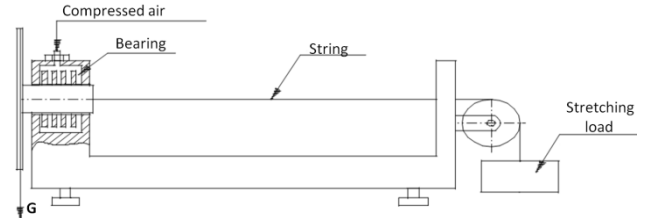


Fig. 6 The scheme of test bench for string calibration, where G is a load making string turns.

Analyzing the figures 7 and 8 can be seen that the real courses differ somewhat from the trend line, a line obtained by least mean squares defining characteristic. Differences may result from inaccuracies in reading the angle from the measuring instruments and an end to the phenomenon of coincidence measurement on the scale. A more accurate readings could be obtain by using the digital measuring instruments.

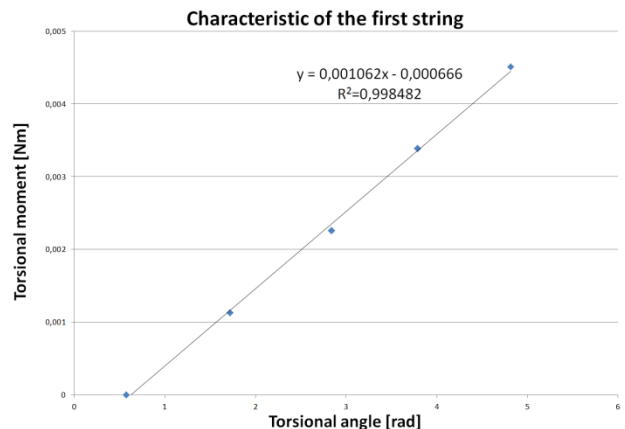


Fig. 7 Characteristic of the first string.

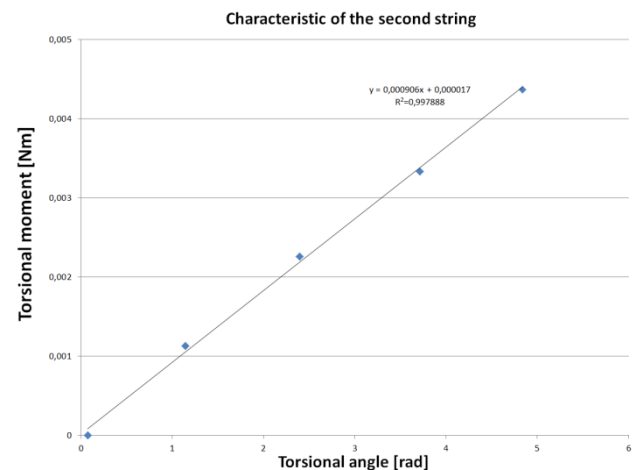


Fig. 8 Characteristic of the second string.

6. Comparison of friction coefficient for the test bench measurements and theoretical calculation

Bearing ball made from steel 100Cr6 with diameter 8mm and ball joint pin from steel were selected to researches. The ball joints selected to researches came from cars: Nissan Maxima (year of production 2008, mileage 185000km), Peugeot 206 (year of production 2007, mileage 95000km), Mercedes Sprinter (year of production 2005, mileage 230000km). All of the ball joints are mounted originally in mentioned cars. Described cars didn't pass the inspection on the diagnostic station for ball joints on the control arm reason.

Test bench researches lead by measure the torsional angle of the string in the loading function. The electric motor was started after mounted the ball joint and measure ball on the test bench. The measurement shaft with ball rotated with constant speed – 36 rpm. Then the test bench was step loaded by 2 N in the range 7,09÷16,9N. After that the test bench was lightened in inversely sequence. Weights were added for 500 cycles. Figure 9 shows the curves of the friction coefficient with approximation equations for the listed cars. Table 1 shows values of the friction coefficient.

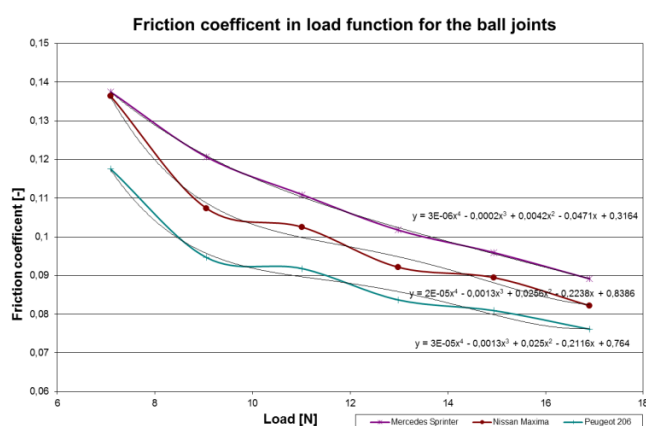


Fig. 9 Friction coefficient in load function for Nissan Maxima (green), Peugeot 206 (red) and Mercedes Sprinter (purple)

Tab.1 Values of friction coefficient and P_{max} for selected cars.

Load [N]	P_{max} [Pa]	μ - Friction coefficient [-]		
		Mercedes Sprinter	Nissan Maxima	Peugeot 206
7,09	1,04E+09	0,13748	0,13638	0,11754
9,05	1,13E+09	0,12067	0,10739	0,09465
11,01	1,20E+09	0,11091	0,10251	0,09178
12,97	1,27E+09	0,10176	0,09216	0,08371
14,94	1,33E+09	0,09593	0,08946	0,08092
16,91	1,39E+09	0,08914	0,08218	0,07609

7. Conclusions

1. Values of the friction coefficient decrease directly proportional with load increase.
2. The character of friction coefficient course in load function for analytic determinate is near to experimental course assigned.
3. Values of the friction coefficient read from the scale plotted on the table allow plastic strain.
4. Differences of friction coefficient for analytic calculations and from experimental don't cross 0,0025 in whole load range.

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