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WORLD CASTING INDUSTRY – PREVIEW

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ABSTRACT: In this paper is analyzed situation in the world casting industry starting from the 2008 i.e. period of global economical crisis, trough recovery period untill the current time. The top leading countries in the world and their casting production is presented. Special attention is devoted do the products cost of castings, influence of casting production to the environment and perspective of casting as a industry branch are discussed.

INTRODUCTION

The foundry industry is one of the fastest developing industries in the world in regards to production, modernity, and technological invention. Increase in the production of casting and its use in recent years has proven in significance of modern industry and world economy [1].

Castings are mainly used in automobiles, railways, pumps, compressors and valves, diesel engines, cement industry, electrical industry, textile machinery, sanitary pipes and fittings, power generation, construction, and many other specialized applications. About 32% global output of foundry industry goes to auto industries and the balance to other downstream engineering sectors [2]. After economical crisis in 2008 global casting production exceed prerecession levels. The United States., after retaking the secondspot in the world's top 10 from India in 2011, strengthened its position by increasing production for 28%. After an impressive 15.1% boost in total production in 2012, the U.S. market increased at a more modest pace. The three largest casting producers in the world provided the most growth in the past four years, with China, United States and India Among the great world producer such situation was not characteristic in Brazil with 16,9% drop in volume

production 2012. In the beginning of 2013 casting was pretty was pretty low but at the end of the year situation became much better. Global casting production grew in 2013, but other than the large gains in China, total tonnage increase by less than half-milions metric tons. Total Chinesse production in 2013 was 44.5 million tons. Cast production in China has risen 3.5 times since 2010 and in India almost 3 times [3].

The most important casting producing country in the world

China is the world leader in casting production followed by United States and India (figure 1a). Distribution of foundries accros the world is given in figure 1b. Production of casting per year of the top six countries is presented in figure 3. It is clear that only China has permanent increase inannual production. In production per plant, which means total production of castings divided by number of foundries, world leader is Germany and United states are on the second place. (figure 4). Only two of the top 10 nations reported growth in production per plant in 2012. The U.S. continued to increase production per plant in 2012, by 28%, with Korea improving 3% [4].



Figure 1. (a and b) Global casting production (a) Distribution of foundries across the world (b)

China cover 43% world casting production [5]. Besides United States and India, European Union is the most important factor in the global casting market (figure 2).

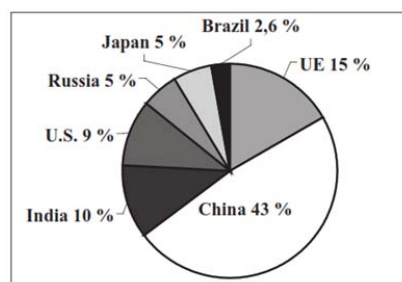


Figure 2 World leading casting producers in % (2012)

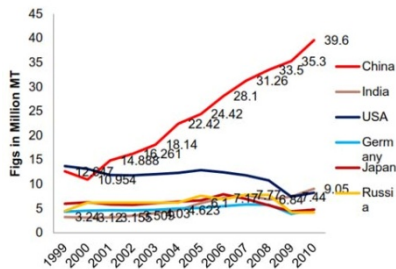


Figure 3 Production of casting per year for top 6 countries

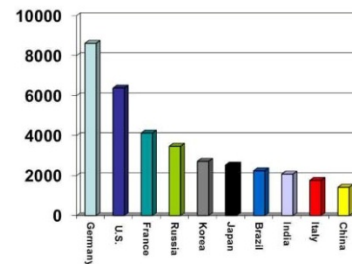


Figure 4 Production of castings per plant

Germany is a leader in the world concerning relationship between casting production and number of employed, figure 5.

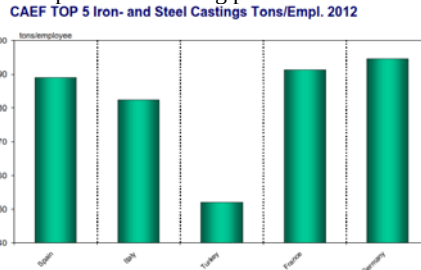


Figure 5 Top five casting producer (tons/empl.)

Production of castings from different raw materials, in period 2004-2012 can be seen in table 1. The most often used materials are grey iron, ductile iron and steel [6].

Table 1 Global production of castings from different raw materials.

	2004	2008	2010	2012
Gray Iron	40,435	42,958	43,258	45,130
Duc. Iron	18,706	23,841	23,451	24,108
Steel	6,594	10,538	10,215	10,919
Cu-base	1,239	1,808	1,652	1,763
Alum.	10,357	12,932	10,879	13,844
Mag	134	268	196	217
Zinc	907	664	528	549
TOTAL	79,745	93,449	91,673	98,269

Globally, 46% of iron castings produced are in gray iron, compared to 25% produced in ductile iron. But this type of disparity is not present in every country. Austria, Denmark, Finland, France,

Norway, Spain, Switzerland, the U.K. and the U.S. produce more ductile iron than gray iron [7]. Production of castings from different steel types is presented in figure 6.

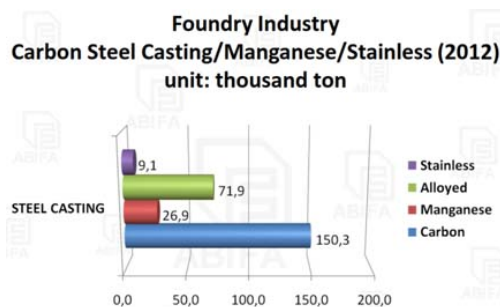


Figure 6 Production of casting from different types of steel

Aluminium play very important role in global casting production. From total aluminium casting production, about 73% are for automobile industry (Figure 7).

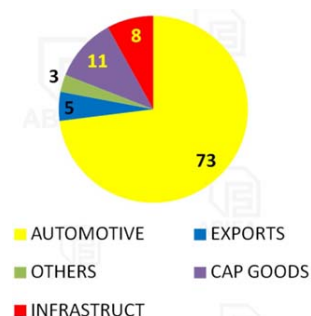


Figure 7 Implementation of aluminium castings

From the figure 8 can be seen which are the most important sectors industrial which use different types of castings. About 50% from

total casting production are used in automobile industry and about 30% in engineering industry [8].

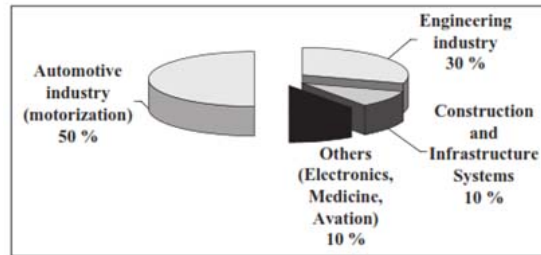


Figure 8 Main market server by the foundry industry

As an industry branch metal casting has strong influence to the country economy. The most significant influence of casting production to the GDP in the top leading countries can be seen in figure 9. The strongest influence of casting production to GDP is in the United States.

China is watching the yuan carefully and controlling it to maintain their own economy. As can be noticed from figure 10 Chinese yuan is still positive but the rate of growth has slowed. Because of that there is no great interest among Chinese casting companies for export in the US market. Current situation is successfully used by Mexico casting companies which increase export in United States [9].

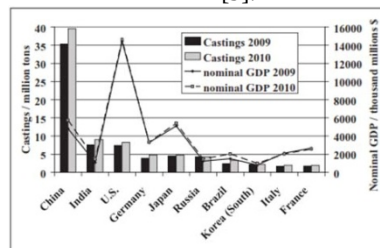


Figure 9 Influence of metal casting production to the GDP in the top 10 casting production leading countries

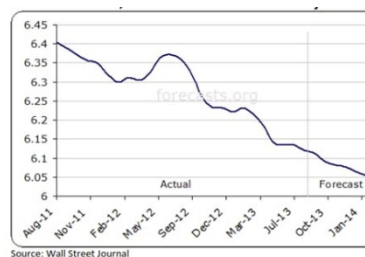


Figure 10 Chinese yuan to US dollar exchange currency rate

Metal casting industry has very important role in economy of the EU countries too. The leading country in the casting production is Germany. In the group of top 10 world countries besides Germany

are France and Italy. The biggest casting producers in EU are given in figure 11.



Figure 11 The most important countries in EU according casting production

EU countries have a significant production of ferrous and non ferrous castings. But, as can be seen from figure 12, in both cases

castings for automobile industry are most important (78% in nonferrous casting industry and 54% in ferrous casting industry).

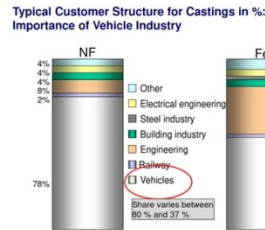


Figure 12 Customer structure for castings in EU countries

Energy consumption in casting production

It is well known thing that the great amount of energy is used for casting production, The foundry industry in the U.S. uses more than 485 billion kJ energy a year, from which around 346 billion kJ (71%) is used for metal casting. Most industrial energy (73%) comes from fossil fuels (83% gas, 16% coke, 1% other sources) [1]. Considering the great amount of used energy in production of casting it is necessary to introduce a wide range of activities and conduct research into saving energy. Foundry industry depends on energy cost which, due to production costs and the condition energy plants, is becoming an increasingly expensive resource. Similar to

energy, there is a problem of emissions of greenhouse gases. European Union countries, have fixed limits for CO₂ emission established by the European Committee. They are then shared by governments among different industries, including the foundry industry. Some countries, like Poland for example. From another point of view situation is quite different in Brasil. As can be seen from the figure about 73 percent of energy used for casting production is hydro electricity. What is the structure of production cost in casting production in different countries can be seen in figure 14

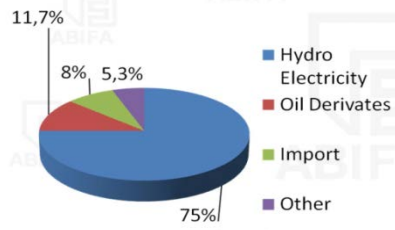


Figure 13 Different types of energy used for casting production in Brasil

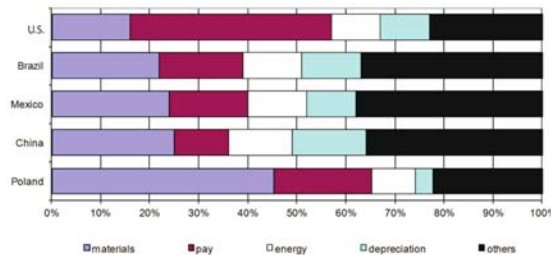


Figure 14 Structure of production costs for casting productions in different countries

Influence of foundry industry on the environment

- Castings are a very propulsive industry branch.
- Foundry industry is the key factor in ferrous and non-ferrous metal recycling of waste, which can be re-melted into new products and used 100 %.[3]
- Castings are intensive energy consumers. [4]
- Intensive environmental pollutants of: soil, air, and water. [5]

Environmental influences of the casting processing are mainly related to waste gases, and for reuse or as disposal of mineral residues.

Due to stringent environmental pollution control norms in the developed countries and non availability of work force for working in trying conditions of foundries, western economy is procuring their casting requirement from BRIC countries.

Harmful emissions caused by casting melting and production are basically related to the use of additives and fuels or raw material impurities. The use of coke or oil might cause the emission of the product of burning. The use of additives in the process generates a reaction. The presence of impurities in waste that blend by melting may cause the formation of a product with incomplete combustion or a recombination and dust. Dust from the process might consist of metal and metal oxides. During the melting process, elements evaporate and tiny metal dust particles are released. Metal particles appear during the final processing [8].

IS THE FOUNDRY INDUSTRY AS THE PRODUCTION TECHNIQUE HAVING FUTURE?

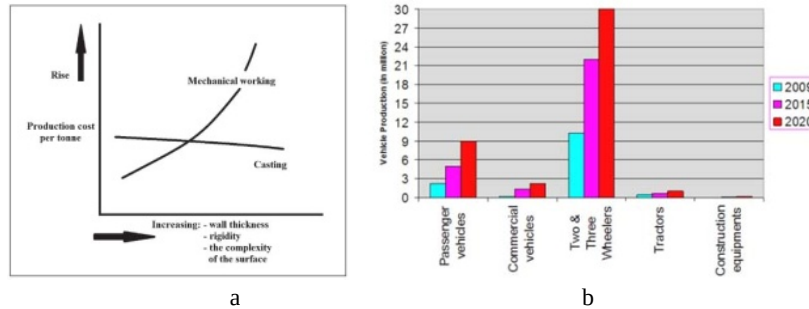


Figure 15 (a and b)
Production cost of casting and mechanically machined parts (a)
Figure Forecast of vehicle production in India until 2020 (b)

Comparing production cost of casting and mechanically worked products it is obvious that as a production technique, casting has perspective in the future (Figure 15 a). Forecast for car production in India until 2020 is another proof for casting perspective, because many casted parts are build in the different types of vehicles [4].

CONCLUSIONS

Casting industry is perceived as old, dirty and dangerous. Therefore, there is a need for new and younger leadership to be involved in the developments, opportunities and marketing of the industry to provide employment opportunities for the younger generation.

Research directions leading to further development of the foundry industry

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

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

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OBJECTS AND EFFECTS OF COMPOSITE MATERIALS APPLICATION IN THE AUTOMOTIVE INDUSTRY

Professor A. Polilov, PhD N. Tatus, postgraduate M. Rumachik

Abstract. *The structural weight reduction is the most visible effect of composite application, but it's primarily important for aircraft or spacecraft only. In engineering branches the major effect of fiber reinforcement plastics (FRP) application is the ability to solve some fundamental technical challenge, for example: simplifying design of construction, the overall dimensions reducing of the elastic element, non-fragile, etc. In this paper the methodological approach to FRP application considered. Some examples of engineering design for vehicle load-bearing FRP element are presented.*

KEYWORDS: FIBER REINFORCEMENT PLASTICS, MECHANICS OF COMPOSITE MATERIALS, STRENGTH, ELASTIC, JOINING OF COMPOSITE ELEMENTS, BENDING, ENGINEERING BRANCHES, VEHICLE.

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A modern design engineer is like a composer (from Lat. compositor - a composer, writer) because the materials with which to work; and created products with the correct (rational, optimal) design is a work of engineering art. And created construction should have not only the specified strength, stiffness, operating and other characteristics, but also be aesthetically pleasing.

Traditional materials used in mechanical engineering (various steel and alloys) impose severe restrictions on the product. Firstly, to achieve the desired strength, engineer selects the known material and selects the appropriate sectional element dimensions (overall dimensions), hence the second - it is difficult to vary the form of construction elements, inasmuch as for many years the use of metals was accumulated a sufficient number of standard forms (triangles, channels, I-beams, pipes, etc.).

In addition, obtaining metal products requires huge amounts of electricity: ore mining, smelting of metal, creating an alloy, casting blank, machining, welding. The situation with fibre-reinforcement plastics (FRP) is different though. One of their main advantages is simplicity of obtaining complex shapes and in most cases, without subsequent machining.

The main FRP advantage over metals is that the structure and the material are created simultaneously. The first composite material is "clay - straw" - the prototype of the modern ferroconcrete: the stems straw resist to tension and clay - compression. Adobe bricks were used and are still used in the building houses.

The modern composite products are the top of engineering and technical thought: the most complex reinforcement because design really is woven from fibers, each fibers may be laid along a predetermined trajectory. These technologies are used for the manufacture bodies of spacecraft and aircraft.

FRP, which are reinforced with carbon, glass, aramid and others fibers, are widely and effectively used in aerospace engineering, due to its unique high specific (per unit weight) strength and stiffness. We can not talk about the simplicity with "weaving" fuselages of the airplanes with holes for windows and hatches, which in are mounted tail and wings. Although in spite of the complexity of manufacturing leading aircraft manufacturer companies are expanding the use of FRP in their designs. For example: the modern civil airplane Boeing 787 contains 50% FRP.

The effectiveness of the use FRP (including economic indicator) for aircraft achieved mainly due to weight reduction, but for the civil engineering industry (as well as construction, medicine, sports) performance criteria are quite different than for aviation. The economic effect is achieved due to the solving technical challenges, unrealizable using traditional structural materials.

The most popular material of construction for the entire history of mankind is wood. The trees themselves are optimal natural design but mankind to create such a so far.

The Nature implemented in the trees one of the principles of creating optimal fiber structure: the fibers are laid along the lines of maximum normal stress, i.e. in those directions where the greatest forces act. Moreover this lively construction adjusts to environmental conditions. From the same seed, if it planted in the

field, in the forest or on a mountain top, will grow different types of trees but each of them will be optimal for the conditions (loads) in which it grows. And it is impossible to find fault with the aesthetic point of view. The places where the branches "grow into" the trunk or root "grows into" the trunk have unique strength characteristics: the branch will be broken if to jump on it, but will not wrenched of the trunk. None engineer could not create anything like this: the critical loads "man-made" construction ever destroys at the joint. Constriction elements may be designed of the FRP by analogy with the wood: the fibers should be laid along the lines of action of maximum stress.

The traditional elements of all constructions such as beams and bars which work on a bend, logically apply unidirectional reinforcement, i.e. fibers should be laid parallel to each other, to achieve maximum effect. The elements with such a structure most effectively resists on a bend. For creating a torsion pipe, the fibers are wound at angles of $\pm 45^\circ$ to the axis. For creating a compressed gas cylinder - $\pm 54^\circ$ because the circumferential stress twice more than axial stress. The material is designed for efficient operation.

The huge advantage of fibrous FRP (in particular fiberglass) over metals shows in elastic elements. The first high-profile use of fiberglass as a new "storage" of elastic energy was at the XV Olympic Games in Helsinki (Finland) in 1952: "At the pole vault R. Matias (USA) was first who used fiberglass pole, though the result was much lower than the world record, this jump was powerful push for the use of fiberglass in the sport. Before this athletes have used bamboo poles (a record 4.77m, 1942), aluminum poles (a record 4.82m, 1957) and steel poles (a record 4.80m, 1960), and the successful application of new technologies has led to a rapid growth results (a record 6.14m, 1994)".

Glass-fiber reinforced plastic (GFRP) or fiberglass (one of the most inexpensive FRP) due to the low modulus of elasticity (!) is most effective for the elastic elements because the elastic energy is stored at a predetermined force is inversely proportional to this modulus.

In sports, fiberglass is used for the manufacture of poles for pole vault, bows and sticks; in the automobile production fiberglass is used for an interior, exterior and pressure vessels. Fiberglass is used less often for the power components: springs, torsion bars, although is more effective than steel analogues. In the power elements (of beam type) from composites are most clearly visible analogy with live natural design - with a tree.

Beam and bar are the most studied construction elements the use of which began long before they have learned to calculate. In the traditional course "Strength of Materials" is considered mainly not the materials themselves but beams and bars with different stressed states. It would seem that in the calculations beams everything is clear. But on this simplest example of profiled beams, as sketchy, learning task, is conveniently to show the effects of the use of fiber composites in elastic elements (that require strength calculation at a predetermined stiffness), features the optimum and rational design, ways to improve the durability of composite elements.

This article covers the following issues (about the rational design of beams worked on a bend):

1. Changing the form - the most suitable geometry to meet the requirements to the beam.
2. Changing of mechanical characteristics due to the curvilinear laying of fibers.

1. Changing the form

The features of rational design easily illustrated by the console profiled beam (Fig. 1), which section dimensions are: width $b(x)$ and thickness $h(x)$ varies along the length l according to power laws:

$$\begin{aligned} b(x) &= b(0) \left(1 - \frac{x}{l}\right)^\alpha \\ h(x) &= h(0) \left(1 - \frac{x}{l}\right)^\beta \end{aligned} \quad (1)$$

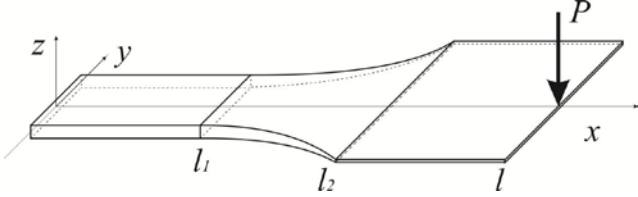


Fig. 1. Design scheme console beam

Selecting of power-law dependences (Eq.1) for creating a "equal strength" (Eq.4) beams with the same maximum stresses in each section $\sigma_{max}(x) = const$: is determined by the linear changing of the bending moment along the length of the beam.

When the rational designing of elastic elements, working on a bend, you need (specified properties of the material: longitudinal elastic modulus $E(x, y, z)$ and the bending strength $[\sigma]$) to find the size of the root section $b(0)$ and $h(0)$ the laws of their changing (α и β) for the simultaneous execution of conflicting requirements specification:

- the requirement for stiffness:

$$c = \frac{P}{v} \quad (2)$$

- the requirement for strength:

$$\sigma_{max} \leq [\sigma] \quad (3)$$

Additional condition "equal strength":

$$\sigma_{max}(x) = \frac{6 \cdot P \cdot (l-x)}{b(x) \cdot h(x)^2} = \frac{6 \cdot P \cdot l}{b(0) \cdot h(0)^2} \text{ is resulting from (1) to a linear function:}$$

$$\alpha + 2\beta = 1. \quad (4)$$

The sag v of shaped console beam in accordance with (Eq.1) with the load P is easily to determine from the equation $\frac{1}{2} P v$ and accumulated elastic energy:

$$v(l) = \int_0^l \frac{P \cdot (l-x)^2}{E(x) \cdot I(x)} dx = \frac{P \cdot l^3}{3 \cdot E \cdot I(0)} \cdot \frac{1}{1 - \alpha/3 - \beta} \quad (5)$$

where the moment of inertia is

$$I(x) = \frac{b(x) \cdot h(x)^3}{12} = \frac{b(0) \cdot h(0)^3}{12} \left(1 - \frac{x}{l}\right)^{\alpha+3\beta} \quad (6)$$

In (Eq.6) for the sake of simplicity the elastic modulus assumed to be constant. In the future it will be considered the change because of disorientation of the fibers. In the first approximation is also not take into account additional sags of interlayer shifts and the type of criteria (Eq.3) for the possible destruction of the tangential stresses.

The shape factor for a sag (Eq.6):

$$\delta_v = \frac{v(l)}{v_0(l)} = \frac{1}{1 - \alpha/3 - \beta} \quad (7)$$

It equals to the ratio the maximum sag $v(l)$ of the profiled beam by sag $v_0(l)$ of a rectangular beam with the same dimensions of the root section.

The simultaneous fulfillment of the conditions (Eq.2) and (Eq.3) allows from (Eq.4) and (Eq.6) to find the rational sizes of root section of the profiled beam:

$$\begin{aligned} h(0) &= \frac{2 \cdot c \cdot [\sigma] \cdot l^2}{3 \cdot E \cdot P_{max}} \delta_v = h_0 \cdot \delta_v \\ b(0) &= \frac{27 \cdot E^2 \cdot P_{max}^3}{2 \cdot c^2 \cdot [\sigma]^3 \cdot l^3 \cdot \delta_v^2} = \frac{b_0}{\delta_v^2} \end{aligned} \quad (8)$$

where h_0 , b_0 are constants cross-sectional dimensions of the rectangular beam which satisfy the same conditions (Eq.2) and (Eq.3).

Factor of reduction mass depends on the resizing cross-section. The main advantage of fiberglass springs is that due to the low modulus of elasticity which is compared with steel (at approximately the same strength) it is possible to reduce the number of sheets in 5-10 times and make a single sheet embodiment ($n = 1$). It means a transition to profiled beam whose mass $m(l)$ equals to the mass m_0 of the rectangular beam with the same dimensions of the root cross section, multiplied by form factor of mass

$$\begin{aligned} m(0) &= \int_0^l \rho \cdot b(x) \cdot h(x) dx = \frac{\rho \cdot b(0) \cdot h(0) \cdot l}{1 + \alpha + \beta} = \\ &= m_0 \cdot \delta_m \end{aligned} \quad (9)$$

where ρ - material density,

$$\delta_m = \frac{1}{1 + \alpha + \beta} - \text{form factor of mass.}$$

By substituting in (Eq.9) the sizes of the root section (Eq.8), we finally obtain:

$$m(l) = \frac{9 \cdot \rho \cdot E \cdot P_{max}^2}{c \cdot [\sigma]^2} \cdot \frac{\delta_m}{\delta_v} \quad (10)$$

where $\frac{\delta_m}{\delta_v} = \delta_\Sigma$ - factor of reduction mass.

From (Eq.10) we may see that the mass of the beam depends not only from material density ρ , but also from the elastic modulus E . It is this effect makes fiberglass most suitable for the elastic elements, for example in automotive engineering, because it reduces the unsprung mass.

Any engineer knows that the triangular beam with equal strength is in 2 times lighter than rectangular with the same sizes of the root section. However, as the elastic elements, which besides must have sufficient strength and predetermined stiffness, have been found more interesting regularities. Factor of reduction mass δ_Σ (after satisfying the condition of strength with the predetermined stiffness) can be written from (Eq.7), (Eq.9) and (Eq.10) as:

$$\delta_\Sigma = \frac{3 - \alpha - 3\beta}{3(1 + \alpha + \beta)} \quad (11)$$

Applying to the beams with equal strength (Fig. 2) from (Eq.5):

$$\delta_\Sigma = \frac{2 - \beta}{3(2 - \beta)} = \frac{1}{3} \quad (12)$$

i.e. when conditions are met simultaneously for stiffness and for strength, any (!) of equal strength "ideal" beam with a power law of resizing is in three times lighter than rectangular beam. This is the best limiting case, more weight reduce for the specified homogeneous material can not achieve.

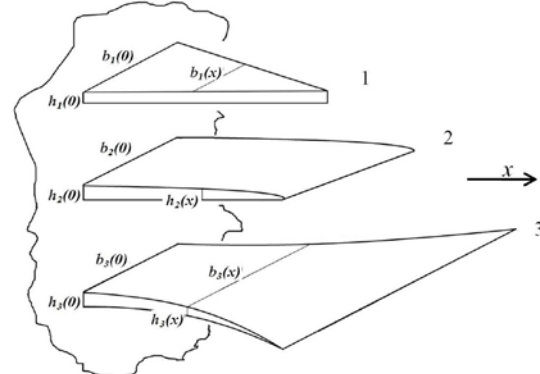


Fig. 2. Profiled beams of equal strength: triangle (1), parabolic (2) and constarea (3)

2. Changing of mechanical characteristics

Authors the most interested in equal strength beam (Fig. 2) with constant cross-sectional area (constarea) as the most rational in terms of location of the fibers. The ideal beam constarea is such a beam which at the free end the thickness tends to zero and the width tends to infinity.

To account for the effect of fibers disorientation on the sag, it is necessary to take some of distribution “fibers” model in the beam. The task is quite complex. Indeed, let us imagine that the root section of the centers “fibers” are located at the nodes of a rectangular grid which consists of layers m (height) and rows n (in width). Then (almost) “ideal” constarea beam in the elongated section under load (at the right side in Fig. 1) should remain a single layer in which are located a row $m \times n$ of “fibers”. But in the intermediate sections can not obtain an integer number of “fibers” in rows and in layers. Specified has only a straight trajectory of central fibers and the trajectory of the extreme fibers in width (Fig. 3), determined by the profile of the beam (Eq.1).

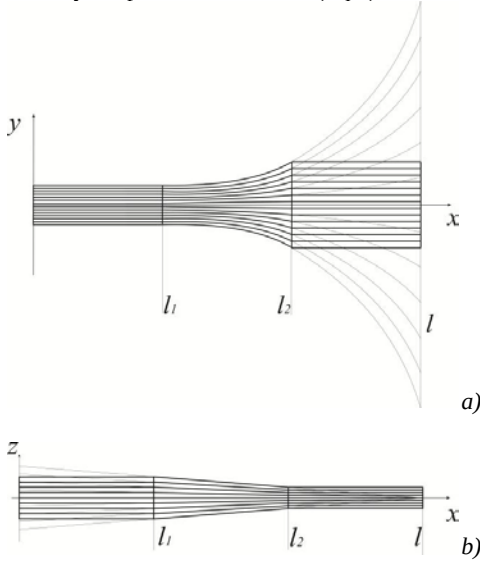


Fig. 3. Fiber location in width (a) and in thickness (b) of spring-constarea

In this paper we proposed to use the principle of “smearing” when from infinitely thin “fiber” remains only the volume content and direction at each point. In this case the trajectories are agreement with the beam form (Eq.1) and are determined the initial coordinates $y(0)$, $z(0)$,

$$\begin{aligned} y(x) &= y(0)(1 - x^*)^\alpha, \\ z(x) &= z(0)(1 - x^*)^\beta, \end{aligned} \quad (12)$$

where $\alpha = -1$, $\beta = 1$,
 $x^* = \frac{x}{l}$.

The derivatives of these functions are characterized the slope of the trajectories in the plane xy and xz :

$$\frac{dy}{dx} = \frac{y(0)^*}{(1-x^*)^2}, \quad \frac{dz}{dx} = y(0)$$

Fig. 4 illustrates the calculation of disorientation angle. Element of “fiber” has projections (along the axis 1) on the axis: dx, dy, dz . The angle φ between the axis 1 and the axis x is defined by one of the obvious ratios:

$$\cos \varphi = \frac{1}{\sqrt{1+A}} \text{ or } \tan \varphi = \sqrt{A}$$

$$\text{where } A = \left(\frac{dy}{dx}\right)^2 + \left(\frac{dz}{dx}\right)^2.$$

Knowing of disorientation angle can be calculated the local value of the longitudinal elastic modulus of E_x which depends from coordinates x , $y(x)$, $z(x)$ associated (Eq.12) with the initial coordinates of each “fiber” $y(0)$, $z(0)$. Approximately, assuming the longitudinal elastic modulus (along the fibers) is much greater than the transverse modulus and shear modulus can be replaced by:

$$E_x(x, y, z, \varphi) \approx E_1^0 \cos^4 \varphi = \frac{E_1^0}{(1+A)^2}. \quad (13)$$

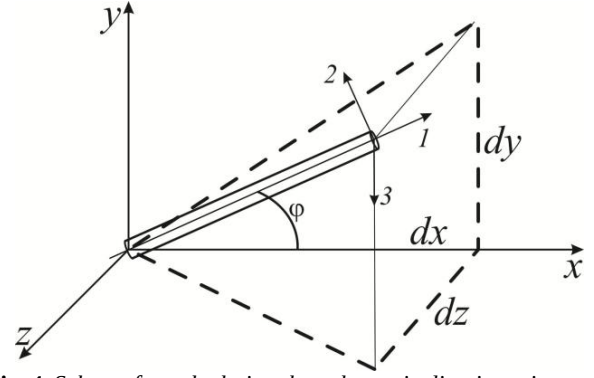


Fig. 4. Scheme for calculating the volumetric disorientation angle

The effective modulus of elasticity for the layer, for the cross section of the whole beam is value of module for a homogeneous element with the same sizes and with the same total stiffness.

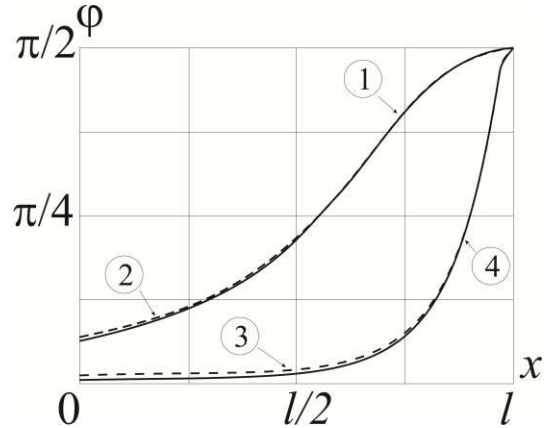


Fig. 5. Changing the disorientation angle from (13) for extreme “fibers” (1, 2 - $y(0) = b/2$) and for almost central “fibers” (3, 4 - $y(0) = b/20$) of ideal constarea. Full lines 1, 3 - $z(0) = 0$ - accounting only flat disorientation, dashed lines 2, 4 - $z(0) = h/2$ - accounting volumetric disorientation

In case of stretching bar is reasonable to assume that the deformations in each section are homogeneous, i.e. the same for each structural element (“fiber”). This hypothesis (Voigt type) for each cross-section, from which the effective modulus can be found directly by averaging:

$$E_x = \frac{1}{N} \sum_{i=1}^N E_1^0 \cos^4 \varphi_i. \quad (14)$$

Here, i is the number of “fibers” in section, N is the total number of “fibers”. Of course, nothing fundamentally will not change if instead of the simplified recording (Eq.14), use the full expression for the transformation of the tensor of elastic modulus.

The more complicated problem of bending in the engineering approach can be solved only based on some natural kinematic hypotheses which are accepted in the following form:

1. At the height (along the axis z) from layer to layer deformations change linearly (a traditional “hypothesis of plane sections”).
2. In each layer (in width - along the axis y) deformations in the rows “fibers” are considered the same, so that the effective modulus of the layer can be determined by the formula (Eq.14).
3. If the section height is very small compared to the width, it is possible to consider only the “flat” disorientation and to consider effective modulus the same of each layer in cross-section, and then you can apply for the whole cross section of average (Eq.14).

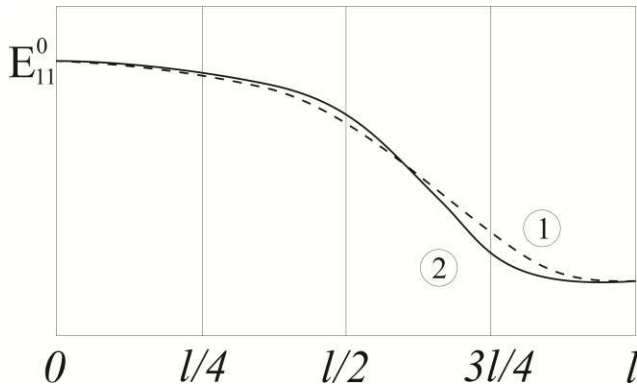


Fig. 6. Changing the effective module in cross-section along the beam length with “volumetric” (1) and “flat” (2) disorientation for an ideal constarea

These hypotheses are tremendously simplifies visual analysis and graphic calculation, but for the FEM (finite element variational method) are not required and in future optimization problems will be solved in refined tasks.

4. In general when calculating the sag of composite beam necessary to take into account the amendment at the expense of the interlayer shifts.

$$\frac{1}{E_x^l} = \frac{1}{E_x^*} + \frac{k \cdot h^2}{l^2 \cdot G_{xy}} \quad (15)$$

where E_x^* - “true” Young’s modulus, E_x^l - “apparent” effective modulus calculated at the experiment using the standard formulas from the hypothesis of plane sections excluding the impact shifts, k - numerical coefficient that depends on the form of the cross-section: for console beam with a rectangular cross-section $k = \frac{6}{5}$, G_{xy} - interlayer shear modulus.

Concept of interlayer shifts loses direct meaning in pultrusion beam with disoriented, twisted fibers, and the definition of G_{xy} represents a separate experimental problem. The procedure for considering the effect of shifts became the standard for composites, its application by resulted formula (Eq.15) is not difficult, especially in computer modeling. But in this (analytical) presentment it will not be used because is clutters the calculations.

When bending for each cross-section with sizes $b(x)$ and $h(x)$ we can calculate the effective modulus:

$$E_x^{eff}(x) \cdot b(x) \cdot h^3(x) \approx \int_{-b/2}^{b/2} dy \int_{-h/2}^{h/2} E_x(x, y, z) z^2 dz \quad (16)$$

If we neglect disorientation “fibers” in height, then the beams with a small ratio of height to width we can evaluate the effectiveness module, averaging it only in width, and assuming this average value like constant over the whole cross-section:

$$E_x^{eff}(x) \cdot b(x) = \int_{-h/2}^{h/2} E_x(x, y) dy \quad (17)$$

For example, consider the scheme of the beam in Fig. 1 with $l_1 = l_2 = l_3 = l/3$. At Fig. 7 shows the lines of sags as a function of the longitudinal coordinate and for rectangular shaped beam (consisting of three equal parts: two areas with constant elastic modulus and one area with a variable elastic modulus, Fig. 1).

The results of calculation of the beam with the “volumetric” elastic modulus is almost exactly the same for a beam with a “flat” modulus: the difference is not more than 0.5%.

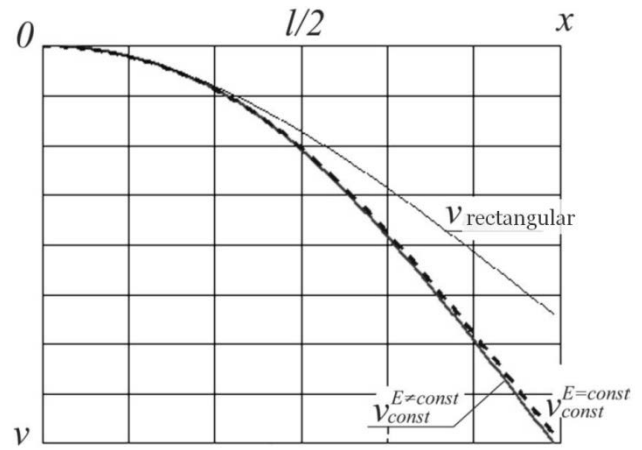


Fig. 7. Graphics of a sags: a thin line - a simple rectangular beam with constant elastic modulus, the dashed line - a shaped beam with constant elastic modulus, a thick curve: beam - a shaped with a variable elastic modulus

In this paper we did not consider a very important question about the strength of the beam element. Fibers disorientation has not only a positive effect (an increase of sag) but also has a negative effect - a decrease of strength. It should not be forgotten. That is why in Fig. 7 shows graphs of the sags of the beam consisting of three areas, which leads to restriction of disorientation angle within acceptable limits. After exceeding the disorientation angle $\varphi = 5^\circ$ is a significant decrease of strength and requires additional improved analysis.

Findings

Modern computer methods allow to model and design the structures with any complexity and from any desired materials, calculating and visualizing the whole process of manufacturing. Analytical methods are fading. The more valuable ability is to show this or that effect “on the fingers”. Very valuable skill is on a few strokes of chalk on the blackboard to show the fundamental possibility or no possibility of this or that construction, and then confirm it lasting many hours computer calculations.

One of the main tasks for engineer working with composites in the XXI century is to understand the biomechanical principles of building structures, such as trees. The authors hope that this work will make a bit closer to modern technologies (creating a new fiber composites and structures) the laws of Nature, the study of which became the cornerstone great mechanics of the past.

Acknowledgement

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WASTE MOLDING SAND AS AN AGENT FOR THE REMOVAL OF Cu(II) AND Zn(II) IONS FROM AQUEOUS SOLUTION

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Abstract

This article presents the application of non-hazardous waste molding sand from gray cast iron foundry as an inexpensive adsorbent for removal of Zn(II) and Cu(II) ions from aqueous solutions. The experiments were performed at room temperature using a multi solution (Zn + Cu) with concentration was 100 mg/l. The process of removal of Zn(II) and Cu(II) ions was monitored at different contact times of waste molding sand and metal ions. The experimental data were processed by two different kinetic theories. The pseudo-first-order and pseudo-second-order models were used for modeling the kinetic rates.

Obtained results show that the waste molding sand has significant potential for the removal of Zn(II) and Cu(II) ions from aqueous solutions. Research shows that the removal of Cu(II) ions was better than removal of Zn (II) ions. It is possible to conclude that the mutual competition of Cu(II) and Zn(II) ions for adsorption sites affect the intensity of their removal.

KEYWORDS: WASTE MOLDING SAND, Zn(II) IONS, Cu(II) IONS, ADSORPTION

1. Introduction

There are many factors that influenced the development of new ways for sustainable development, such as: a large amount of various industrial wastes, environmental pollution and high consumption of natural resources. Achieving sustainable development is possible only with an increase in resource efficiency. This is possible if we reduce the consumption of materials and energy. Therefore, it is beneficial to use a variety of by-products or solid wastes from industries. For example, in the production of concrete it is possible to use slag from metallurgical aggregates and waste mold sand from foundries. Production costs and environmental problems were reduced by this approach. Resulting concrete has adequate quality and environmental acceptability [1].

By-products from the production process create significant difficulties for foundries. If we take into account all the by-products from the foundry, more than 70% relates to the foundry sand which is used for mold making [2].

Different binders are used for binding of grains of foundry sand. Expendable molds are widely used in production of metal castings. They are usually produced from clay-bonded (green) sand or chemically bounded sand. Clay-bonded (green) sand for molds consists of silica sand (80 – 95%), bentonite clay (4 – 10%), water (2 – 5%) and carbonaceous additives (2 – 10%). Chemically bonded sand consists of silica sand and chemical binder (1 – 3%). It is used for making molds and cores. Chemical binder is mixed with silica sand. The chemical reaction which occurs under the effect of the catalyst results in curing of the mixture. For making mold and cores in foundries, different chemical binders are used, such as: sodium silicate, furfuryl alcohol, phenolic resins, alkyd oil type resin etc. [2].

When the properties of sand become unsuitable for further use, such sand is called waste foundry sand and removed from the foundry [1].

2. Prerequisites and means for solving the problem

In the production process of one ton of cast metal, approximately one ton of waste is produced. [3]. Safe disposal of waste materials is a demanding task, which is important as maintaining the quality and profit. Therefore, efforts should be made to reduce the amount of waste materials through reuse or use for other purposes. In this context, the use of foundry waste molding sand as the adsorbent for heavy metals from wastewater is very interesting. In addition, this approach reduces the cost of disposal of waste materials.

In the process of adsorption, adsorbate molecules are concentrated on the surface of the adsorbent.

The molecules of adsorbate come from the bulk phase and being adsorbed in the pores in the partially liquid state. The ratio of the concentration to the solubility of the compound is the driving force for adsorption. Detailed research of adsorption, adsorption kinetics and equilibrium, as well as influential parameters, such as temperature, pH, surface area, etc. was performed by Dound [4]. Adsorption is a useful and economical method at low concentrations of pollution. In comparison to membrane filtration or ion exchange and other conventional methods, the adsorption has advantages, such as low cost, easy to perform, efficiency, availability, low cost and environment friendly [5-8]. Recently, a lot of research has been done on the use of inexpensive and easily available materials in wastewater treatment. Currently, the adsorbent which is most often used in wastewater treatment is the activated carbon. However, the activated carbon is expensive. Therefore, intensive research performs on the use of inexpensive and available materials (particularly waste materials), as a substitute for the activated carbon [9].

This paper presents the possibility of using sodium-silicate-bonded sand (chemically bound mixture) for the adsorption of Cu (II) and Zn (II) ions from aqueous solutions. The adsorption process is presented by kinetic models.

3. Solutions of the examined problem

Waste sodium-silicate-bonded sand used in the present study was obtained from foundry and had the following chemical composition: 91 % SiO₂, 2.1 % Al₂O₃, 9.6 % Fe, 0.4 % Mg, 0.05 % Ni, 0.03 % Cr, 0.76 % C and 0.02 % Mn.

A stock solutions of Cu(II) and Zn(II) for batch adsorption experiment were obtained by dissolving the exact quantity of CuSO₄·5H₂O and ZnCl₂ in ultra pure water. The test solutions containing single ions were prepared by diluting 1000 mg/L of stock solutions of metal ions to the desired concentrations. For the investigation with binary solutions, the desired combinations of 100 mg/L Cu(II) and 100 mg/L Zn(II) ions were used.

Waste foundry sand (sodium-silicate-bonded sand) in an amount of 1 g, 25 ml of the Cu (II) ions and 25 mL of the Zn (II) ions were mixed for study of the adsorption process. The kinetics of the process is monitored in a time of 10, 20, 30, 40, 50 and 60 minutes.

The concentrations of Cu(II) and Zn(II) ions in solution after adsorption were determined by spectrometric method (Atomic Adsorption Spectrometry with graphite furnace). Before that, the samples were filtered (Whatman- blue ribbon filter).

The kinetics of Cu(II) and Zn(II) ions adsorption was modeled applying the first- and second-order kinetics models [10].

The pseudo-first-order (Lagergen's model) equation is generally expressed as follows:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (1)$$

where q_e and q_t are the adsorption capacity at equilibrium and at time t , respectively (mg/g), k_1 is the rate constant of pseudo first-order adsorption (1/min).

The pseudo-second-order (Ho's model) equation is expressed by the following formula:

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (2)$$

where k_2 is the rate constant of pseudo-second-order adsorption (g/(mg·min)).

The fitting of the all models (isotherms and kinetics) was performed using regression analysis. Performance of the models to the experimental data was checked by comparison of the correlation coefficient r^2 .

4. Results and discussion

Kinetic analysis of adsorption represents the determination of the amount of adsorbed substance depending on time [11].

The obtained results for the adsorption of Cu(II) and Zn(II) ions per unit mass of waste foundry sand as a function of time are shown in Figure 1. It shows that the adsorption capacity q_t increases very rapidly in the beginning of process. Maximum capacity is achieved in 30 minutes for both investigated ions. These results indicate that the kinetics of fixing Cu(II) and Zn(II) ions on waste foundry sand surface was fast. It is assumed that the cause of this rapid adsorption was a sufficient number of places on the surface of the adsorbent. When the system reaches equilibrium state, free places on waste foundry sands are probably filled in. Adsorption capacity of Cu (II) ions at the time of achieving equilibrium was 2.465 mg/g, while the adsorption capacity of Zn (II) ions was smaller (2.335 mg/g). Different adsorption capacities may be associated with various radius of ions. The ionic radius of Cu is smaller, which allows faster and more easily positioning of this ion to the free places on the investigated adsorbent. Similar observations were presented by the other authors who have studied different adsorption systems [12-14].

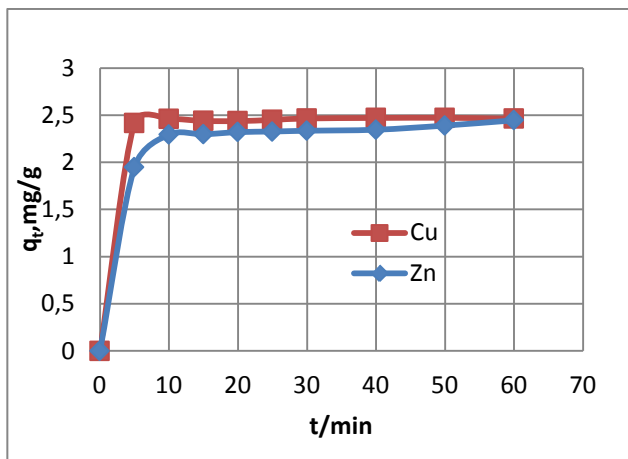


Fig. 1 Dependence of adsorption capacity on the time of contact of the investigated system of waste foundry sands/binary solution Cu (II)-Zn (II) ions

The obtained kinetic results were modeled using pseudo first model and pseudo-second order kinetics models (Figures 2 and 3).

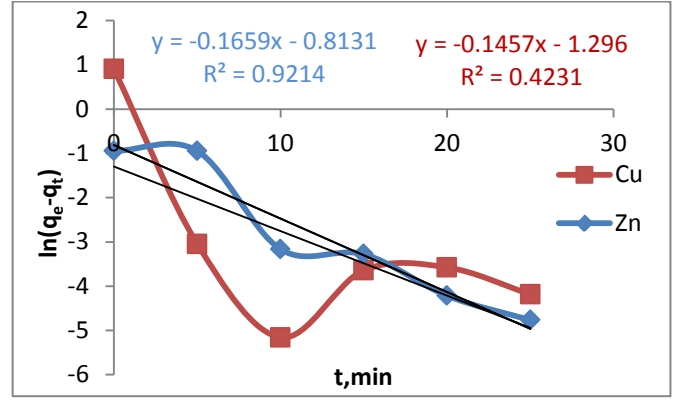


Figure 2. Pseudo-first order kinetics plots for the adsorption of Cu(II) and Zn(II) ions on waste foundry sand

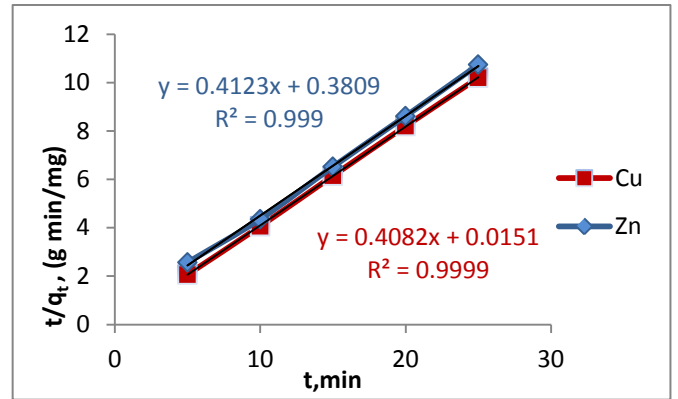


Fig. 2 Pseudo-second order kinetics plots for the adsorption Cu(II) and Zn(II) ions on waste foundry sand

Table 1 contains the constants and correlation coefficients for the kinetic models of adsorption of Cu(II) and Zn(II) ions on waste foundry sand.

Table 1: Constants and correlation coefficients of kinetic models for the adsorption of Cu(II) and Zn(II) ions on waste foundry sand

Pseudo-first order	Cu(II)	Zn(II)
$q_{e, \text{exp}}$ [mg/g]	2.466	2.335
$q_{e, \text{theor}}$ [mg/g]	-	-
k_1 [1/min]	0.1451	0.1659
R^2	0.4231	0.9214
Pseudo-second order	Cu(II)	Zn(II)
$q_{e, \text{exp}}$ [mg/g]	2.466	2.335
$q_{e, \text{theor}}$ [mg/g]	2.450	2.425
k_2 [g/(mg·min)]	11.033	0.446
R^2	0.9999	0.999

Comparison of the correlation coefficients in Table 1 shows that the correlation coefficients for the pseudo-second order kinetics ($R^2=0.9999$ for Cu(II) and $R^2=0.999$ for Zn(II)) are higher than for the pseudo-first order kinetics ($R^2=0.4231$ for Cu(II) and $R^2=0.9214$ for Zn(II)). This fact indicates that the adsorption of the Cu(II) and Zn(II) ions was performed according to the reaction kinetics of the second order. Furthermore, a comparison between the experimental

adsorption capacities ($q_{e,exp}$) and modeled adsorption capacities ($q_{e,theor.}$) shows that the modeled adsorption capacities from pseudo second order model very well correspond to the experimental with a small. The modeled adsorption capacity for the pseudo-first order kinetics could not be calculated. This also contributes to the previously mentioned fact.

The constant for the pseudo-second order kinetics of the adsorption Cu(II) ions on waste mould sand has a higher value in relation to the constant for the pseudo-second order kinetics of the adsorption Zn(II) on waste foundry sand. This is also further proof that the adsorption of Cu(II) on waste foundry sand is better than adsorption of Zn(II).

5. Conclusion

- The obtained adsorption capacities for systems waste foundry (mould) sand/binary system Cu(II)-Zn(II) ions are a good indicator of waste foundry sand potential for use in aqueous adsorption system.
- Adsorption equilibrium was achieved very quickly, for 30 minutes.
- The results indicate that the kinetics of Cu (II) and Zn (II) ions on waste foundry sand can be described by the pseudo-second order kinetics model.
- Comparing the kinetic constants ($k_2Cu(II)= 11.033 \text{ g/(mg}\cdot\text{min)}$, $k_2Zn(II)= 0.446 \text{ g/(mg}\cdot\text{min)}$) it is possible to conclude that the adsorption of Cu (II) ions on waste foundry sand is better than the adsorption of Zn (II) ions.

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COMPUTER MODELING OF CASTINGS QUALITY WITH TAKING INTO ACCOUNT THE DIFFERENTIATION OF STRUCTURE-DEPENDENT CORES AND MOLDS MATERIAL PROPERTIES

МОДЕЛИРОВАНИЕ ПРОЦЕССОВ ФОРМИРОВАНИЯ КАЧЕСТВА ОТЛИВОК С УЧЁТОМ ДИФФЕРЕНЦИАЦИИ СТРУКТУРНО-ЗАВИСИМЫХ СВОЙСТВ ФОРМ И СТЕРЖНЕЙ

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Abstract: Typical casting simulation procedure doesn't consider exact cores and molds material properties as a primary factor. Sometimes mold is considered as an isotropic body characterized with constant averaged thermophysical and other properties. On the other hand there are a lot of practically collected data confirming the fact that input of exact non-uniformly distributed thermophysical mold properties during casting simulation may seriously improve the prognosis of casting quality. The present work is dedicated to interconnections between molds compacting conditions and castings quality. It has been proposed to carry out the computer modeling of compacting process for further use of the calculation results as a part of input for casting simulation software.

KEYWORDS: COMPACTING, NON-UNIFORM STRUCTURE, FOUNDRY MOLDS AND CORES, SAND DENSITY, SAND PROPERTIES, CASTING SIMULATION.

1. Introduction

Common use of casting simulation software (CSS) involves necessity of a knowledge database for material properties and initial data considered as the part of mathematical models that form a basis of CSS. Accuracy of the data defines adequacy for casting quality prediction. The data consists of molds and cores properties, which are non-uniformly distributed in compacted sand due to its structure differentiation, temperature anisotropy and local material transformations. Taking into account the spatial distribution of thermophysical, filtration and other mold properties provides significant increase of CSS use effectiveness.

2. Computer modeling of sands compacting process

Degree of sand compaction is one of the main characteristics for mold quality, which directly affects to casting quality. Evident demands to foundry mold are connected to necessity in satisfactory dimensional accuracy and sand mechanical properties. Besides of that, non-uniform structure of compacted sand establishes complex conditions for gas and moisture migration, heat transfer from casting, etc.

Empirical and analytical solutions for sand compacting were obtained during, basically, 60's-70's of previous century [1-4]. In modern times the sand compacting problem for arbitrary shape tooling may be successfully solved with a numerical simulation analysis in the special Arena-flow software [5], or appropriate modulus in CSS ProCast, MagmaSoft [6, 7] or in multipurpose finite-element software [8-10]. In the present work numerical analysis of sand compacting during its pressing was performed in NX Advanced Simulation application. Sand was considered as a linearly elastic body, which is, as shown in number of works, allowable assumption in case of a single load and if stress values lay in a certain range [3].

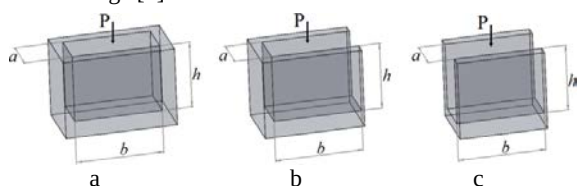


Figure 1: Types of pockets configuration:
a – one-sided; b – two-sided; c – three-sided

Considering replication of a pattern profile, the particular interest is in reaching a sufficient sand density in so called pockets which may exist in pattern itself, gaps between pattern and flask wall, etc. Three types of pockets [4] could be defined (Fig. 1). The most complex pocket is one-sided if ram from the top. Appropriate

molding pressure for reaching the sufficient sand density on the pocket bottom depends on proportions between main sizes *a*, *b* and *h*.

Mix compositions and properties of sands [3] compacting of which has been investigated in the present work are summarized in the Table 1: *E* – structural strain modulus (analogue of Young's modulus); *μ* – transverse strain ratio (analogue of Poisson number); *ρ*₀ – initial density of the mix. Coefficient of contact friction between sand and pattern walls was assumed *f*=0,20-0,35. Mechanical properties of sands were determined experimentally for triaxial compression material state. As for initial density, which is, in the general case, non-uniformly distributed within the sand prior to its pressing, the task may be solved with molds and cores blowing simulation software.

Nr.	Addition, % wt.			<i>ρ</i> ₀ , kg/m ³	<i>E</i> , MPa	<i>μ</i>
	Sand K016 (95 AFS)	Clay	Water			
1	100	-	-	1500	170	0,32
2		-	3,5	1240	37	
3		10,0	2,5	1200	9,3	
4		12,0	3,0	1450	17,5	

Table 1: Mix composition and properties of investigated sands

Strains in the system obtained through finite-element analysis of sand strain-stressed state during pressing procedure allowed identifying the ratio between initial *V*₀ and final *V* local volumes in the depth of sand pack. Local (inside the element) effective density *ρ* distribution was calculated through the criteria analysis option embedded into the software postprocessor by the next evident formula:

$$\rho = \rho_0 \frac{V_0}{V} \quad (1)$$

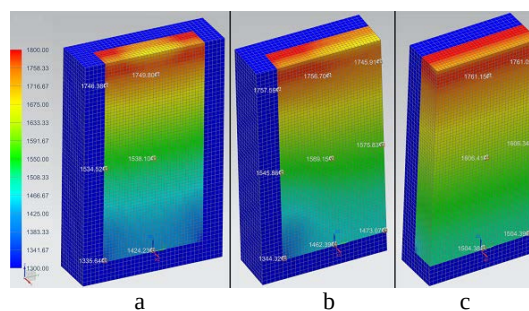


Figure 2: Sand Nr. 3 density distribution (kg/m³)
after pressing in differently configured pockets
(cross-sectional view, *ρ* values are marked for selected regions):
a – one-sided; b – two-sided; c – three-sided

Fig. 2 shows sand Nr. 3 density distribution in the moderately deep pockets ($a:b:h=1:2:4$) of different shape for compacting pressure $P=1$ MPa. Sand density increases, in particular at the bottom, along with simplification of the pocket type. Satisfactory sand density (depending on demands, equals to 70-90% from maximum possible ρ_{sc}) at the bottom, i.e. in the working area which directly contacts to liquid metal, could be observed for the selected pressure and system sizes in the case of three-sided pockets; other cases show necessity for compacting pressure increase.

Density distribution calculation results for one-sided pocket ($a:b:h=1:2:4$) are shown in Fig. 3. Clay-bonded sands compactability depends on, first of all, initial density, clay and water content. Dry silica sand shows low compactability which could be improved with water addition.

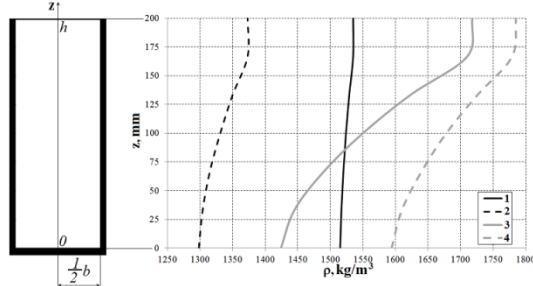


Figure 3: Density distribution on the axial line of one-sided pocket for sands Nr. 1-4 pressing cases

Non-uniform density distribution is a reason for spatial non-uniformity of other sand properties. Fig. 4, a shows calculated prediction of a spatial distribution of locally-effective (within every element) heat conductivity coefficient λ and volumetric heat capacity C_v of compacted sand. The prediction is based on special structure models of bonded sands [11] developed on the granular media averaged cell approach [12]. Express-estimation for gas permeability K_g was performed with a further mentioned criteria analysis comfortable option which allows instant plotting the full

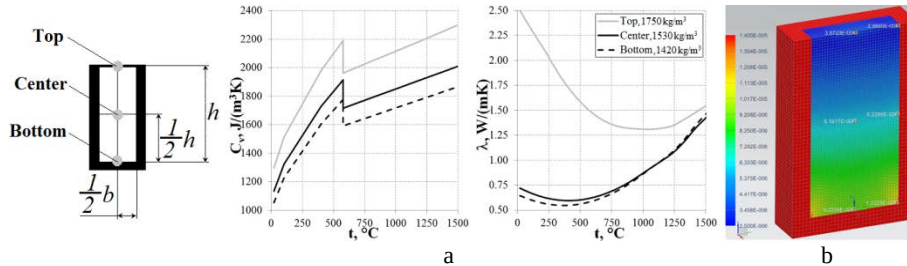


Figure 4: Calculative prediction for structure-dependent properties of sand Nr. 3 after its compacting in one-sided pocket:
a – temperature-dependent thermophysical properties in the axial line regions;
b – gas permeability distribution ($m^4/(N \cdot s)$) at normal temperature (cross-sectional view)

Non-uniform distribution of sand thermophysical properties and gas permeability, furthermore which are instable during mold heating due to structural transformations (volumetric changes of mix components, thermal decomposition, evaporation and condensation of moisture, etc.), leads to nontrivial thermal and gaseous regimes of the mold, so all of that circumstances influence on cast result in a complicated way.

3. Numerical simulation of castings with taking into account the non-uniform mold structure

The above-mentioned mold and core production simulation software prognoses completeness of occupancy of tooling cavities and differentiating in density distribution. As a result of work with the software tools Based on the analysis made with the aids of special software an optimal tooling design and blowing regime could be developed. At the same time the calculated data on non-uniform mold structure cannot be further utilized during casting simulation procedure. At this stage the data is lost and mold is considered as a quasiisotropic body, at the best case endued with temperature-dependent, but not spatial-dependent, thermophysical properties. However, it seems reasonable to inherit previously

field of calculated value on the three-dimensional model (Fig. 4, b). The user formula [13] utilized for the criteria analysis is similar to known Kozeny–Carman equation:

$$K_g = \frac{d^2 m^3}{36 \xi \mu_g (1-m)^2 (3-m)}, \quad (2)$$

where m – sand porosity calculated from the evident proportions between ρ and individual densities of mix components; d – sand particles size; ξ – pore tortuosity (for typical foundry sand mixes it could be assumed, in average [13], $\xi=1.5$); μ_g – dynamic-viscosity coefficient. Spatial distribution for K_g is essential for mold gaseous regime calculations through appropriate differential equations [9, 13].

Effective conductivity value (Fig. 4, a) for overcompacted sand in the top pocket zone ($m \sim 0.36$) is influenced significantly by individual conductivities of solid components of sand, at the same time radiative transfer is depressed due to relatively low pore amount. Other situation is observed in the moderately compacted layer at the pocket bottom ($m \sim 0.47$): in the range of low and medium temperatures t sand conductivity is relatively low due to weak contact interactions between mix particles, while in the range of high temperatures conductivity rises actively due to intensification of radiative transfer in sand pores. Effective volumetric heat capacity rises evidently with a growth of sand density.

Sand gas permeability (Fig. 4, b) decreases with increasing of the distance from the pocket bottom, which is not complied with recommendation based on the abstract concept for favorable gas transport conditions. The evident recommendation says that K_g must increases with increasing of the distance from the mold working surface which will be in contact with liquid metal. In general case it is recommended [1] to have uniform distribution of K_g in the mold volume (i.e. uniform distribution of ρ); well-grounded selection of optimal compacting conditions may help to get near that.

obtained calculative results for molds and cores structure, arrange appropriate differentiate assigning of thermophysical and filtration mold properties distribution for further casting simulation with improved accuracy.

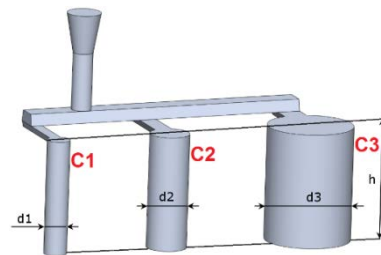


Figure 5: Cylinder sample castings

In order to determine how much the density non-uniformity may affect on cast result a number of computational experiments with a cylinder sample castings (Fig. 5, identification marks for cylinders are C1, C2, C3 as long as their diameter is increased) were carried out. The cylinders are produced of different alloys (Table 2) in clay-bonded molds compacted with different pressure. The mold for cylinders includes a sort of three-sided

pockets so the degree of compacting in them will vary after pressure differences.

Nr.	Alloy type	Alloy grade (Rus)	Solidification range, °C
1	Hypereutectic silumin	AK18	670-560
2	Grey iron	SCh30	1220-1150
3	Carbon steel	20L	1530-1480

Table 2: Foundry alloys for cylinder sample castings production

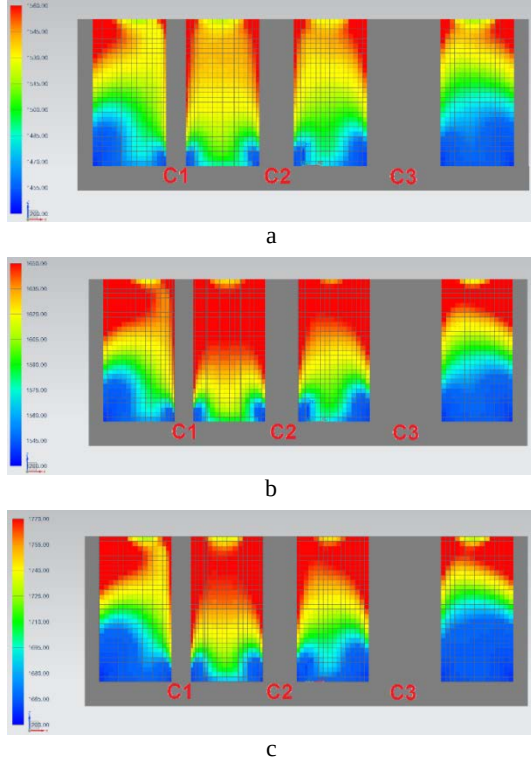


Figure 6: Sand density differentiation (cross-sectional view) in three-sided pockets around cylindrical elements of the pattern ($h=200$ mm, $\varnothing 40$ mm – C1, $\varnothing 70$ mm – C2, $\varnothing 150$ mm – C3) as a result of sand Nr. 3 compacting calculations with different pressures: 0,6 MPa (a), 0,8 MPa (b) u 1,0 MPa (c)

Compacting of sand Nr. 3 was considered as a method for cylinder sample casting mold production. Three-dimensional analysis in NX Advanced Simulation was utilized to predict sand non-uniform structure within the mold (Fig. 6), the data was further taken into account during castings simulations in CSS PolygonSoft. To arrange the inheritance procedure calculated density fields after converting in specially made program and additional adaptational mesh converting in Altair HyperMesh software were transformed to finite-element geometry data (Fig. 7). For every mold layer fixed density was assigned which is acceptable assumption due to modest variation of density within the each layer (10-20 kg/m³). Individual temperature-dependent thermophysical properties (λ and C_p) of each layer were calculated on the basis of the structure models [11]

taking into account appropriate densities. These properties were further utilized during solidification analysis of cylinder sample castings of different diameter. In order to prevent influence on calculation results from heat loss on cylinders end boundaries (top and bottom) these planar surfaces were assigned as adiabatic.

As a result of the castings simulations full solidification times and solidification sequences were discovered for each sample cylinder solidified in non-uniformly structured mold. The obtained data was compared with typical results of CSS analysis when the mold is assigned with stable uniform density and appropriate temperature-dependent thermophysical properties. However, the uniform density for each case was defined in reasonable way – the effective value was calculated as an average weighted among all densities previously calculated for each mesh element. That made the result equal to known method for density measuring through sand mold weighting procedure.

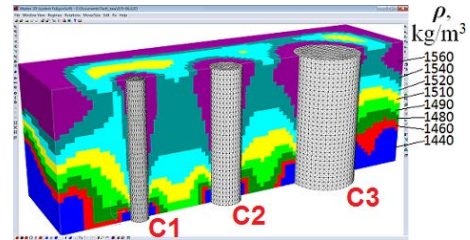


Figure 7: Calculated mold density fields obtained from compacting modeling in transformed view which represents finite-element geometry for casting in the complex structured mold plotted in CSS preprocessor (example for compacting at 0,6 MPa)

Calculation results for test cylinders solidification times are summarized in Table 3. Pressure rise leads to decrease of solidification times due to general increase of mold heat-removing ability. However, the situation isn't as trivial for thick cylinders solidification. In this case the mold experiences deeper heating so the volume of sand, which affects on general heat exchange in the casting-mold system, is significant. In accordance to the run of thermophysical properties curves, the properties could rise or descend with a temperature increase in each layer. Therefore, if overall sand density is slightly raised massive castings may solidify the same time or even a bit longer than in the case of mold with a slightly lower density. Considering complex castings, it must be taken into account that neighboring elements of the casting may affect each other through appropriate mold regions; the regions are able to heat-up faster and deeper in consequence of overall increase of thermophysical properties.

Solidification times vary significantly from one alloy to another which is not only connected to solidification range, individual alloy thermophysical properties, interval between pouring and initial mold temperatures which results in faster cooling of high-temperature alloys, etc. Additional reason for the variety is significant difference in sand thermophysical properties when mold is heating from different initial temperatures of an alloy. In such a way radiative transfer isn't affect as much in case of aluminum alloy radiating in comparison with steel pouring – however, the effect isn't so evident in case of highly compacted sand.

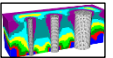
Mold properties distribution	Alloy	Cylinders solidification times, s								
		C1, $\varnothing 40$ mm			C2, $\varnothing 70$ mm			C3, $\varnothing 150$ mm		
		0,6 MPa	0,8 MPa	1,0 MPa	0,6 MPa	0,8 MPa	1,0 MPa	0,6 MPa	0,8 MPa	1,0 MPa
Non-uniform 	AK18	553	445	200	1622	1020	552	7380	4879	2416
	SCh30	322	303	176	922	849	495	4048	3680	2169
	20L	190	181	125	531	505	346	2269	2154	1495
Uniform 	AK18	541	488	183	1603	1443	513	7257	6512	2237
	SCh30	311	293	157	895	839	444	3931	3683	1933
	20L	185	177	114	518	494	314	2222	2118	1348

Table 3: Solidification times for test castings produced in differently compacted molds

Solidification analysis for castings in molds with well-defined material properties anisotropy is considered as more accurate in comparison with traditional casting simulation practice when the

mold appears as “equivalent” isotropic body. Comparison result for the cases shows good agreement between calculated solidification times – average difference is about 10%. The main reason for that is

well-grounded averaging for isotropic mold effective density. Increase of solidification time, as well as test cylinder diameter, and its height (as shown with additional calculations in this case difference between top and bottom densities may increase dramatically) lead to much more significant solidification time mismatching.

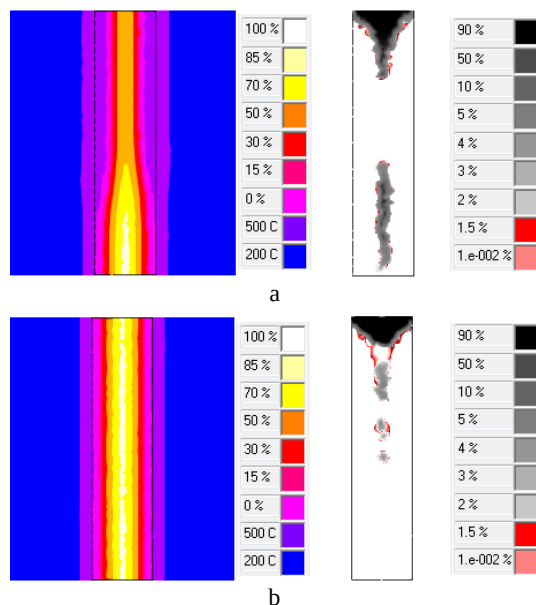


Figure 8: Solidification of steel test cylinder of $\varnothing 70$ mm in differently structured molds pressed at 0,8 MPa:
a – typical liquid phase distribution at intermediate moment of casting cooling in anisotropic mold and final porosity prognosis;
b – the same for “equivalent” isotropic mold

Undoubtedly, consideration of solidification time differences is insufficient to ground or deny applicability of traditional isotropic mold approach. In addition to that, solidification sequence must be considered. The sequence is critical for solidification directionality, tendency to defects formation, features of metal structure, for example, local chilling on iron castings, etc. Fig. 8, a shows liquid phase distribution at intermediate moment of cylinder solidification in the mold with non-uniformly distributed density decreased from top to bottom and appropriate porosity prognosis. The result is clearly not a same as the idealized case of solidification in the mold with uniform density distribution (Fig. 8, b). In the first case hot spot migrates to bottom region which leads to porosity located under $1/2h$ level while idealized case shows porosity above the level only.

4. Conclusion

The present investigation proves reasonability of casting simulation procedure improving through taking into account the data on foundry molds non-uniformly compacted structure. This allows increasing calculation accuracy for heat-transfer and metal flow processes, gaseous regime in casting-mold system, etc. The approach offers opportunity to solve a number of problems connected to mold-dependent casting defects on new improved level of quality. Development of the approach is connected to, first of all, creation of sustainable interface for data exchange between computer modeling software, improving the mathematical models for sand compacting as well as for sand structure and material properties transforming after the melt is poured into the mold.

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THERMAL REGIMES AND CRYSTALLIZATION KINETICS DURING CASTING LIGHT VITRIFY GLASS MELTS INTO A METAL MOLD

ТЕРМИЧЕСКИЕ РЕЖИМЫ И КИНЕТИКА КРИСТАЛЛИЗАЦИИ ПРИ ЛИТЬЕ ЛЕГКО СТЕКЛЮЮЩИХСЯ РАСПЛАВОВ В МЕТАЛЛИЧЕСКУЮ ИЗЛОЖНИЦУ

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Abstract: Using an original mathematical model the calculate analysis of the relationship of thermal modes of castings production with crystallization kinetics and microstructure parameters of the alloy $\text{Cu}_{47}\text{Ni}_8\text{Ti}_{34}\text{Zr}_{11}$ is made. It is shown, that at cold mold casting in castings of different thickness are fixed three types of microstructure: amorphous with inclusions of so-called "quenching nucleus", amorphous-crystalline and polycrystalline with microscale size of the crystals. For castings with a completely crystallized nanocrystalline structure proposed method of isothermal quenching melts, which is realized by casting the melt into the preheated mold. Determined values of the initial mold temperature interval provides for the formation of castings having a grain size of 100 nm for justifiable from an economic point of view intervals.

KEYWORDS: METAL MOLD CASTING, ISOTHERMAL QUENCHING OF MELT, CRYSTALLIZATION KINETICS, MICROSTRUCTURE PARAMETERS

1. Introduction

Creation of metal materials with amorphous and nanocrystalline structures concerns priority directions of a science and modern technologies. Progress in this area require deep understanding of interrelations of a chemical composition of alloys and technology factors with the physical parameters which control a kinetics of crystals nucleation and growth processes. The important role in studying of noted interrelations is played a method of mathematical modeling. Results of modeling researches create theoretical preconditions for working out of new production technologies of precision alloys which provide controllability with processes of structure formation and reception of materials with predicted microstructures and properties.

One of ways of amorphous alloys production is casting in metal mold. This way apply to the class of so-called bulk metal glasses [1] developed in last years which solidify without crystallisation in sections more than 1 mm, i.e. at melt cooling rates less than 10^3 K/s. In the present work calculated analysis of structure formation processes at solidification of easily amorphization alloy $\text{Cu}_{47}\text{Ni}_8\text{Ti}_{34}\text{Zr}_{11}$ (Vit 101) in copper mold with thickness of working walls of 15 mm, are presented. The first block of calculations carried out in the assumption, that before melt casting the mold is at a room temperature (such technological version of process we will name casting in cold mold). In calculations of the second block initial temperature of mold set from relation $T_2^0 = T_g + (5-43)$ K, where $T_g = 671$ K – glass transition temperature an investigated alloy [2] (casting in hot mold [3, 4]). In the latter case analyzed possibility of creation of an isothermal mode of crystallisation, assume, that with its help can be received completely crystallized casting with the sizes of structural components to 150 nm.

2. Method of calculations.

Calculated researches carried out a method of the coordinated numerical decision of thermal and kinetic problems. Thermal problem represented system of one-dimensional differential Fourier equations for melt, which contain of latent transformation heat source, and copper mold with boundary conditions, which formalize physical assumptions used in model relative to initial temperatures of melt and mold, and also heat exchange conditions on borders a melt-mold-working environment.

Solidification kinetics of casts modeled in assumptions, that process occurs by spontaneous nucleation and the subsequent normal growth of spherical crystals. Delay of transformation at the expense of collisions of the adjacent crystals considered by means

of approach of effective nucleation and growth rates [5], according to which increments of number of the crystallization centers and the crystals sizes for an elementary time interval are proportional to a volume fraction of a parent phase. Within the limits of this approach the kinetic equation describing change in due course of a crystallized volume fraction, received in the form of:

$$x(t) = \frac{4}{3} \pi \int_{t_m}^t (1 - x(t')) I(t') \left[R_c(t') + \int_{t'}^t (1 - x(t'')) u(t'') dt'' \right]^3 dt' \quad (1)$$

where I , R_c – properly, formation frequency and critical radius of crystal nucleus; u – growth rate of crystals; t_m – time of achievement by melt a fusion temperature T_m ; t , t' , t'' – present situations times; $t_m \leq t' \leq t'' \leq t_e$, t_e – time of the crystallization ending ($x(t_e) \approx 0,99$).

Besides calculations of the basic kinetic dependence $x(t)$, approach [6] allows to make the additional analysis of the crystals nucleating and crystals growth kinetic processes, which results give the valuable information on features of a microstructure rapid quenched materials [6, 7].

The coordinated decision of the equations of heat conductivity with the kinetic equation (1) carried out a method of final differences with implicit difference scheme [8]. All details of mathematical basis of model, computing algorithm and calculations temperature dependent parameters I , R_c , u for alloy Vit 101 are presented in works [9, 10].

3. Results and analysis

For studying of influence of mold temperature on a thermal mode and crystallization kinetics of casts Vit 101 counted dependences on time of temperatures of melt $T_1(t)$ and mold $T_2(t)$, and also crystallized volume fraction $x(t)$. Calculations carried out for casts in the half-thickness $l_1 = 0,7 \cdot 10^{-3}$ m, derived by casting under pressure in Cu-mold with thickness of working walls $l_2 = 15 \cdot 10^{-3}$ m. Initial temperature of mold T_2^0 changed in limits from 333 to 714 K, initial temperature of melt, and also values of heat-transfer coefficient on borders the melt-mold-air environment accepted the equal: $T_1^0 = T_m + 100$ K; $\alpha_1 = 2,67 \cdot 10^3 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$, $\alpha_2 = 5 \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$.

As follows from fig. 1, at casting of melt Vit 101 in the cold ($T_2^0 = 293$ K) mold the temperature of melt with time $T_1(t)$ continuously decreases to values, less T_g , keeping during all period of process t_e higher values in comparison with temperature of mold. The amorphous structure is as a result fixed with is negligibly small ($\sim 2,3 \cdot 10^{-5}$) a volume fraction so-called „frozen nucleus”, having the

average sizes $\bar{R} \approx 23$ nm. Qualitatively similar structure is predicted by the modeling calculations executed in the assumption $T_2^0 \leq T_g$.

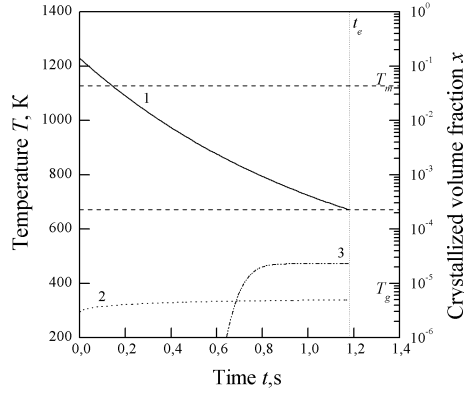


Figure 1 – Plots of changes in due course temperatures of melt (1), mold (2) and crystallized volume fraction (3) for casts from alloy Vit 101 with half-thickness $l_1=0,7 \cdot 10^{-3}$ m, received by casting in copper mold with initial temperature $T_2^0=293$ K.

At heating of mold to temperatures $T_2^0 > T_g$ character of dependences $T_1(t)$, $T_2(t)$ and $x(t)$ essentially changes. The analysis of the calculation data presented on fig. 2 ($T_2^0=T_g+20$ K), show, that during rather short time interval $t_{iso} \approx 56$ s curves $T_1(t)$ and $T_2(t)$ approach and the further stages of transformation occur in isothermal conditions ($T_1 \approx T_2 = T_{iso}$) at deep supercoolings of melt $\Delta T_r^{iso} = (T_m - T_{iso})/T_m$. For a considered example the temperature of an isothermal stage makes $T_{iso}=719$ K, and the reduced supercooling $\Delta T_r^{iso}=0,36$. In similar conditions crystallization is carried out by rapid nucleation ($I_{iso}=3 \cdot 10^{17} \text{ m}^{-3} \cdot \text{s}^{-1}$) and the subsequent growth of crystals with very low rates ($u_{so}=1,4 \cdot 10^{-10} \text{ m} \cdot \text{s}^{-1}$). At such combination of parameters I and u increasing of crystallized volume fraction occurs preferentially at the formation of new crystallization centers which by the moment of the termination of transmutation $t_e=1,3 \cdot 10^3$ s reach sizes $\bar{R}=94$ nm.

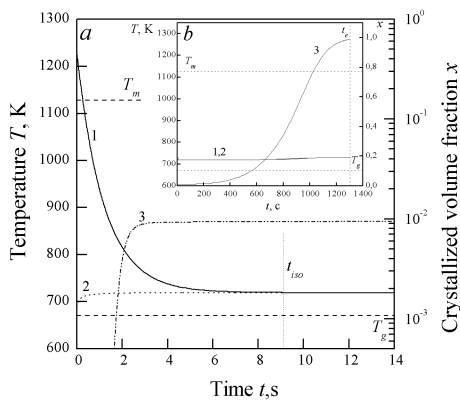


Figure 2 – Calculated dependences $T_1(t)$ (1), $T_2(t)$ (2), $x(t)$ (3) for the thin ($0,7 \cdot 10^{-3}$ m) casts from an alloy Vit 101, obtained by casting in the hot ($T_2^0=691$ K) copper mold: a – initial stage of process; b – isothermal stage.

As can be seen from fig. 3, at a mold heating to temperature 714 K, which on 43 K exceeds temperature of a glass transition of alloy Vit 101, the isothermal condition of crystallisation is maintained only on the limited temporary segment. At the final stage of process the balance escaped at crystallisation and outputed

in mold thermal streams is broken, that induce increasing of crystallising casting temperature from 742 to 796 K and caused by a change of a temperature condition deceleration of nucleation processes and acceleration of crystals growth. Consequence of similar modifications of parameters I and u is essential roughening microstructures of casts, which medial sizes of grains make 137 nm.

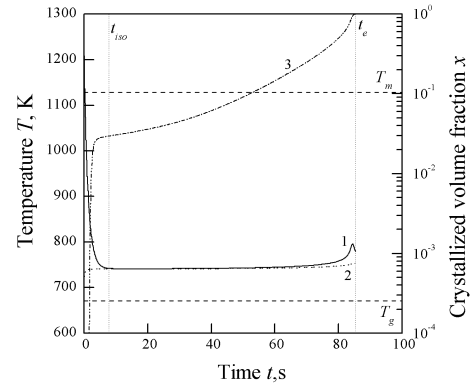


Figure 3 – Results of the calculated analysis of a thermal condition and crystallisation kinetics of casts with half-thickness $0,7 \cdot 10^{-3}$ m, obtained by casting of melt Vit 101 in copper mold, heated to temperature $T_2^0=714$ K: 1 – $T_1(t)$; 2 – $T_2(t)$; 3 – $x(t)$.

The analysis of all set of the obtained calculation datas shows, that with increase of a preliminary superheat of mold concerning temperature of a glass transition from 5 to 43 K number of the crystallization centers formed in unity of volume during all continuance of a solidification, decrease approximately on one order of magnitude (10^{20} - 10^{19}) m^{-3} , and mean sizes of crystals are incremented from 68 nanometers to 137 nm. Thus common duration of process is reduced from $\sim 9,0 \cdot 10^5$ s (~ 250 hours) to 85,4 s.

Thus, results of the performed modelling explorations argue to the basic possibility of realisation of the method of isothermal quenching of melts which allows to obtain nanoscale structures in thin casts of alloy Vit 101 immediately in the course of their solidification.

4. Conclusions

1. On an example of alloy Vit 101 features of structure formation are explored at moulding in hot casting-form. Determined the interval of casting-form temperature values $T_2^0=(676-714)\text{K}$, which providing an establishment of an isothermal mode of a solidification castings, at temperatures on (5–71)K exceeding a glass transition point.
2. It is shown, that at an isothermal stage of process crystallisation is carried out with close to maximum $\sim(10^{15}-10^{18}) \text{ m}^{-3} \cdot \text{s}^{-1}$ nucleation rates and very low $\sim(10^{-13}-10^{-9}) \text{ m} \cdot \text{s}^{-1}$ rates of crystals growth, owing to what it is fixed completely crystallized structures with in the average crystal sizes from 67,6 до 137 nm.

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LIQUID PHASE MODIFICATION METHODS THROUGH NANOPOWDER INJECTION IN TIG AND IMPULSE TIG WELDING METHODS

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Summary: In practice there are several known methods of inserting the nanopowder to the welding layer, they are specified according to the conditions needed for the welding process. This article examines some new and innovative opportunities of liquid phase modification through insertion of nano-sized particles without being melted, according to TIG and Impulse TIG overlay welding methods.

Keywords: Nanopowder, TIG, Impulse TIG, Overlay Welding

1. Introduction

Overlay welding is a technology where a layer of metal alloy is being laid on the work piece. The overlay welding with different kinds of metal with specific chemical and mechanical properties performed on the working surfaces of the parts, increases their durability and reduce the weariness [6].

The area of operation of the overlay welded surfaces are defined by the chemical composition of the layer. The alloy is being produced by melting the main metal and by adding other metal, powder or flux. Main principles to evaluate the alloy are: homogeneousness of the composition in the welded volume, cost effectiveness, application capability of the alloying method and other. To insert alloy elements in to the base metal, following methods are being used[4]:

- Use of solid electrode wires or tapes – traditional method of becoming an alloy with particular chemical composition in wide scope of welding conditions where the alloying elements are well distributed in the volume.
- Alloying with use of electrodes – the most widely spread method. The overlay metal is homogeneous by composition, well formed, lack of pores and slag and also the chemical composition is fully based on the electrode.
- Another method of overlay welding uses low carbon wires or tapes and ceramic flux or flux mixtures, from which the alloying elements are being transferred to the overlay metal. In this method the flux is the main source of alloying and the more the volume of the melted flux the bigger is the quantity of the elements inserted in to the overlay metal. That is why the composition of the metal is dependent of the welding regime, the mass and composition of the used flux.
- Alloying using pastes which are being deposited on the welded layer and then melted with or without additional low carbon wire. The chemical composition of the welded metal is determined by the quantity of the paste and also by the quantity of the melted alloying material. (Fig.1).
- The alloying of the surface layers with carbide powders, nitrides, oxides, etc. which have the size of nano particles could be observed as another innovative method (nano particles have the size $1 \cdot 10^{-9} \text{m}$). By melting these powders, the alloying is similar to the method with the pastes (Fig.1). On the other hand, if the nano particles are inserted in the lower temperature area of the weld seam without being melted, they will take places in the crystal lattice of the melted metal and will make the structure refined, which will lead to better mechanical properties of the overlay layer (Fig.2). The new metal will be then a composite material, obtained by matrix consistent of

construction steel and particles of nitrides, carbides and other which contains the welding powder [2].

The innovation of the method lie on the fact that the powder maintain it's state, it is not being melted and so the liquid phase is being modified [5].

Because of the low power of the arc, the use of TIG and impulse TIG welding precesses is not very efficient compared to the plasma powder welding method. On the other hand it could be used to weld smaller parts (blades, wear resistant plates, etc), where a smaller amount of heating is required, so that the deformations could be avoided.

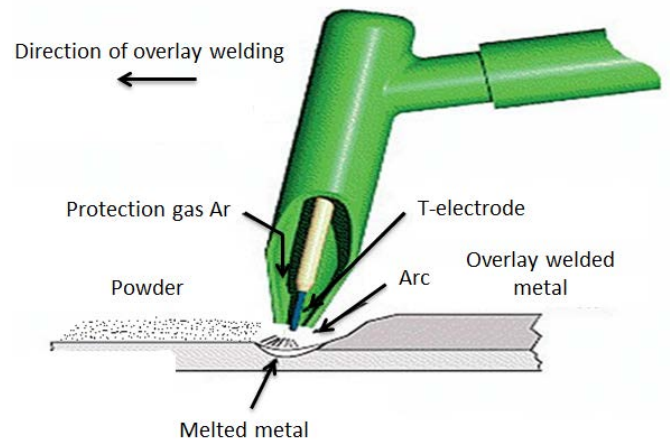


Fig. 1. Welding with melting of powder

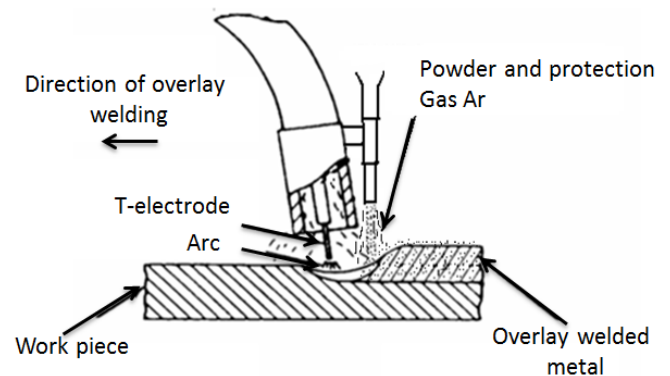


Fig. 2. Welding without melting of powder

2. Methods for modification of the liquid phase using nano-powders without melting them.

Several variants of welding without melting the nano-powders has been explored. These methods as well as some of their features will be observed in short.

A) The powders could be inserted at the end of the weldseam using proper additional device mechanism (Fig 3). It points 35°- 45° in relation to the direction of welding, it has the shape of bended wire 2mm in diameter and at the one end it has the contour of the weldseam (elliptical). The devise is being attached and "towed" by the gas nozzle. A few millimeters parallel to the welding line there is the powder trail which is being pulled in by the device to the weldseam. The powder trail is laid on the work piece in safety distance from the heat so that it could not be melted. It is 2-3mm wide and 2mm high. By the movement of the nozzle the powder is being pulled to the end of the weldseam. The powder is additionally pushed from the additional device so that it can penetrate better in to the seam.

TIG overly welding is flexible because of the manual movement of the nozzle, the arc is very powerful in gas environment and there is no need of additional materials in case of welding thin sheet metal layers. These characteristics make the method universal. Other advantages of the process are: inert-gas protection and T-electrode have no effect on the chemical composition of the metal; there is no slag and splashes; the arc is being observed; fine adjustment of the welding regime is possible; mechanizing and automation is also possible; nano-particles could be inserted in different temperature zones of the weldseam. With the time the bended wire bends because of the heat, deforms and it could not push the nano-powder proper any more to the melted metal.

B) Fig. 4 shows an innovative method for insertion of nano-powders with or without melting. The devise is designed to deliver a mixture of inter gas and powder. It ensures a control over the amount of powder being used for the welding. The inert gas goes in through inlet 1, then enters the injector 3 and creates vacuum in channel 7. This leads to sucking the particles out from the reservoir 5. The control over the amount of the powder that has been sucked out is ensured through the valve 6. Inlet 2 is also supplied with inert gas so that air can't get to the mixture and from there to the weldseam. That way the particles that enter the weldseam make its structure refined.

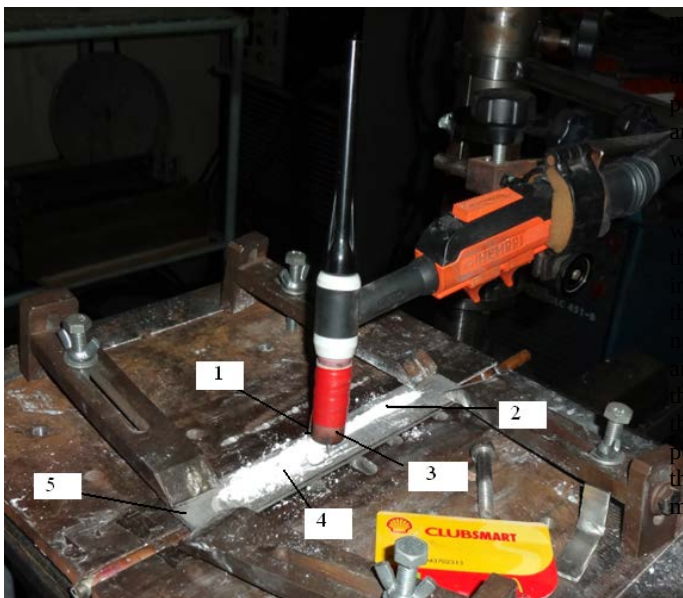


Fig.3. TIG and impulse TIG welding without melting the nano-powder.

1 – wire, with weldseam contour bend; 2 – powder on the side; 3 – nozzle ; 4 – powder after welding ; 5 – work piece.

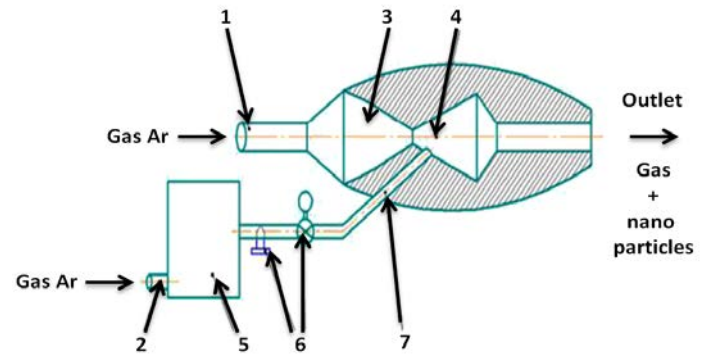


Fig. 4. Principle view of device for nano-powder insertion with or without melting.

1,2 – inert gas insertion nipples; 3 – injector; 4 - mixture chamber; 5 – powder reservoir ; 6 – valve for controlling the amount of powder ; 7 – channel



Fig. 5. Insertion of nano-powders behind the weldseam in the low temperature area 1 – nozzle; 2 – insertion tube for nano-powder and inert gas; 3 – nano-powder reservoir; 4 – inlet for the protection gas argon; 5 – heated metal right after the arc goes out; 6 – work piece.

Fig.5 shows the insertion of nano particles in to the melted metal direct after the arc, in the area of lower temperature. The end of the device 5 is positioned in an angle according to the nozzle 1 and the melted metal 5. The inert gas goes in through inlet 4 and passes through the nano-powder reservoir which is being sucked out and transported behind the welding arc. The direction of overlay welding is from right to left.

Fig.6 shows another way of insertion of nano-powders. The working principle is shown on Fig.4. The inert gas is being fed through the reservoir 3, the transport gas correspondingly through inlet 5. In the body 4 there is a needle which is being pushed back through the button 7. After releasing the button a spring pushes the needle back to the initial position. That way the needle goes back and forward and prevents the blocking of the hole which delivers the powder after the arc. The pressure of the inert gas that goes through the reservoir is in this case of most importance. It is possible that at high pressure the powder could be squeezed in and that could lead to blocking the hole of the reservoir from which the mixture of powder and inert gas should go out.



Fig. 6 Insertion of nano-powder behind the arc of welding in the low temperature area.

1 – nozzle; 2 –device outlet; 3 – nano-powder reservoir; 4 – body of the device; 5 – inert gas inlet; 6 – work piece.

4. Conclusions

1. There have been made experiments with all methods for insertion of nano-powders behind the welding arc in to the low temperature area.
2. Best result was produced with the method described on Fig.5 where the protection and transport gases are being fed from the same source.
3. The results are shown on Fig.7. It shows the overlay welding of one, two on $\frac{1}{2}$ from the width overlapping or tree also overlapping lines. There are no visible defects, the lines are consistent and well formed.
4. That gives us reason to continue the research of these methods for insertion of nano-powders in the area behind the welding arc.

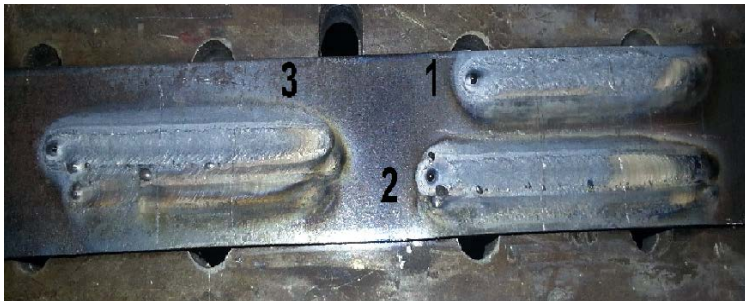


Fig. 7 Overlay welded lines. 1 – one line ; 2 – two overlapping lines; 3 – tree lines

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IMPACT OF INTRODUCTION OF REINFORCING ADDITIONS TO QUARTZ SANDS ON PHYSICAL AND MECHANICAL PROPERTIES OF FOUNDRY MIXTURES BY THE METHOD “NO BAKE” (PART 2)

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Abstract: Contemporary production of castings is inevitably associated with improvement of foundry mixtures, and in particular with quartz sands as a basic moulding material. The interest is motivated by opportunity of reaching mixture's appropriate parameters at different combinations between sands and binding compositions. One option of particular importance in obtaining mixtures' physical and mechanical, and technological properties is to get a greater number of contact points among individual grains of quartz sands.

The report examines the impact of dispersive mineral particles for increasing contact points of interaction between individual sand particles in the process of solidification. A theoretical basis for the possibility of applying such reinforcement in the preparation of mixtures is presented. An attempt for optimization has been done by some criteria – porosity, morphology, gas permeability and other properties. Results and conclusions from the conducted tests have been graphically presented.

KEYWORDS: CASTING, QUARTZ SAND, DISPERSIVE REINFORCEMENT, PHYSICAL AND MECHANICAL PROPERTIES

1. Introduction

As noted before [1], finding technically and economically effective solutions for optimal balance among parameters of foundry mixtures and their components is, and remains a very important task for the technologists. It is known that foundry mixtures are complex rheological systems which in combination with many factors should ultimately secure the necessary mould and core characteristics after solidification.

2. Presenting the problem and ways of its resolving

Mixtures' physical and mechanical properties are a result of two processes running simultaneously at solidification – formation of adhesive bond between sand grains and the binding composition and cohesive hardening of the composition itself. These processes are effected on the contact grain surface as the binding composition seeps into the contact points forming the so-called “bridges” [2].

On the other hand, the current foundry mixtures are characterized by a high degree of gas permeability (up to $700-900 \times 10^{-8} \text{ m}^2/\text{Paxs}$) i.e. 1.8 to 4.5 times greater than the normal one securing good gas regime of the mould [3,4]. The difference of around $250-400 \times 10^{-8} \text{ m}^2/\text{Paxs}$ is explained by the availability of pores of greater sizes at use of modern enriched sands.

Namely, the existence of the above-mentioned pores appears to be a reason to implement a series of tests associated with reinforcement (strength improvement) of mixtures through introduction of dispersive particles of respective sizes, rising the contact points among sand grains and improving the properties at retaining the optimal gas permeability.

The goals set have been:

1. Defining pore size at quartz sands;
2. Defining diameters of reinforcing dispersive particles;
3. Relationship between the coefficient of morphology [5] and porosity varying at sands of equal and mixed particle size;
4. Determining the permissible content of reinforcing dispersive particles in mixtures;
5. Impact of kind, amount and viscosity of the binding substance at constant compaction of pore size;
6. Influence of the degree of pore size compaction at constant parameters of the binding substance;
7. Technological features. Functional relationship between size and number of pores and size and number of dispersive particles;
8. Techno-economical parameters;

9. Technological regulations for practical application of dispersive reinforcement of foundry mixtures. Materials and properties.

We have noted [5] that we can create the best picture considering the structure of a foundry mixture obtained from spherical grains of equal diameter.

Theoretically, the spatial distribution of sand grains can be realized in three variants [4]:

- cubic, with the greatest space among grains, and porosity = 47.5%,
- prismatic, with porosity = 39.6%, and
- pyramidal, with 25.5 % pores,

with pore sizes being calculated according to the formula:

$$Q = [(1 - \pi \cdot D^3/6) : D^3] \cdot 100 (\%) \quad \{1\}$$

However, our idea is to rearrange in the space among grains such of less size than that of the pore, i.e. it already comes (ideally) to spheres of different diameters. Therefore, the smaller grain of diameter “d” can be disposed in a pore formed by grains of diameter “D” (Fig.1) only if the condition {2}[4] has been met:

$$d = [\sqrt{(2D - 1)}]D \quad \{2\}$$

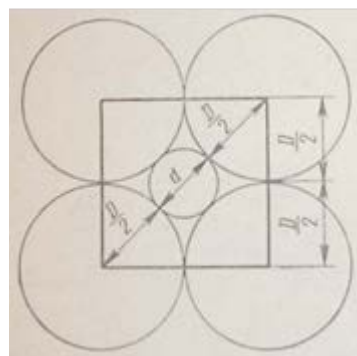


Fig.1 Theoretical basis for calculating “reinforcing” sand grain diameter [6]

Actually, in the mixtures there exist all the three spatial structures simultaneously and unevenly distributed, and hardly ideal distribution conditions can be ever implemented. Similarly, it can't be argued that the dispersive reinforcing particles will be disposed exactly in the pores among the sand grains.

It is necessary to note that the diameter of the dispersive particles will vary in conformity with the pore diameter.

It is also true that the layer thickness of the binding substance on the sand grain surface will be of essential significance, its

tendency to wetting (for example on the quartz base) and seepage into the zone of connecting bridges.

Due to the wide variety and a lot of problems in this field, in the present work, a specific task to verify the possibility for a relationship between the coefficient of morphology K_m [5] and porosity in foundry mixtures, and whether it is ever possible to forecast the pore size at certain particle size as well as limit admissible sizes and content of reinforcing particles has been set.

3. Decision of the examined problem

In order to bind the morphology coefficient K_m determined according to “the Russell-Taylor” method [5], (Fig.2) with porosity and pore size, tests on real distribution systems with quartz sands 01PK025, UKSS1 and KLP027 of different nature and morphology, (Figs.3,4 and 5) with grain size = 0.25 mm from Kaolin AD were carried out.

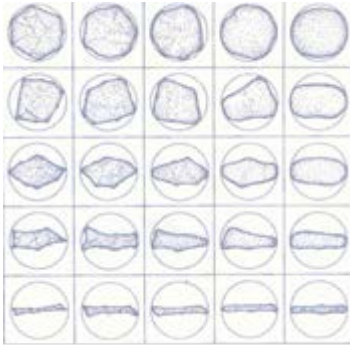


Fig.2. A Russell-Taylor table for determining the coefficient K_m

The comparison of the tested sands geometry shows that at 01PK025 the roundness is within 0.55-0.75, at KLP027 it varies from 0.60 to 0.80, at UKSS1 it is between 0.70 and 0.90.

For sands, the valid opinion is that when forming foundry mixture pack in real conditions these can be orientated relative to one another both with their protruding and concave parts. This significantly affects the pore magnitude and number of contact points.

To all this, we have to add that the sand specific surface and degree of compaction will exert significant impact on the physical and mechanical properties as well.

The former is directly related to the distribution of the binding substances at wetting in conformity with the state of this surface, viscosity and chemical content of the components.

This is a function of film thickness of the bounding substances and their even distribution.

The applied under all conditions compaction will exert a great influence on the strength and other properties, mainly on the number of contact points and size of “bridges”; moreover, a solidification to handling strength is effected in the process of applying outside impact.

If at ideal conditions and above accepted ratios of spatial distribution, the average value of porosity is 33.33%, then, it is really required to make a correction in accordance with the orientation, at sand grains contact with respect to one another, or:

- For sand 01PK025, aggregate average (min/max) correction factor = 0.13;
- For sand KLP027, aggregate average (min/max) correction factor = 0.24, and
- For sand UKSS1, aggregate average (min/max) correction factor = 0.46

Recalculating, we will obtain that the average porosity for mixtures with sand of 01PK025 is 28.9%. The one for sand KLP027 is 25.3%, and that for sand UKSS1 is 17.9%.

Pore sizes will vary within the limits, respectively, for 01PK025 = 0.013 – 0.035, for UKSS1 = 0.061 – 0.105, and for KLP027 = 0.026 – 0.063, or these are the maximum values of dispersive

particles sizes for adding to the tested mixtures to check up the idea of reinforcement.

It is evident that if we reinforce with the above sizes, then porosity will fall sharply, gas permeability will decrease and foundry mould operation will deteriorate at pouring.

In order to search optimal quantitative values of the above additions, we conducted a series of tests on gas permeability with sand UKSS1 and quartz flour at different size ratios and content in mixtures.

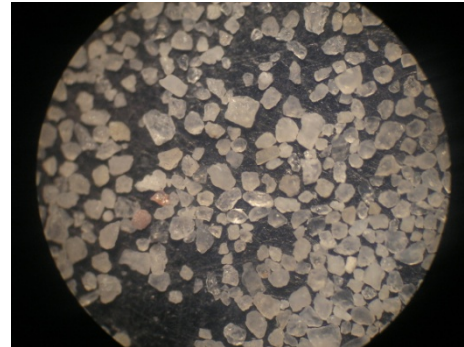


Fig. 3. Sand 01PK025

Mixtures are produced in a KLEIN vibrating mixer, type STATORMIX 22 with automated dosing of constant amount and proportion of the identical components

The binding system (resin + hardener) was from Huttenes – Albertus.

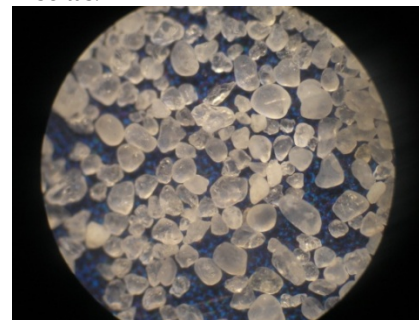


Fig.4. Sand UKSS1

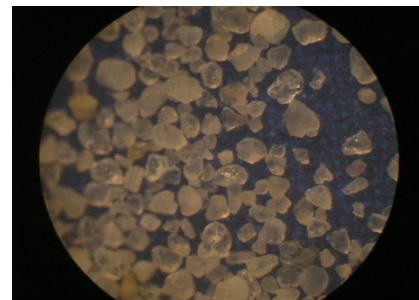


Fig.5. Sand KLP026

The specimens were obtained with the help of a laboratory press, for cylindrical specimen with 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.

Mixtures' physical and mechanical properties (specimens based compressive strength, erosion resistance and gas permeability) are determined by laboratory test devices LRu and LfR1 on IO PI.

4. Discussion results

Data from the conducted tests are shown in Fig.6 and 7.

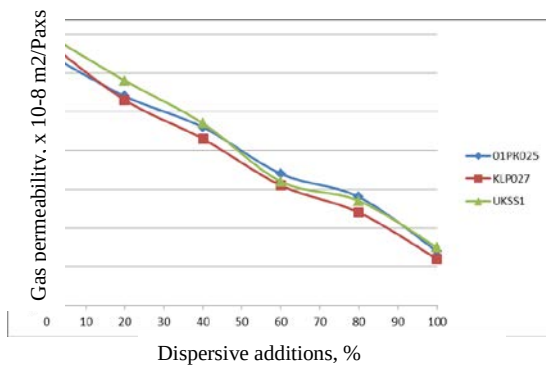


Fig.6. Gas permeability depending on the content of dispersive additions of constant size

In the first graph, it is presented the change in gas permeability as a function of the content of dispersive particles in the range to 100% of the estimated limited amount.

It is observed a gradual reduction of the pore size at their filling by dispersive particles, hence the gas permeability reached almost a "sanitary minimum" (80-100, x 10⁻⁸ m²/Paxs). Dispersive particle size was constant.

Substantial difference in the above changes between various types of tested sands has not been observed.

In Fig.7, data on influence of dispersive particles size is presented.

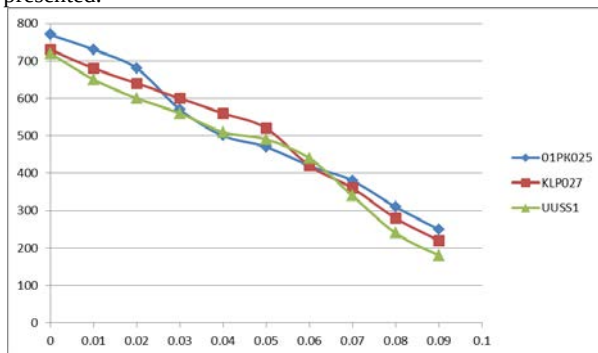


Fig.7 Gas permeability depending from the size, in mm, at constant content of dispersive additions

From the graph, it is seen that at selected constant content of the dispersive additions in the mixture of sand 01PK025, a rapid decline in gas permeability is observed within the size range of 0.02-0.04 mm, for KLP025 the fall is within the span of 0.05-0.07 mm, and for UKSS1 it is between 0.07-0.08 mm.

Graph no. 6 gives us a possibility to also determine a supposedly optimal content of the dispersed reinforcing additions at various tested sands.

It is known that for normal gas permeability values in real conditions, a value of around 500 x 10⁻⁸ m²/Paxs is accepted. Therefore, for 01PK025, an optimum in the physical and mechanical properties of the foundry mixture will be expected at a content of reinforcing dispersive particles : 25-30%, for KLP027 : 20-25%, and for UKSS1: 30-35%.

5. Conclusions

1. For the tested quartz sand grades, pore parameters (size and amount) were determined;
2. It was established the relationship between morphology coefficient and porosity, and a possibility to forecast dispersity of reinforcing particles;
3. Admissible content to optimize reinforcing dispersive particles in mixtures was determined.
4. A base to improve mixtures' physical and mechanical properties through reinforcement was established.

INVESTIGATION OF THE OBTAINING OF THE MMC WITH METAL MATRIX Al AND Fe REINFORCEMENT PHASE

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Abstract: The aim of the present paper is to test the synthesis of moulded metal composites (MMCs) with a metal matrix Al and a strengthening metal phase Fe of type „in vitro” and „hybrid”. There was a test done for the preparation of composites using a method similar to “capillary forming”, such as the metal matrix (melt of aluminium) was infiltrated in the space between the iron blasting grit which is the inversely option of solving similar problem in which problems the blasting grit (the strengthening phase) are forcibly implemented into the melts (the metal matrix). In this way the problem which needs to be solved, in which the melt is infiltrated between the space of the iron blasting grit, allows for the maximum reduction of the volume of the metal matrix on account of the strengthening phase. The experiments were conducted with laboratory equipment elaborated on the base of another equipment for “capillary forming” with extra vacuum, patent protected developed by the department “Materials Science and Technology”. From the received moulded metal composites (MMCs) were establish areas of reaction between aluminium and the iron powder. The experiment produced significant results as received alloying between iron and aluminium at a relatively low temperature of melting of the iron in which there were received metal-composites structures of the type „in vitro” and „hybrid”, which were tested by metallography and micro-hardness analysis.

Keywords: MMCs, IRON-BASED ALLOYS, ALUMINIUM POWDER, IRON POWDER, CAPILLARY FORMING, VACUUM

1. Introduction

The formation of moulded metal composites (MMCs) is one of the most modern trends in the development of materials technology. In general, the metal composites are a heterogeneous system consisting of a relatively homogeneous metal base (matrix), which through various technologies is imported and distributed differing in kind, form, content, and certain characteristics, called the phase of strengthening (reinforcement) [4].

Manufacturers and engineers increasingly find opportunities that composite materials offer to produce high quality sustainable and cheaper products.

MMCs are classified on the basis of the state of the intensifying phase: “in vitro”- the intensifying phase is in solid form throughout the whole production cycle; “in situ”-when the intensifying phase is a result of the crystallization process or chemical reactions; “hybrid”-occurring as a result of a more complex interaction involving elements of both. Methods and technologies for the production of metallic composites are different in origin and are numerous. Some of the most frequently used methods and techniques are gravity casting, moulding under pressure, centrifugal casting, squeeze casting, forging or vacuum infiltration of the molten metal etc[3,5,6].

In the conducted studies the received metal composites can be conditionally assigned to composites “in vitro”. An interaction of the intensifying phase with the metal matrix is observed as well - a complex interaction referred to in literature as a “hybrid”[1].

Research concerning the methods of formation of MMCs in the present paper are brought to the usage of various schemas of vacuumization of the space for the synthesis of the composites, using the concept of the “Capillary forming” [1,2]

2. Experimental Procedure

The purpose of the conducted studies was related to the preparation of moulded composites from metallic type “in vitro” and composites, in which the presence of a reaction of the

reinforcing phase with the matrix metal can be observed, i.e. composite type “hybrid”.

The classical method of preparing a moulded composite is “in vitro” administers a mechanism of forcible insertion of the reinforcing phase into the prepared melt and subsequent homogenization of the composite structure [5,6]. In our case mixing the matrix with the reinforcement phase itself was carried out on the principle of “capillary forming” [2]. Initially, the reinforcing phase is emptied into the form (Fe-metallic blasting grit), then the matrix metal (Al) in the form of a melt is infiltrated forcibly in the spaces between the metallic blasting grit. Thus following the created scheme of mixing the metal matrix and the reinforcement phase additional firmness is added to the composite with force being produced.

$$P = P_a - P_k \quad (1)$$

$$P_a = p_a \cdot F_a, \quad (2)$$

$$P_k = p_k \cdot F_k \quad (3)$$

P_a - atmospheric pressure;

p_k - pressure of the melt in the space between the metal particles, i.e. in the metal matrix; p_k approximately equal to the vacuum gauge readings;

F_a - area under atmospheric pressure;

F_k - area of the melt in the composite;

$F_a \approx F_k$.

As mentioned above, in the present studies – pure aluminium has been used for the metal matrix, and blasting grit from pure iron for the reinforcing phase.

To complete the assigned task there has been developed a laboratory system schematic diagram that is shown on Fig.1.

As it is shown in Fig.1, the source of heat is a gas burner (10) and the flame it produces envelopes the area in which the flux is positioned (1), the metal matrix (aluminum powder) (2) and the reinforcement phase (iron powder)(3).

After the temperature in the area of the flux interaction have been reached around 1000 °C (thus high castability is attained), the molten aluminium powder (2) infiltrates into the space between the iron pellets. By opening the stopcock 12, dilution (sub pressure) is generated in the space around the reinforcement particles through the buffer system and the filter and it is the melt above them that ensures the pressurization of the entire system. Such infiltration is possible owing to the difference in the pressure above the aluminium melt and under it. Over the melt acts the atmospheric pressure, and under it the pressure is lower because the space in this area is connected to the vacuum system. The aforesaid makes it clear that in the system of heating and vacuuming chosen, the flux melts first and as a surface-active substance it wets the aluminium and iron pellets. Then the aluminium pellets melt and because of the difference in the pressure above and under the aluminium melt, the aluminium melt forcibly infiltrates into the space between the pellets of the reinforcing phase. As a result, the matrix and the metal pellets are soldered. This process takes place very fast and after it is completed the vacuum system is switched off and the quartz tube is removed. After the crystallization and solidification of the melt filling up the space around the particles, a metal composite structure is obtained.

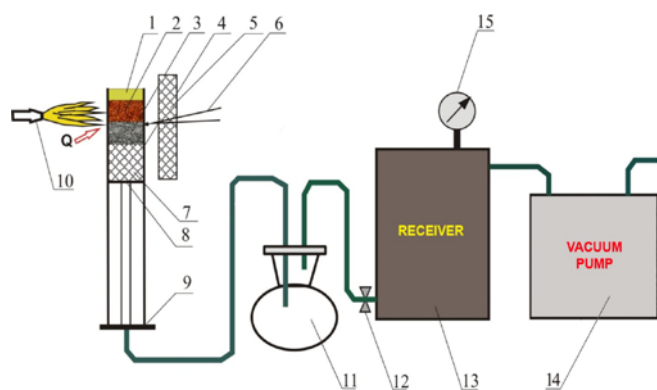


Fig.1 A general view of a laboratory system of obtaining cast composites by a metal matrix of pure aluminium and reinforcement phase pellets of pure iron.

- | | |
|--------------------------------|-----------------------------|
| 1- Flux; | 9- packing; |
| 2- aluminium powder; | 10- a burner; |
| 3- iron powder; | 11- an intermediate vessel; |
| 4- a quartz tube ; | 12-a stopcock; |
| 5- a fireproof plate (screen); | 13- a receiver; |
| 6- a thermocouple; | 14 -vacuum pump; |
| 7- refractory wool; | 15- vacuum meter; |
| 8- an underthrust; | |

The preliminary experiments have proved that in the absence of any flux no interaction occurs between the two metal phases and it is obvious that there is not any wetting of the reinforcement phase by the metal matrix. That is why the experiments covered in this paper were conducted after the metal matrix and the reinforcing phase were first wetted with some molten flux for aluminium alloys welding.

With the laboratory system described, series of experiments have been carried out in order to obtain cast metal composites by a aluminium matrix and a reinforcing phase of pure iron. **Table 1** illustrates the material used and contains some of its main characteristics.

The experimental samples obtained are used to prepare some samples for a microstructural analysis. The prepared metallographic polished sections were examined under a Neophot32 metallographic microscope. In addition, the microhardness of the structural composites obtained was determined.

Table1. The material used and some of its main characteristics.

Material		Main characteristics			
		Density γ [g/sm ³]	Hardness	T _m [°C]	Size [μm]
Metal matrix	Aluminium (Al)	8,86	25HV	660,3	20
Reinfor-cement phase	Iron (Fe)	7,87	60HV	1539	50-100

3. Results and Discussions

The experimental studies conducted confirm to a large extend the possibility of obtaining cast metal composites by a metal matrix of pure aluminium and a reinforcing phase pure iron.

By the elaborated experimental system, samples of composites of the type “in vitro” and “hybrid” were obtained.

Fig.2 illustrates microstructures before etching of the samples by a metal matrix aluminium and a reinforcement phase pure iron.

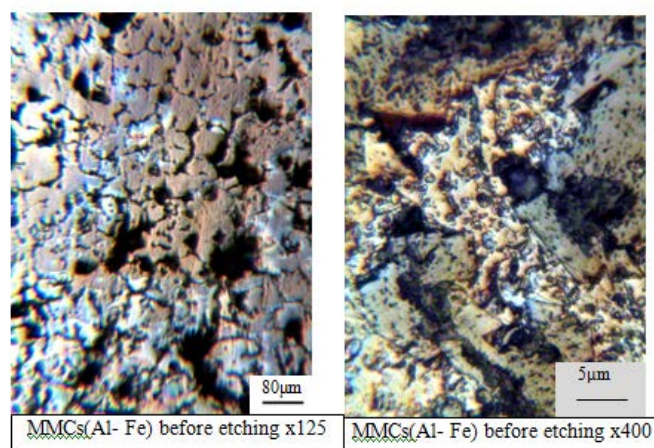


Fig.2 Microstructures before etching of the samples by a metal matrix aluminium and a reinforcement phase pure iron.

Among the microstructures in Fig.2, there are some closed micro-volumes (pores), in which practically no infiltration of the melt (aluminium) has taken place. One of the reasons for that may be the insufficient quantity of liquid metal (aluminium), that in its turn leads to the premature depressurizing of the system. That is why it is not possible to fill up all the space with some melt around the reinforcement phase. Other factors, such as the extent of dilution during vacuuming, the cooling rate during and after crystallization, the extent of thickening, may also be the cause of the presence of such defects. The clarification of these factors may be a subject of future studies.

Fig.3 illustrates some microstructures after etching of the samples by metal matrix aluminium and a reinforcement phase pure iron.

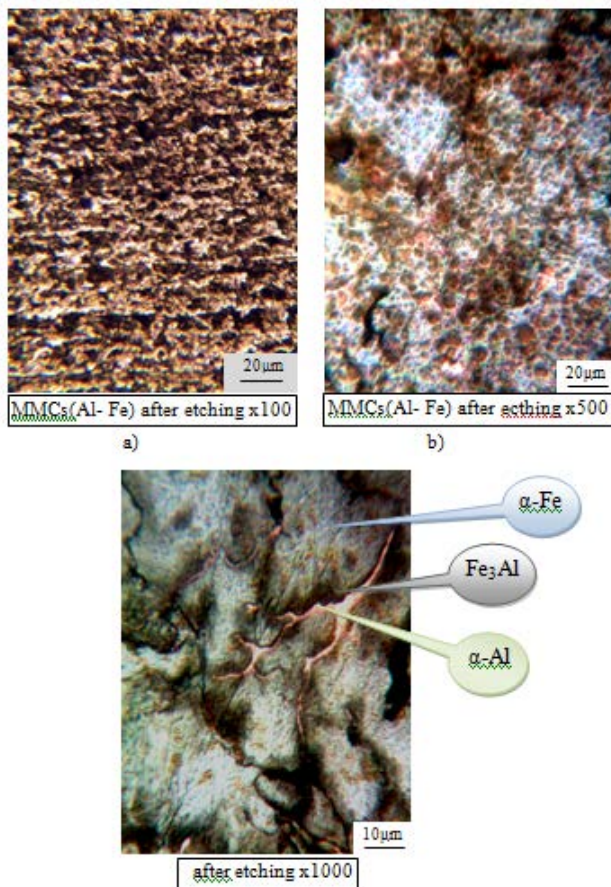


Fig.3 Illustrates some microstructures after etching of the samples by a metal matrix aluminium and a reinforcement phase pure iron.

As it is seen in **Fig.3.c)**, iron and aluminium interact with one another because of the high temperature (1000°C) and the diffusion processes taking place. As a result, α -Fe and α -Al are obtained. In addition, a chemical compound Fe_3Al is observed and that is indicated by the microhardness of 85HV measured in some sections (**Fig.4**).

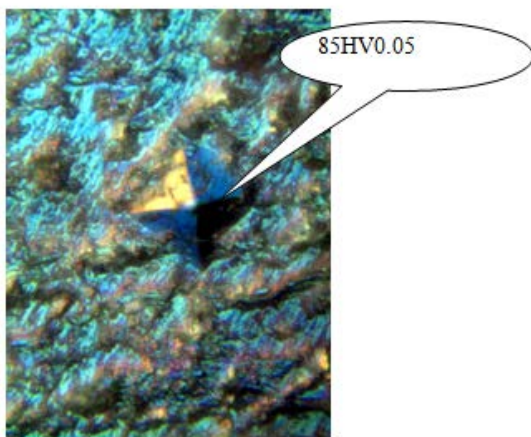


Fig.4. Microstructure of the sample by a metal matrix aluminium and a reinforcement phase pure iron, which microhardness was measured.

In the sections with molten and crystallized aluminium micro hardness of 35HV was measured, which is 10 units more than that of pure copper and is due to the solubility of iron into copper. In the sections with unmelted reinforcement phase iron the hardness measured was 75HV- 85HV, which is 15 units more than that of pure iron and it is due to the solubility of aluminium into iron. Such a result may be considered significant, because an alloy between aluminium and Fe is obtained at comparatively lower temperatures than the melting temperature of iron.

4. Conclusions

After the experiments were conducted, on the basis of the results obtained, the following major conclusions may be drawn:

1. Some methods of building cast metal composites by a matrix (pure Al) and reinforcement phase (pure Fe) are developed by applying the method of “capillary moulding” and vacuuming.
2. In the building of the composite Fe-Al it was established that, as result of the high temperature, some diffusion processes take place and solid solution of aluminium into iron α -Fe and solid solution of iron into aluminium α -Al are obtained. In addition, a chemical compound Fe_3Al is observed too.
3. The durometric analysis conducted has revealed an increase in the hardness of the phases and structural composites in the composite obtained by a matrix of aluminium and reinforcing phase of iron, in comparison with the initial components (pure aluminium and pure iron). It is due to the solubility of aluminium into iron.
4. The cause of defect generation (pores) in the structure that are due to the incomplete filling of the capillary space with melt is related to the parameters of the technological process (the extent of diluting during vacuuming, the cooling rate during and after crystallization, the extent of thickening, etc.) in the preparation of metal matrix composites. This problem may be solved in the course of further studies.

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RECAST LAYERS ON HIGH SPEED STEEL SURFACE AFTER ELECTRICAL DISCHARGE TREATMENT IN ELECTROLYTE

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Abstract: In this work are discussed some experimental data about the obtaining of recast layers on the surface of high speed tool steel after electrical discharge treatment in electrolyte. The electrical discharge treatment of steel surface in electrolyte produces a recast layer with specific combination of structure characteristics in result of nonequilibrium phase transformations. The modification goes by a high energy thermal process in electrical discharges on a very small area on the metallic surface involving melting, alloying and high speed cooling in the electrolyte. Obtained recast layers have a different structure in comparison with the metal matrix and are with higher hardness, wear- and corrosion resistance.

Keywords: RECAST LAYERS, HIGH SPEED TOOL STEEL, ELECTRICAL DISCHARGE TREATMENT IN ELECTROLYTE

1. Introduction

The recast layers on metals and alloys are mainly created by treating the surface with high energy stream such as laser, ion beam or electrical discharge for a very short time and pulse characteristics. The high energy attack on the surface involves local melting and in many cases vaporizing of metal microvolumes. After the cooling, on the treated metal surface a recast layer with different structure and properties from the substrate is formed. This recast layer can be with the same chemical composition as the substrate or with different one if in the thermal process suitable conditions for surface alloying are created. When the recast process is not controlled there are on the surface microcracks and pores which have negative influence on the surface properties and the recast layer must be removed. In the controlled recast processes it is possible to produce surface layer with determinate chemical composition, thickness, structural characteristics and properties, which are unique for the material with the very high hardness, corrosion- and wear resistance. The basic techniques that give opportunities in this direction are laser surface treatment, electrical discharge machining and plasma electrolysis.

Laser surface treatment is widely used to recast and modify localized areas of metallic components. The heat generated by the adsorption of the laser light provides a local melting and after controlled cooling is obtained a recast layer on the metal surface with high hardness, wear resistance and corrosion resistance. The laser surface melting is based on rapid scanning of the surface with a beam focused to a power density scale of 10^4 W/cm² to 10^7 W/cm². Quench rates up to 10^8 - 10^{10} K/sec provide the formation of fine structures, the homogenization of microstructures, the extension of solid solubility limits, formation of nonequilibrium phases and amorphous phases or metallic glasses, with corrosion resistance 10–100 time higher compared to crystalline [1]. Laser surface melting is a simple technique as no additional materials are introduced, and it is especially effective for processing ferrous alloys with grain refinement and increase of the alloying elements content in solid solution. In fact the process has been employed for improving the cavitation erosion and corrosion resistance of a number of ferrous alloys.

The laser surface melting can be combined with a simultaneous controlled addition of alloying elements. These alloying elements diffuse rapidly into the melt pool, and the desired depth of alloying can be obtained in a short period of time. By this means, a desired alloy chemistry and microstructure can be generated on the sample surface and the degree of microstructural refinement will depend on

the solidification rate. The surface of a low-cost alloy, such as low carbon steels, can be selectively alloyed to enhance properties, such as resistance to wear and corrosion [2].

Electrical discharge machining is a thermoelectric process that erodes workpiece material by series of discrete but controlled electrical sparks between the workpiece and electrode immersed in a dielectric fluid [3]. It has been proven to be especially valuable in the machining of super-tough, electrically conductive materials, such as tool steels, hard metals and space-age alloys. These materials would have been difficult to machine by conventional methods, but EDM has made it relatively simple to machine intricate shapes that would be impossible to produce with conventional cutting tools. In EDM process, the shapes of mold cavities are directly copied from that of the tool electrode, so time-consuming preparation work must be done on the fabrication of the corresponding tool electrode.

The electrical discharge machining uses electrical discharges to remove material from the workpiece, with each spark producing temperature of about 8000-20000 °C. This causes melting and vaporizing of small volumes of the metal surface and after cooling in the dielectric fluid the melted zones are transformed in recast layer with specific structure. The EDM modified surface consists from two distinctive zones [4-6]:

- Recast layer
- Heat affected zone

The recast layer is also named white layer and it crystallizes from the liquid metal cooled at high rate in the dielectric fluid. The depth of this top melted zone depends on the pulse energy and duration. Below the top white layer is the heat affected zone with changes in the average chemical composition and possible phase changes.

At Plasma Electrolysis the processes are of similar nature as EDM and it can be obtained recast layers with the same characteristics. Significant differences are the replacing of liquid dielectric with electrolytes and in result of that increasing the distance between the electrodes which causes displacement of electrical discharges on boundary electrode-electrolyte. There are developed on technology level processes for plasma-electrolysis oxidation and plasma-electrolysis deposition [7].

2. Materials and Experimental Procedures

The objects of study are specimens with diameter 6 mm which are made from HS 6-5-2 steel with structure after the typical heat treatment for tools of this steel. In this most popular high speed steel the tungsten content is reduced to 6 % while it is additionally alloyed with 5% molybdenum and vanadium content is about 2 %. The steel is quenched in oil from 1220 °C and after that triple-tempered at 550 °C for 2 hours each. The measured hardness of the specimens is 63-65 HRC. The electrolyte composition and its characteristics are of great importance for the process parameters and for the microstructure and properties of recast layers. By these experiments the electrolyte is on water basis and in it are dissolved glycerol and sodium carbonate. In the electrolyte is suspended fine sized B_4C .

For the electrical discharge treatment in electrolyte is developed a laboratory device, shown in Fig. 1 [8,9], giving opportunities for treatment of cylindrical workpieces with diameter up to 20 mm. The electrolyte 3 is in active movement by mixing from a magnetic stirrer 4. After passing of electric current with determinate characteristics through the suspended electrolyte between the workpiece 1 which is on the cathode and electrode 2 starts an active sparking on the workpiece surface.

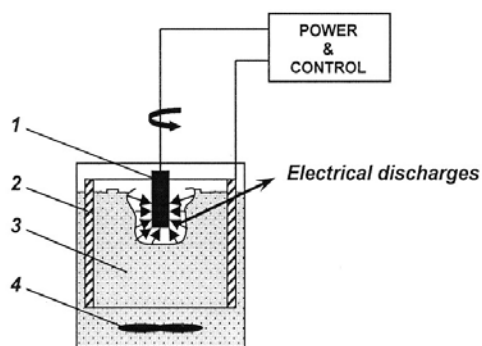


Fig. 1. Electrical discharge treatment in electrolyte:
1 – workpiece, 2 – electrode, 3 – electrolyte, 4 – magnetic stirrer.

The sparking characteristics depend on different factors such as parameters of the electric current, type and composition of the electrolyte, movement of the workpiece and electrolyte. The high-alloy steel gives an opportunity for higher effectiveness of treatment on structure and properties of modified surfaces after the nonequilibrium phase transformations from liquid state. Under the high temperature of discharge column, the surface layer can dissolve activated elements formed in it from the electrolyte and receives structure with different characteristics and properties.

For the experiments between the electrodes is applied direct current with voltage from 80 to 240 V. The time of treatment is from 1 to 10 minutes. The investigations show that the optimal time is 3 minutes. Obtained layers have been investigated by light microscopy, SEM, XRD and Hanneman microhardness testing.

3. Results and Discussion

The electric discharges generate an enormous amount of heat, causing local melting on the workpiece surface and thereupon it is rapidly quenched from the liquid state by the electrolyte. This recast area has a specific structure, which can be composed of several microscopic metallurgical layers, depending of machining conditions. The high rate of the recasting process gives opportunities for formation of metastable phases and considerable decreasing of grain size. The electrolyte type is of great importance for the chemical composition, microstructure and properties of the recast layer. The melted and resolidified layer during this process is

also referred as the “white zone”, since generally no etching takes place in these areas at the metallographic preparation. The structure of recast layer can be seen after SEM investigation on Fig. 2.

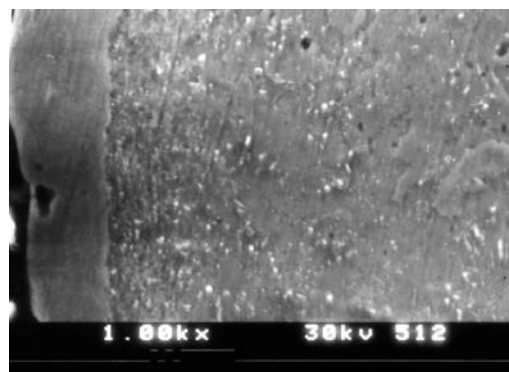


Fig. 2. SEM micrograph of recast layer on HS 6-5-2 steel after electrical discharge treatment in electrolyte

At short times of treatment it is not observed diffusion of elements from the electrolyte in the modified surface, but it is available diffusion process inside the workpiece between the white layer and the matrix – Table 1. The strong carbide-formed elements such as Mo, W, and V diffuse from the white layer to the matrix and Cr, Co in the opposite side.

Table 1. EDS analysis of modified workpiece from HS 6-5-2 steel

Chemical element	Matrix of workpiece	White layer
Si	<0.01	<0.01
Mo	5.58	4.87
V	2.30	1.63
Cr	4.25	4.52
Co	<0.01	0.19
Ni	<0.01	<0.01
W	8.34	5.75

The specific properties of recast white layer in a case of tool steels are the remarkable high hardness, strength and corrosion resistance related to the nonequilibrium phase transformations in the high alloyed metallic system. The white layer characteristics, its homogenous structure and thickness, are of dependence on the electric current parameters and on the duration of treatment. By lower voltage the obtained recast white layer is inhomogeneous and local deposited on the metal surface. The treatment time increasing in this case shows an insignificant influence on process. In Fig. 3 is shown an optical micrograph of surface microstructure after electrical discharge treatment in electrolyte at 150 V for 3 minutes. The thickness of obtained layer is under 0.01 mm.

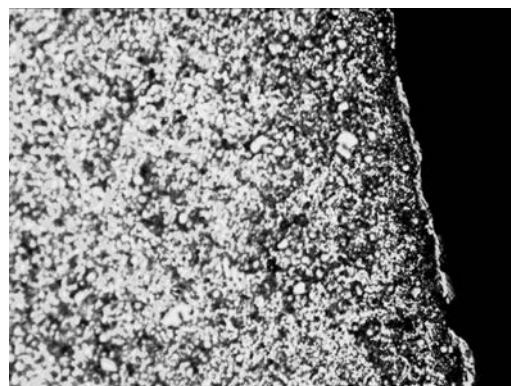


Fig. 3. Optical micrograph of modified HS 6-5-2 steel surface at 150 V for 3 min, 800x.

The investigations show that it is possible to obtain a white layer on the high-speed tool steel surface at voltages of about 100 V, Fig. 4, but the electrical discharges energy is insufficient for dissolving of carbides and the hardness of the modified surface can not receive the expected high level.

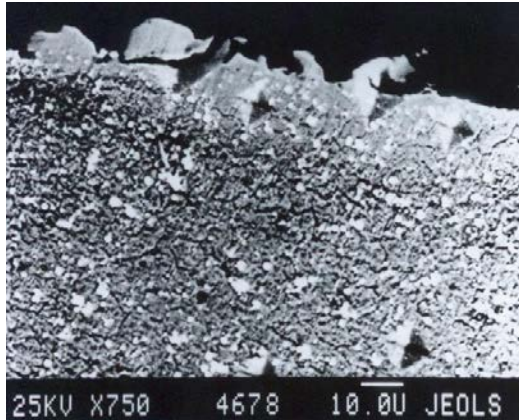


Fig. 4. SEM micrograph of modified HS 6-5-2 steel surface at 100 V, 2 min.

The voltages above 200 V give a very high intensity of sparking on the metal surface with energy enough for melting of the metal and dissolving of the carbides and it is possible to obtain compact recast layer with homogeneous structure. By the high speed quenching from liquid state the solubility of the alloying elements remains very high in a supersaturated solid solution and after nonequilibrium phase transformations metastable structures with high hardness and wear resistance are formed. In Fig. 5 an optical micrograph of the recast layers obtained after 3 minutes treatment at 200 V is shown. The thickness of the obtained white layers is about 0.05 - 0.06 mm. The modified surface has a very high corrosion resistance and the microhardness of the white layer in these cases reaches more than HV 1500.

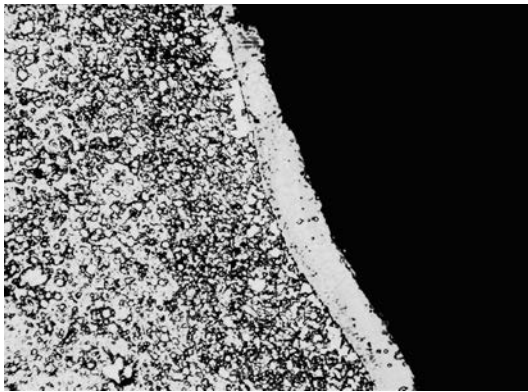


Fig. 5. Optical micrograph of modified HS 6-5-2 steel surface at 200 V for 3 min, 800x.

The XRD investigation of the modified by electrical discharge treatment in electrolyte high-speed steel surface shows a significant difference between the recast layer and bulk material (Fig. 6 and Fig. 7). The modified surface has typical diffraction patterns for nanocrystalline structures. The XRD analysis also proves the mass transfer of boron from the electrolyte and its diffusion in the surface layer. In the modified steel surface along with carbides typically for the high-speed steel structure Me_2B is also presented.

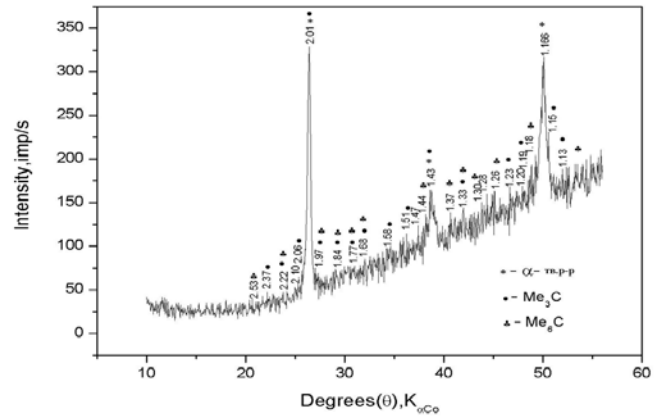


Fig. 6. XRD patterns of HS 6-5-2 steel surface before electrical discharge modification in electrolyte

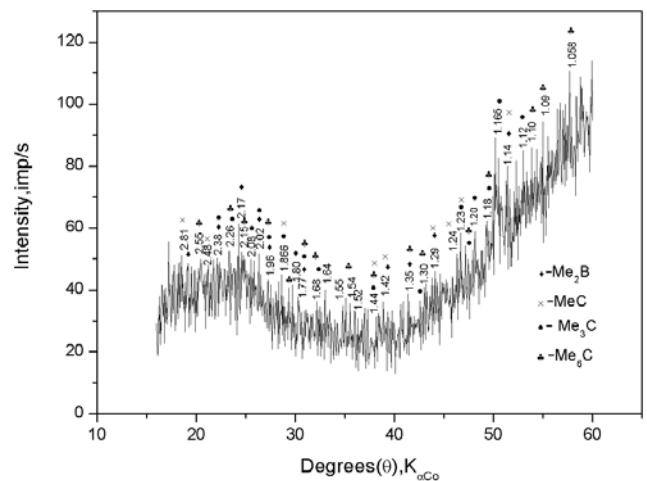


Fig. 7. XRD patterns of HS 6-5-2 steel surface after electrical discharge modification in electrolyte

Homogeneous structure of the recast layer can be observed by a higher magnification on SEM micrograph in Fig. 8. The modified surface has a very high corrosion resistance and can not be etched. The microhardness of the white layer in these cases reaches HV 1500–1600 compared to HV 780–820 of the core.

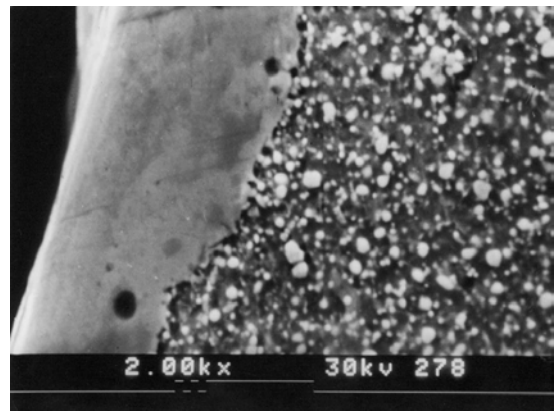


Fig.8. SEM micrograph of modified punch surface.

Combination of high voltages with increasing duration of the electrical discharge treatment causes a significant heating of the workpiece, melting the surface and penetrating of the diffusion

process in depth to the grain boundaries (Fig. 9). The surface recast layer in this case has ledeburitic structure with higher concentration of carbon and boron.

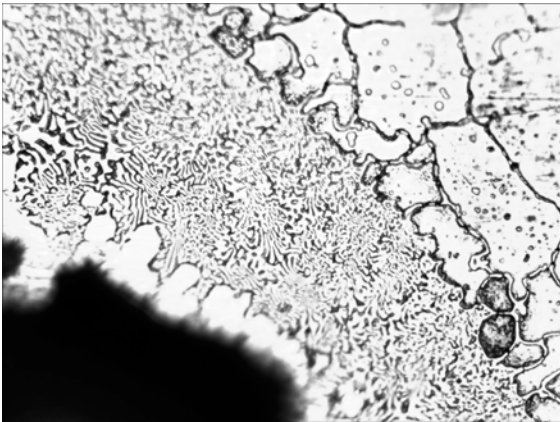


Fig. 9. Optical micrograph of the recast layer on HS 6-5-2 steel after electrical discharge treatment in electrolyte at 230 V for 10 min, 800x

4. Conclusions

The high energy process of electrical discharge treatment in electrolyte and the nonequilibrium phase transformations in the high alloyed metallic system of HS 6-5-2 steel causes considerable modifications of the metallic surface and obtaining of recast layers with finecrystalline and nanocrystalline structure. The modified surfaces have high hardness, strength, wear- and corrosion[10], resistance related to the supersaturated solid solution of alloying elements in the obtained recast white layer and the nonequilibrium phase transformations by the high quenching speed from liquid state. Investigations show that obtained recast layers reach a thickness about 0.05 mm. The hardness of the modified layers can vary considerably and depend of the treatment conditions, electrolyte composition and microstructure, but in principle it is higher then the hardness of the typical microstructure of this steel. The microhardness of the recast layers measured by Hanneman test shows values after the different treatments up to 1600 HV which are very higher than the microhardness of HS 6-5-2 steel microstructures after the typical heat treatment. The experiments show that tools with such surface hardness have higher wear resistance and working capacity.

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THE DESCRIPTION OF DRIVE OF CLAMPING MECHANISM OF AUTOMATIC LATHES BY USING GENETIC-MORPHOLOGICAL APPROACH

ОПИСАНИЕ ПРИВОДОВ ЗАЖИМНЫХ МЕХАНИЗМОВ ТОКАРНЫХ АВТОМАТОВ С ИСПОЛЬЗОВАНИЕМ ГЕНЕТИКО-МОРФОЛОГИЧЕСКОГО ПОДХОДА

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Abstract: *In the article there is proposed a new approach to the methodology for solving problems related to the creation of drive of clamping mechanism of automatic lathes that is development of basic theoretical positions of multilevel morphological synthesis their designs by using the provisions of genetic theory of development of technical systems*

KEYWORDS: DRIVE OF CLAMPING MECHANISM, EVOLUTION OF TECHNICAL SYSTEMS, GENETIC-MORPHOLOGICAL SYNTHESIS

1. Introduction

There are research papers about evolutionary synthesis of anthropogenic systems (AGS), which appear as a result of direct human activity [1]. Nonviable systems is a result of neglecting by technical specialists of research the general laws of development of system (in particular AGS), analysis of obstacles and contradictions which appear in process of development AGS.

There are some positive results in creation metalworking equipment and their components and also electro-mechanical systems, in particular, electric drive, which was achieved by scientists of "Kyiv Polytechnic Institute" by using genetic-morphological approach [2, 5]. These results were used for creation new clamping mechanism (CM) of automatic lathes. CM has significant impact on the productivity and quality of processing of automatic lathes, whilst drive of clamping mechanism (DC) determines (as basic element CM) such characteristic of CM as: kinematical, forces, energetic [4] etc. So, characteristic of CM have an impact on the intensity of cutting conditions, which determines the expenses of basic time of processing; speed of clamping and unclamping that determines spending of auxiliary processing time; stability and reliability clamp's forces, which determines the opportunity and quality of processing of uncalibrated and thin-walled workpieces, limits of cutting speed and reliability of machine tool; quality of surface and precision of detail; energy spend.

At this time, majority of DC has traditional construction that is obstacle to development of lathe's structure whole. Existing methods of creation DC are suitable mostly for adaptation of known technical structures to new "condition of work" therefore all possibilities for technical systems development aren't not used now. Therefore, heuristic potential of design's science provide us only the several new varieties of structural of DC. The solutions of these problems require new scientific conclusions about principals of structure's organization of DC. Genetic conception of building DC can provide us also possibility for using new approaches to solve the problems related with found and creating constructions of DC on a new levels of structural organization. Therefore development of research on this direction opens the possibility to change level representation of synthesis (creation) from slice-object to systematic scientific-predictive one.

2. Preconditions and means for resolving the problem

CM has common structure and functional scheme which is independent from construction form, destination and scheme of work, there are represented in research papers. Structure of CM includes such units as source of energy (E), energy converter (EC), control unit (CU), DC which include gear-amplifying mechanism (GAM) and springy section (SS), clamping chucks (CC) or device with GAM, corps, auxiliary and clamping elements (CE) for direct fixing of the object clamp (OC) such as detail (several details), tool or work unit.

E can be common for whole lathe or individual, only for CM. Energetic characteristics of E can be power of electromotor,

hydraulic pumps, hydraulic motor, compressor, vacuum-pump; force of elasticity of spring, the magnetic interaction, centrifugal forces; impulse of force of DC of impulse and explosive action, pressure etc. CU manages cycle of working the whole system CM accordingly for cycle of working the whole lathe, and connected with DC, CC, E and GAM.

DC can make clamping or/and unclamping. In this case other function, processing by force of springy or centrifugal forces, fore example, clamping is making by spring whilst unclamping is making by using hydraulic motor.

3. Common thoughts to genetical-morfological description of DC

Structure of DC is known to be three-dimensional, it provides many possible variations of spatial configurations and variety of forms and numbers of active elements and power flows. So, structure of DC is determined by spatial geometry and topology of interconnected power contours and power flows. Therefore, the research of the principles of structural organization DC is directly related to the analysis of the spatial geometry of power contours that determines the type, order placement and relative orientation of elements to convert and transfer energy. Accordingly to basics rules of genetic-morphological approach [1, 2] to creation and development technical object, DC can be described on a different levels of organization such as genetic, chromosome, object, species, population, system, intersystem. Accordingly to the genetic approach [6] for describing DC on a chromosome level, it is necessary to use elementary force flow with counting that

1. Several forces or energetic flows on input and output can exist.

2. The input and output flows of force (power) can be the similar and different and include the limit quantity of its types and has limit set of variations of its spatial configurations (coordinate movements).

3. Force flows can be from inner source (actually) and outer source (force of elasticity of spring, the magnetic interaction, centrifugal forces)

4. Connection of some force flows can be sequential, parallel, parallel-sequential.

5. Quantity of GAM (wedge, spiral, lever, gearings, screw, plunger, spring) between input and output of force's flows of DC is limited.

6. There is possible combination of converters of force flows in DC and CC, there is possible just one converter for CM, if DC functions is processed by CC

7. Transmission and transformation force's flows can occur in different environments (solid body, electromagnetic field, liquid flowing medium, air and vacuum medium, constant magnetic field, thermal field, centrifugal force).

The basic criteria that determine the structural organization of DC are characteristics of GAM, that change the characteristics of the input power flow according due to certain laws, provide appearance and support for the stress state (force field) CM for a law of functioning. So, conceptually DC is an intermediate

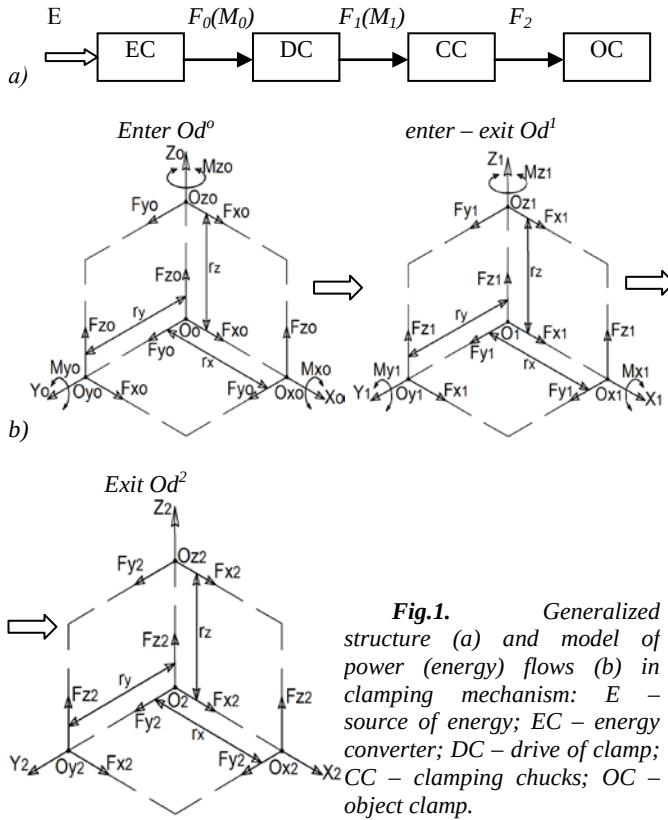
transformer power flows (energy in the form of power flow) among E, EC and CE (Fig. 1, a).

In other words, if abstractly imagine CM, which does not exist now but which should be create, the model of power (energy) flows will consist of two elementary power flows: one in DC $F_0(M_0) - F_1(M_1)$, and other in CC $F_1(M_1) - F_2$ without specifying coordinate direction of forces (torque) for input and output.

In this case, the full flow from energy sources E through converters EC to object clamp OC will be written in the form of genetic formula CM, as interaction of three material points (genes O, O₁, O₂) (Fig. 1, b)

$$F_0(M_0) - F_1(M_1) - F_2$$

where on chromosomal level for DC genetic code is $F_0(M_0) - F_1(M_1)$, and for CC – $F_1(M_1) - F_2$.



As for the CC on the object level elemental power contour can be locked open, locked closed, open-circuited, and combinations in DC elementary power circuit may be of closure, and in the DC elementary power contour can have different circuiting, forces and not elastic (open contour that is always connected with the source and converters of power); elastic force (due to the potential energy of the elastic element, such as spring package); geometric, when disconnected from energy sources and tension of elastic system of mechanism; frictional with self-braking; combination [4].

Power contour denoted 1, 0 on top after writing the genetic code in square brackets (Table. 1).

4. Solving the problem of description of DC

There are several types of energy flows which can be used in DC such as mechanical, electromagnetic, moving environments (hydro-pneumatic), and combinations, which determine the type of energy flow (solid interaction, electromagnetic interaction, the pressure of moving environments) [6]. Thus in the CM and particularly in DC it's possible to use different environments and fields in the flow of power as follows:

MSB (mechanical solid body) – mechanical transmission and converters in which using solid body;

EMF (electromagnetic field) – electromagnetic fields, that acting directly or in composition (structure) of electromechanical transmission and transformation;

LFM (liquid flowing medium) – liquid-fluid and viscous environment for the transmission and transformation (change of flow parameters);

AVM (air and vacuum medium) – gas (air) environment for the transmission and transformation, including the vacuum;

CMF (constant magnetic field) – magnetic attraction and repulsion field;

TRF (thermal field) – heat flows, that cause the appearing forces of thermal expansion (narrowing) of the substance;

CF (centrifugal force) – centrifugal force while rotating unbalanced masses (parts).

At this stage of development the CM of lathes most widely used DC mechanical type. In its executive part (GAM) DC existing mechanical type has geometric prototype (model), number of species which are limited (Fig. 2), such as lever, wedge, plunger,

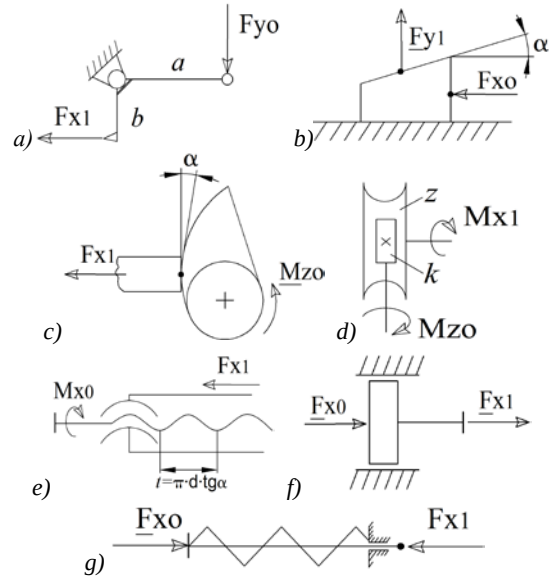


Fig. 2. Variants of mechanical power converters DC lathe machine: a – lever (LV); b – wedge (WD); c – spiral (SP); d – gears (GR); e – screw (SC); f – plunger (PL); g – spring (SR).

Table 1: Definitions of force contour

Clamping chucks (CC)		Drive of clamping mechanism (DC)	
Type of contour	Marking	Type of closure	Marking
locked closed	[1]	geometric	[1]
locked open	1	friction	1
open-circuited	0	force inelastic	0
combined: locked–open–circuited	[1],0; 1,0	force elastic	[0]
combined: open–locked	0,1; 0,[1]	combined: geometric – силовые неупругие	[1],0; 0,[1]
		combined: geometric – friction	[1],1; 1,[1]
		combined: geometric – force elastic	[1],[0]; [0],[1]
		combined: friction – force elastic	1,[0]; [0],1
		combined: friction - force inelastic	1,0; 0,1

spiral, gear, screw, spring. Number of power converters of flows and their types (listed) can be different and combine. In accordance to DC mechanical execution input and output power flows in the form of forces and torque can exist. Evidently, there is possibility of DC existence, power flows of which are arranged in three-dimensional space and have a different set of coordinate movements. To identify new types DC is appropriate to analyze options for spatial location and relative orientation of the input and output power flows.

Since the output unit of DC of lathe is always situated in the spindle that rotates with CC, is appropriate to mark forces and torque in cylindrical coordinates instead of Cartesian (in brackets according to Figure 1):

$F_a(F_x)$ – axial force along the axis of rotation of the spindle (OC);

$F_r(F_y)$ – radial force perpendicular to the axis of rotation of OC;

$F_t(F_z)$ – tangential force tangential to the cylindrical surface of revolution OC;

$M_a(M_x)$ – torque around the axis of rotation OC;

$M_r(M_y)$ – torque around the axis (radius) which is perpendicular to the axis of rotation OC;

$M_t(M_z)$ – torque around the axis which is tangent to the cylindrical surface of rotation OC.

Generative system of elementary power (energy) flows can be represented as two matrices [6] full of "genetic information", where each element of one (input) matrix M_{EN} is associated with an element of another (outgoing) M_{EX} by the rules as there are defined by the laws of functioning of the mechanism. This variant of representation of possible "genetic" information models DC is not very convenient to find new structures DC that contains a large number of "not suitable" for the true state of technological equipment options from the total number – $N_f = 12 \cdot 12 = 144$. For DC of existing technological equipment for rotating bodies are possible options that can be presented by using next matrix:

$$M'_{EN} = \begin{bmatrix} \pm F_{a0} \\ \pm F_{r0} \\ \pm F_{t0} \\ \pm M_{a0} \\ \pm M_{r0} \\ \pm M_{t0} \end{bmatrix} \Rightarrow M'_{EX} = \begin{bmatrix} \pm F_{a1} \\ \pm M_{a1} \end{bmatrix}, \quad (1)$$

which gives $N'_f = 12 \cdot 4 = 48$

5. Using the results of research in unit of lathe machines construction

If the input and output power flow DC located on the spindle node, the number of variants is reduced to $N''_f = 4 \cdot 4 = 16$. So from (1) can be selected (combined) four possible classes DC notwithstanding the direction of the force (torque):

- 1) with axial input and output efforts ($F_{a0} - F_{a1}$);
- 2) with axial input and output torque effort ($F_{a0} - M_{a1}$);
- 3) with torque input and axial output efforts ($M_{a0} - F_{a1}$);
- 4) with torque input and output efforts ($M_{a0} - M_{a1}$).

$$M'''_{EN} = \begin{bmatrix} F_{a0} \\ M_{a0} \end{bmatrix} \Rightarrow M'''_{EX} = \begin{bmatrix} F_{a1} \\ M_{a1} \end{bmatrix} \quad (2)$$

Structure of DC of 1st class (Fig. 3a) is well represented in the existing DC of domestic and foreign lathe machines and is the "classic". Structures of 2nd (Fig. 3b), 3rd (Fig. 3a) and 4th (Fig. 3d) classes hardly used in the design of DC. With the participation of authors developed DC with electromagnetic way to transfer input force which belongs to the 3rd grade.

Considering the fact, that in the each class a significant number of designs and variants of execution of DC can be offered, it is possible to assert about the feasibility of using genetic-morphological approach while of new structures and technical facilities in particular DC creating (and in this case it is also advisable to use the term "detection"). Conditional embodiments of

the structures of each of the classes can be represented as follows:

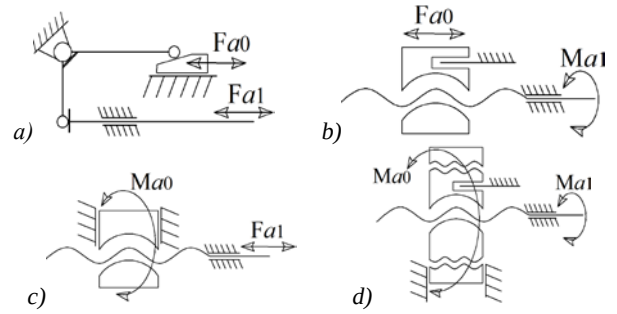


Fig. 3 Variants of structural schemes of detected classes DC for turning machines and CNC machines.

Location DC as a part of spindle unit depends on the design features and elements of the machine tool spindle (it's concerned with the requirements of the technological capabilities of the machine tool), the method of filing (supplying) of the input force (power flow) and joining the unit of controls. Characteristics of machine tool spindle and type of interaction DC and CC (through spindle or directly to the CC hull), which defines the structure (configuration) CM, depends on the case, taken into account (tab.1). At the object level basic power contour, which has different types and depends on the method of keeping the stress condition in the CM by inputted efforts, geometric circuit, self-braking, accumulation of energy in the form of elasticity forces, and as combination of these ways is used as heir-chromosome. On the structure of the power circuit DC options, when power flows are converting parallel, sequential and parallel-serial "ways" can be selected

Due to the regularities, which were found, as a result of research and genetic-morphological approach, existing CM (Figure 4) "classic" design is described.

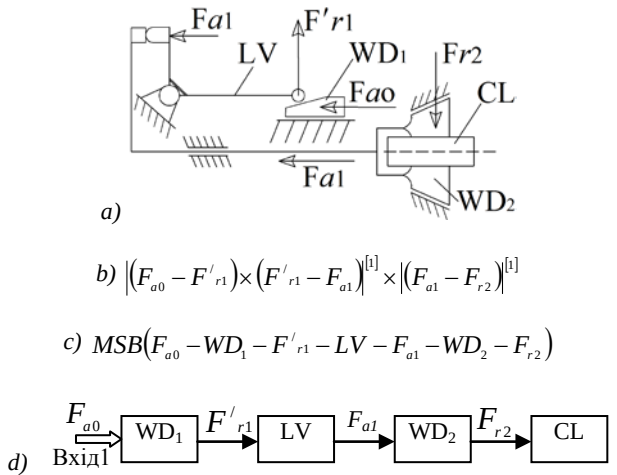


Fig. 4 CM for cylindrical details with collet CC and DC with wedge-lever transmitting-amplification mechanism and geometric locking: a – basic scheme; b – genetic formula for chromosomal level; c – genetic morphological formula at the population level; d – structural formula.

6. Conclusion

1. A new approach to methodology of solving the problem of innovative character in the field of creating DC on the basis regularities of genetic theory of evolution of technical systems is proposed. The feasibility of using the said theory for the synthesis of new designs DC is confirmed.

2. Identification is done and process is provided for coding genetic information which used in the synthesis DC by using genetic theory of development. There is proposed the classification of "spatial compositions", input and output force flows in DC for CM which rotating, according to which the maximum number of structures DC of the possible options of the spatial location of the

input and output force flows equal 48.

3. There is proposed the classification energy converters and carriers of power flows in DC, which amount to a limited number of types. Thus in mechanical type, there are seven type for power converters and seven types of media power flows, that can be used in DC at the present level of technological development.

4. Basic provisions of genetical–morphological synthesis DC that is a prerequisite to create an algorithm of direct search for new kinds of DC of basic level for a given objective function is developed. "Spatial composition" of power flows that contain in its composition torques, not implemented in existing DC is found.

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FEATURES QUALITY ASSESSMENT SAFETY AND FUNCTIONAL PURPOSE OF MACHINES

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Abstract: *The machines are one of the most important pillars in the industrial economy of the European Union. The aim is to reduce the enormous social price paid for accidents at work, by integration of safe design and construction, as well as proper installation and maintenance.*

A harmonized regulatory framework for the design and manufacture of machines is of major economic importance for European industry. At the same time, the safety of machinery makes an important contribution to reducing the social costs of damage to health and accidents at home and workplace.

KEYWORDS: MACHINES, ASSESSMENT, SAFETY, MARK, MACHINERY DIRECTIVE

1. Introduction

Machinery Directive aims to ensure the free movement of machinery in the internal market, while ensuring a high level of health protection and safety of the consumer. [1]

Directive 2006/42/ EC on machinery of the European Parliament and of the Council of 17 May 2006 defines only the essential requirements of general safety and health, supplemented by a number of more specific requirements for certain categories of machinery.

Although no major changes are made, the new Directive introduces a more detailed requirements for ergonomics, measurement of noise and vibration and higher requirements for fixation of the defence barrier. In future fixings of guards will either remain attached to the machine when the defence barrier is removed, or will stay connected with the barrier.

The lack of a transitional period of the directive is not a problem in cases where declarations of conformity are prepared immediately before the machine is placed on the market, but could be problematic for a number of machines which have been kept in storage.

It this condition it must be certified conformity according to the new Directive 2006/42 / EEC.

Another change that affects importers is that now it is required a technical file documentation and a copy of the declaration of conformity to be stored in the European Economic Area, from "authorized representative of the manufacturer." This brings the Machinery Directive in accordance with the directives which have the same requirement.

Producers carry full responsibility for certifying the conformity of their machinery to the provisions of the Directive. For certain types of machinery having a higher risk factor, it is desirable to introduce more stringent certification procedure.

The manufacturer or his authorized representative must ensure an evaluation of the risks for the machinery which intends to send to the market.

For this purpose, he should determine which are the essential requirements for safety that apply to the machine.

The Directive applies to:

- machinery
- interchangeable equipment
- security features
- lifting accessories
- chains, ropes and webbing
- removable mechanical transmission devices of movement
- partly completed machinery

From the scope of the directive are excluded safety components that are intended to be used as spare parts to replace identical components and supplied by the manufacturer of the original machinery, weapons, vehicles, electrical domestic appliances, electric motors and other.

EU Member States shall take all necessary measures to ensure that machinery may be placed on the market and put into service only if

they meet the related provisions of the Directive and does not endanger the health and safety.

Marketing and commissioning.

Before placing on the market or put into service, the manufacturer or his authorized representative shall:

- ensure that it satisfies the essential requirements for safety and health
- to monitor the technical file
- to show the necessary information such as instructions for exploitation
- to apply the appropriate procedures for conformity assessment
- prepare the EU declaration of conformity
- place the CE marking

Annex I adds some new essential health and safety requirements regarding the machinery serving fixed landings. Thus covers the specific risks associated with this type of machinery. [2]

Regarding the procedures of conformity assessment applicable to the elevators on construction sites should be noted that those at risk of falling from a distance higher than three meters are included in Lifting equipment listed in Annex IV, p. 17.

Additional scope of the new Directive is extended to include all lifting equipment whose speed does not exceed 0.15 m / sec. Therefore, low-speed elevators are already subject to the Machinery Directive.

The definition of "elevator" referred to in Art. 1 (2) of the Directive is changed and for elevators instead the term "cabin" is used the term "carrier. This means that the nature of the carrier is not a criterion for application of the Directive on elevators. At the same time, it must be borne in mind that the carrier of elevators subject to Directive 95/16 must be cabin, that is completely closed.

From the scope of the Directive are no longer excepted portable cartridge-operated fixing and other impact machinery designed for industrial or technical purposes.

Presumption of conformity and harmonized standards.

Machinery bearing the mark "EC" and accompanied by a declaration of conformity comply with the Directive.

It is believed that machine produced according to a harmonized standard, complies with the essential requirements for safety and health within the scope of the harmonized standard.

The machine must be designed and constructed according to the results of the risk assessment.

The obligations laid down by the essential requirements for safety and health shall apply only when the corresponding hazard exists for the machine when it is used under the conditions provided by the manufacturer or his authorized representative but also in foreseeable emergencies.

The specified in the particular application essential requirements for safety and health are required. It includes several parts: the first is of general scope and applies to all types of machines. Other parts refer to certain kinds of more specific hazards. During the design of a machine must be taken into account the requirements of the general part and the requirements of one or more of the other parts of the application depending on the results of the risk assessment.

Declaration of Conformity - refers to machinery in the condition they were placed on the market, and excludes components added and / or operations carried out subsequently by the final user.

The obligations created by the Machinery Directive relating to the conformity of machinery and partly completed machinery are at the expense of the manufacturer or his authorized representative.

The procedure for assessment of conformity is mandatory for certain categories of machinery and can choose between several alternative procedures.

One of the main changes in the new directive is the liberalization of procedures for assessing the conformity of machinery. Categories of machinery not listed in Annex IV require internal production control. If the machines listed in Annex IV are designed in accordance with the relevant harmonized standards, the manufacturer has the possibility to certify their compliance and the requirement for storage of technical documentation by a notified body can be eliminated.

The procedure for conformity assessment in this case does not require the intervention of a Notified Body. However, the manufacturer or his authorized representative may seek advice or assistance in conformity assessment. In these cases involved Notified Body can not use and put its identification number to the documentation. For other machines of Annex IV, the manufacturer may apply the EC type-examination by a notified body or a notified body to approve the system of total quality assurance, which covers the design, manufacture, final inspection and testing.

The machine, which ensures safe operation, bear the CE marking. This is the indicator line on the machine with the EU legislation. It is not intended for commercial purposes and is not an indication of origin, because it does not show that the machine is manufactured in the EU.

The CE marking is mandatory and must be placed before placing the machine on the market. When the machines are in the range of several directives, and all of them provides the CE marking it is presumed that they meet the requirements of each of those directives.

The marking shall be affixed only by the manufacturer or his authorized representative. So he takes responsibility for the conformity of the machine with the European legislation. The sign is applied so that it is visible, legible and indelible.

There is a greater number of foreign manufacturers that have made significant investments to ensure that their products are in full

compliance with European directives and their CE marking begins to gain more confidence than their European competitors. These manufacturers, including many Japanese companies have found that with great success they can use this commercial advantage.

Except in cases where the manufacturer is able to operate in strict accordance with the European standard, which is specifically written for the type of his machine, he is obliged to prepare technical file. This is the only legal basis on which the manufacturer can claim for compliance with the European directives for the application of the CE marking. Even if the manufacturer has a European standard that is specifically written for the type of his machine, which is very rare, he can only claim compliance with the Machinery Directive. It is still necessary to ensure that the standard fully meets all the requirements of the European Directive.

As manufacturers bring final justice, they must be very sure that all standards applied are appropriate and are used as intended. In addition, producers must prepare a document that explains why they meet the standard.

2 Conclusion:

Consumers are beginning to learn more about how to become acquainted with the machines and determine whether they comply with the European directives. By improving their knowledge they are becoming increasingly critical to manufacturers who do not comply with European standards, and take positive steps to correct this.

It is generally accepted that the industry resists the introduction of the European directives and as a result does not want to invest in the CE marking, or access to expert estimates. Unfortunately ,this is not only false economy, but inability to recognize the fact that machines that are in full compliance with European Directives are much more salable. CE marking does not need to be a heavy burden and can become a commercial advantage.

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COMBUSTION OPTIMIZATION IN A MODERN DIESEL ENGINE BY MEANS OF PRE-INJECTION STRATEGY

ОПТИМИЗАЦИЯ ПРОЦЕССА СГОРАНИЯ В СОВРЕМЕННОГО ДИЗЕЛЬНОГО ДВИГАТЕЛЯ ЧЕРЕЗ СТРАТЕГИИ ДЛЯ ПРЕДВАРИТЕЛЬНОГО ВПРЫСКА

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Abstract: The article presents a numerical study of pre-injection strategy in order to reduce the rate of heat release and pressure rise in a modern direct injection diesel engine, developed for passenger car. A model of the engine was built in advanced simulation code AVL BOOST. In order to determine the injection rate a supplementary model of the solenoid injector was built in AVL HYDSIM. A study of rate of heat release and pressure rise into combustion chamber was conducted at single operating point. The engine effective power was taken into consideration as well. The results revealed that pre-injection strategy is a promising approach for reducing the rate of heat released and the engine noise at low speed and load. However, a precise control of pre-injected mass and injection timing has to be realised by engine control system.

KEYWORDS: DIESEL ENGINES, DIRECT INJECTION, ENGINE SIMULATION, RATE OF HEAT RELEASE, PRE-INJECTION

1. Introduction

One of the most significant disadvantages of direct injection (DI) diesel engines is the high level of noise as a result of high rate of heat release (ROHR) during the premixed combustion period [1]. That high combustion speed is determined by injected fuel mass during the ignition delay period in DI diesel engines [1]. The more fuel injected during the ignition delay, the stronger the initial pressure rise in the combustion chamber, and the better boundary conditions for NO_x formation occurs. For those reasons it is important to reduce the ROHR during the premixed combustion period [2, 3]. There are a few methods of reducing the ROHR such as control of injection rate at the beginning of injection, dual-stage injection, reduction of ignition delay period by in-cylinder turbulent flow, pre-injection strategy and etc. [1, 2].

However, number of research [4-8] revealed that pre-injection strategy is the most effective approach. In fact, this approach is realized by one or few injections of small fuel mass shortly before the main injection. This small quantity of fuel is called pre-injection. It is easy to realize that strategy by means of the modern common rail fuel systems Fig.1 [2]. A typical injection process in common rail systems consists of a pre-injection, main injection and post-injection. Mainly, the aim of pre-injection is to reduce the rate of heat release as it reduces the engine noise. However, the pre-injection can be used for control the NO_x formation by mean of temperature reduction in combustion chamber. Usually, the pilot injection quantity is not more than 5% of the injected fuel. Common rail systems that use solenoid injectors can realize up to five separate injections which means that not more than two pre-injection can be produced. In order to further reduction of ROHR

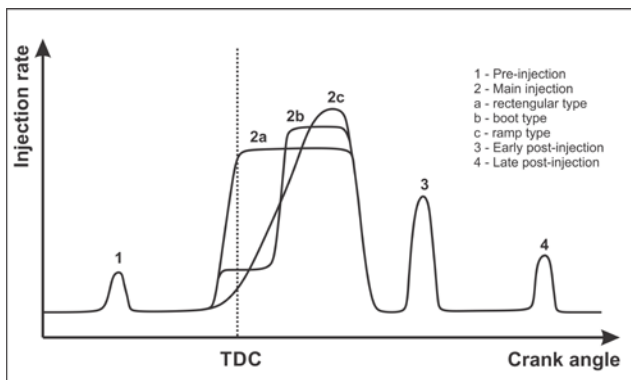


Figure 1. Schematic diagram on multiple injection in modern Common rail DI Diesel engines

at the beginning of the combustion process, the main injection can be realized with different shape such as boot type or ramp type (Fig.1). The most commonly used is rectangular type of main injection due to the simplification of injector design. The early post-injection is used in order to soot formation control as the late post-injection is realized at that engine operating mode in which the regeneration of the particle filter occurs. Piezo-controlled injectors can produce more than five injections due to fast response time of the injector control valve.

The pre-injected fuel mass evaporates before the main injection and pre-combustion reactions start. It increases the temperature in local volumes in the combustion chamber therefore the ignition delay period is reduced significantly. It means that the fuel injected at begin of main injection is involved immediately in combustion process after very short ignition delay period.

2. Pre-injection strategy.

The single pre-injection strategy is most commonly used because it is less complicate to realize. Both common rail injector (servo and piezo-controlled) can inject a small fuel mass before main injection. The effects of this single pre-injection on the ROHR can be seen in Fig.2.

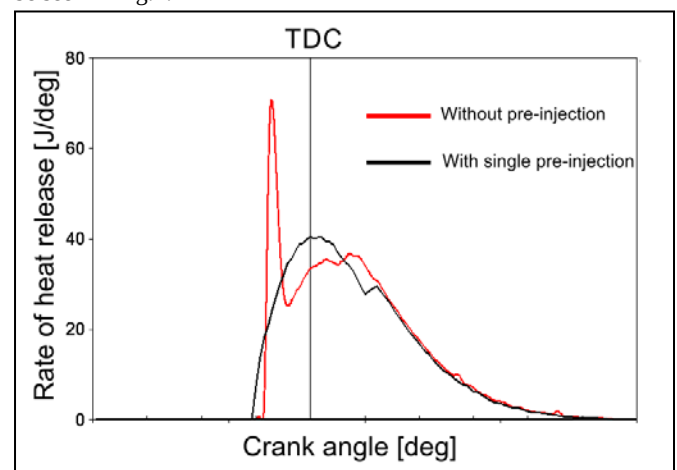


Figure 2. Effect of pre-injection on the ROHR.

The diagram reveals that ROHR increases much slower at the beginning of combustion and the maximum ROHR is reduced almost twice. As a result, the maximum pressure rise in the combustion chamber decreases from 0,85MPa/deg to 0,46MPa/deg. In order to provide the same output power and BMEP it is

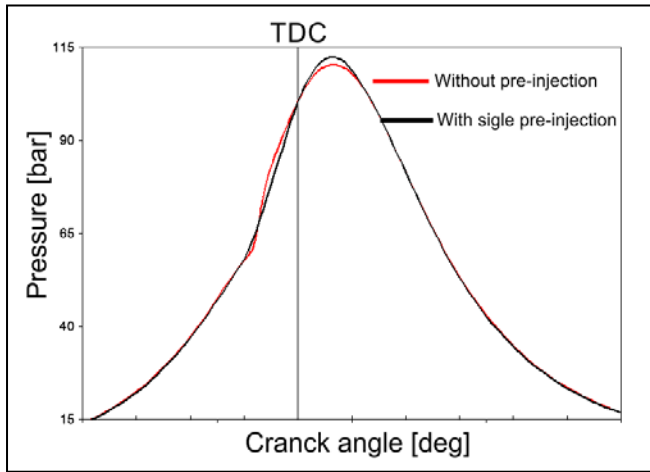


Figure 3. Effect of pre-injection on pressure variation into the cylinder.

necessary to reduce the injection timing (the start of injection) once the pre-injection is realized. It is a result of the shorter ignition delay period. The main injection timing has to be reduced from 15deg BTDC to 10deg BTDC.

Several parameters have to be taken in consideration: the mass of pre-injected fuel, the timing of pre-injection and the rotation angle between pilot and main injection. The various research on pre-injection has been reported [2, 7, 8]. Based on previous study it is important to note that the quantity of pre-injected fuel should be chosen within the range of 2% and 5% of overall injected mass [7]. The start of pilot and main injection should be chosen in way that start of main injection coincides with the start of combustion.

The basic research shows that a single pre-injection is an efficient method of reducing the maximum pressure rise in combustion chamber respectively the noise produced by diesel engines. For that reason the main aim of this paper is to study the influence of multiple (dual) pre-injection on the ROHR and pressure rise in a DI diesel engine.

3. Simulation model.

A simulation model was built in advanced simulation package AVL. It consist an engine model built in AVL Boost and an injector model built in AVL HYDSIM. This model provides opportunities to study the combustion process by means of rate of injection, previously defined by injector simulation. The engine performance, pollutant emissions, fuel consumption and other parameters can be estimated as well.

The engine under study is 2.0liter four cylinders direct injection diesel engine, developed for passenger car. The maximum output power is 101kW at 4000rpm as the maximum torque is 320Nm at 2000rpm. The engine is equipped with variable geometry turbocharger. The boost pressure is limited to 1.4bar. The common rail fuel system of the engine is delivered by Delphi. The maximum injection pressure is 1600 bar. The engine is also equipped with EGR system and post treatment system including catalytic converter and DPF. The cylinder is equipped with four valves per cylinder. The main geometrical parameters of the engine are listed in Table 1.

Table 1

Type of engine	HDI
Number of cylinders	4
Total volume	2L
Cylinder bore	85 mm
Cylinder stroke	88 mm
Compression ratio	17,6
Valves per cylinder	4

3.1. Engine model

In order to build a realistic engine model it was necessary to input geometrical parameters of intake and exhaust system as well as valves diameters and valves lift curves. The parameters (diameters and length of the pipes) of intake and exhaust system were measured on a real engine mounted on a test bed. The valves lift curves were calculated as the cams lifts had been measured by means of special equipment and the kinematic scheme of valve train mechanism was used. The valves seats diameters were taken from the technical documentation.

The engine model was built in advanced simulation code AVL Boost by means of elements available into (Fig. 4). The main elements which were used are: cylinder, plenum, pipe, intercooler, turbocompressor and general engine element (E1).

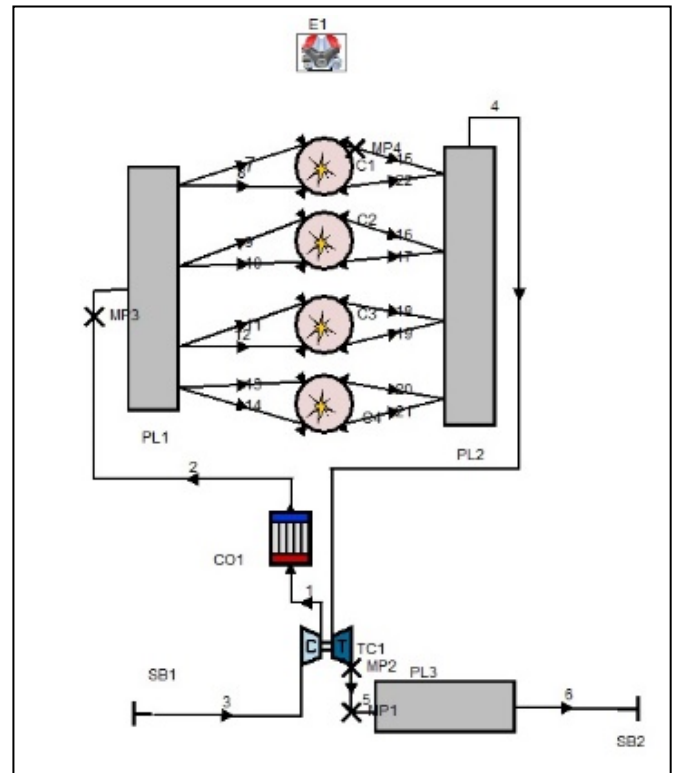


Figure 4. Engine simulation model, built in advanced simulation software AVL Boost

The main control parameters such as engine speed, number of cylinders, type of engine and simulating duration was input into the element E1. The parameters needed for estimation the mechanical losses into the engine are also defined in this element.

The element "Cylinder" was used to define the geometrical parameters of the cylinder, injection and combustion model as well as heat transfer to cylinder wall. Mixing-controlled combustion model, developed by AVL was used in this simulation. For this model it was necessary to define the injection parameters such as rate of injection, injected mass, nozzle geometrical parameters, injection pressure and injection timing. Air-excess ratio was used as a control parameter of the injection process. The most commonly used model of Woschni was chosen for heat transfer estimation.

The intake system includes: air filter, compressor, intercooler, plenum and pipes. The elements by means of which exhaust system was developed are: plenum, turbine, silencer and pipes. The compressor and turbine turns with same speed due to the connection shaft.

3.2. Injector model

In order to estimate the rate of injection an injector model was built in simulation software AVL HYDSIM. Engine fuel system was developed by Delphi. The system includes: high pressure pump driven by engine camshaft, pressure control valve (IMV), a common rail and solenoid injector for each cylinder. High pressure pump is developed to operate up to 1650bar. A transfer pump is

mounted into the high pressure pump due to provide fuel supply pressure of 6bar. The pressure is electronically controlled by a solenoid valve on the low pressure side of the high pressure pump. The system operates with great flow at the return fuel line due to necessity of intensive fuel cooling. The injectors can realize up to five injections for a cycle.

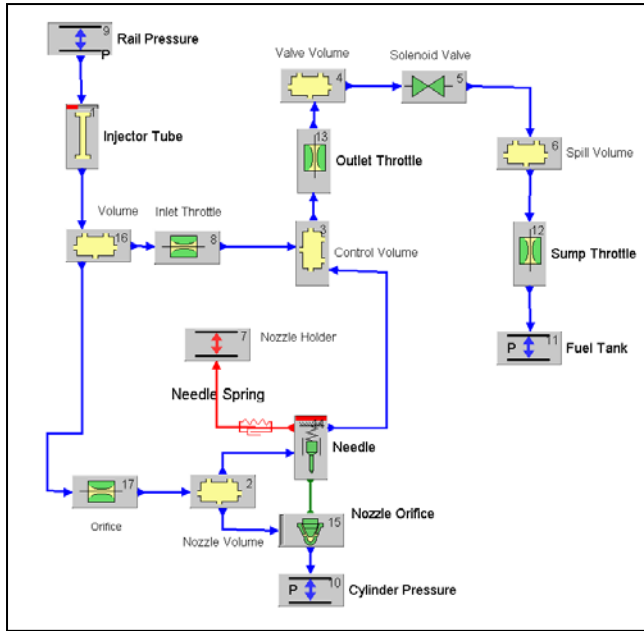


Figure 5. Injector simulation model, built in AVL HYDSIM.

Injector model includes various elements such as mechanical components (needle and spring), hydraulics elements (volumes, tubes, throttles and nozzle orifices), electronic component (solenoid valve) and constant pressure elements (rail, cylinder and fuel tank). Some geometrical parameters such as needle mass and size, needle spring stiffness, injector tube length and diameter as well as the volumes were measured as an injector was disassembled. Other parameters such as throttles sections and nozzle orifices were taken by Delphi technical documentation. The injector model is presented in Fig. 5.

The main injector parameters are listed in Table 2.

Table 2

Type of injector	Delphi DFI 1.3
Nominal voltage	Battery voltage
Initial current	22 to 26A
Operating pressure	100 to 1650bar
Number of nozzle holes	6
Diameter of nozzle holes	0.15mm
Spray angle	50°
Minimum injected mass	0.5mg

By means of the injector model, injection rate was estimated as injected mass was separated up to three – two pre-injections and a main injection (depending on injection strategy). The amount of fuel injected by each pre-injection was 0.5mg or 1mg. In this article the timing interval between each injection was not studied. An injection simulation was conducted at engine speed corresponding to maximum engine torque – 2000rpm. Single engine operating points was studied. The overall injected fuel mass was 25mg. At studied operating point the reference engine output power was 27,5kW. The rail pressure was 800bar due to provide the duration of the main injection counted to 19deg by crank angle rotation. In order to realize the targeting pre-injected mass of 0,5mg and total injected mass of 25mg the injector solenoid valve was opened respectively for a period of 0.29ms and 0.83ms. The variation of injection rate estimated by the model in case of double pre-injection is shown in Fig. 6.

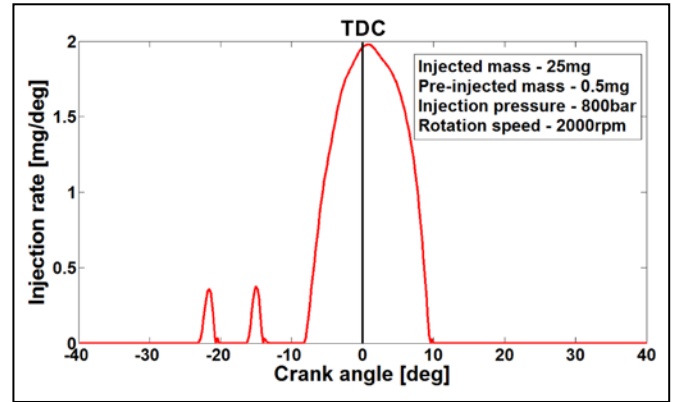


Figure 6. Fuel injection rate with two pre-injection, estimated by injector model

4. Results and discussion.

The numerical study was conducted at an engine operating point, defined by engine speed of 2000rpm and air-excess ratio of 2.

Firstly, a study of pre-injection strategy was conducted. For that the ROHR and in-cylinder pressure rise were estimated as three injection strategies was applied – without pre-injection, single pre-injection and double pre-injection. In order to achieve comparative results some constrains was defined:

- The overall mass of injected fuel was 25mg;
- The start of main injection was constant – 8deg BTDC;
- The overall mass of pre-injected fuel was 1mg;
- In double pre-injection case, the pre-injected mass was separate by two equal parts;
- The start of first pre-injection was constant – 20deg BTDC.

The influence of injection strategy on ROHR is presented in Fig. 7. It was observed a significant reduction of ROHR in case of pre-injection. The maximum ROHR was reduced from 89,1J/deg without pre-injection to 67,4J/deg in case of pre-injection. The function variation revealed that pre-injection strategy eliminated the pre-mixed combustion period. It provides slightly increasing of ROHR up to maximum value.

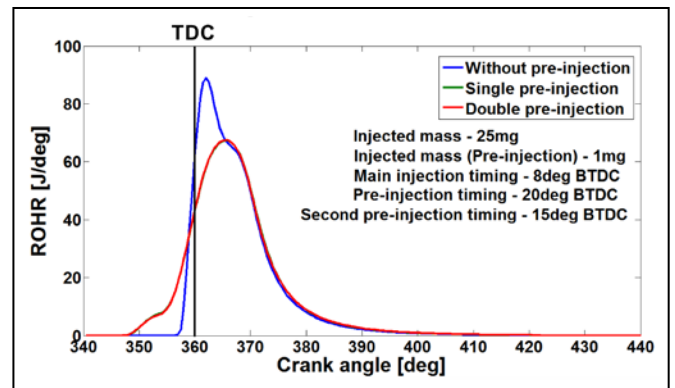


Figure 7. ROHR variation as function of injection strategy

Obviously, the reduction of ROHR decreases the maximum pressure rise into the cylinder – Fig.8. Pre-injection reduced maximum pressure rise from 0,65MPa/deg to 0,37MPa/deg. This significant reduction accounts to 43% lower maximum pressure rise. Although the combustion noise was not studied, we expected much lower noise level.

The influence of double pre-injection strategy on combustion parameters was insignificant in comparison with single pre-injection. Practically, the ROHR and pressure rise curves were absolutely the same and were not influenced by pre-injection separation. That interesting fact can be explained with equal pre-injected fuel mass.

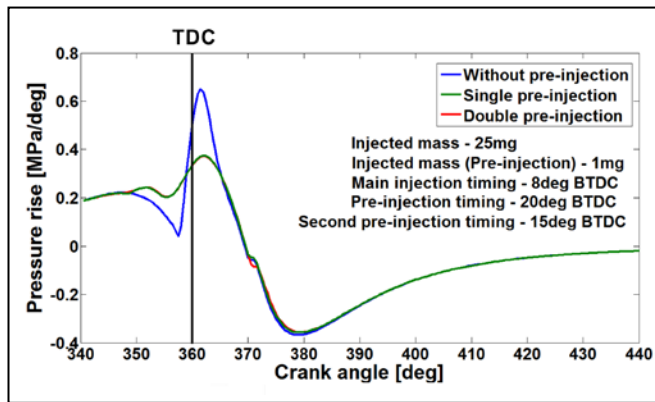


Figure 8. Pressure rise variation as function of injection strategy.

The single pre-injection reduced engine output power by 0,3%. In order to achieve the same effective power, respectively the same engine efficiency injection timing of both pre and main injection were retarded by 2deg. It was applied to single pre-injection mode. In result of that, the maximum pressure rise was additionally reduced to 0,29MPa/deg or the final reduction by 55% was observed compared to the maximum pressure rise achieved without pre-injection. The effect of late injection on the variation of ROHR and pressure rise is shown in Fig. 9 and 10.

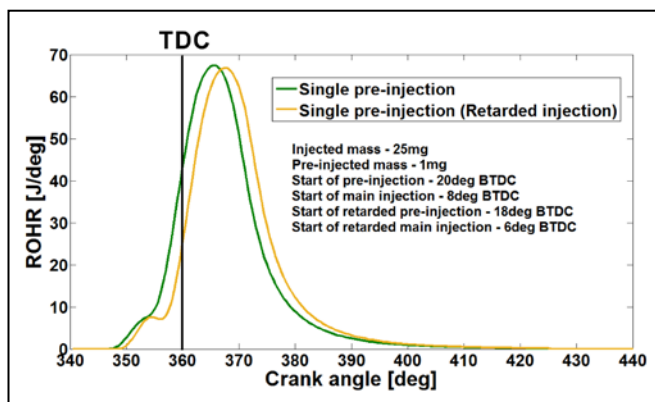


Figure 9. ROHR variation as function of injection timing

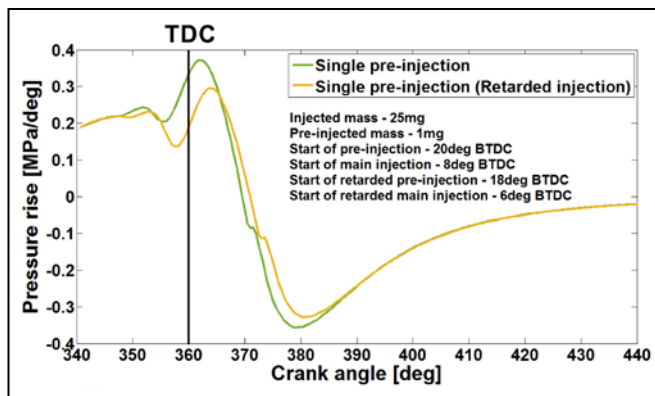


Figure 10. Pressure rise variation as function of injection timing

Finally, a study of double pre-injection strategy was conducted as the pre-injected fuel was increased up to 2mg. The injected fuel was separate equally between first and second pre-injection. The pre-injection timing was the same as that in the first study. Increasing of pre-injected fuel reduced the engine effective power by 0,7% and the effect on ROHR and pressure rise was not significant. The maximum ROHR was 65,6 J/deg and maximum pressure rise was 0,36MPa/deg. In order to eliminate engine efficiency reduction the double pre-injection process was retarded by 3deg as the timing interval between each of injection was the same. The pressure rise variation is shown in Fig. 11.

The combination of double pre-injection with high pre-injected fuel mass and retarded injection timing reduced maximum pressure rise up to 0,25MPa/deg. It was observed that pressure rise curve had

two maximums with the same values. This fact revealed that further increasing of pre-injected fuel mass would increase maximum pressure rise due to increasing the first maximum of the curve. The timing retard in case of double pre-injection has not reduced significantly the maximum of ROHR.

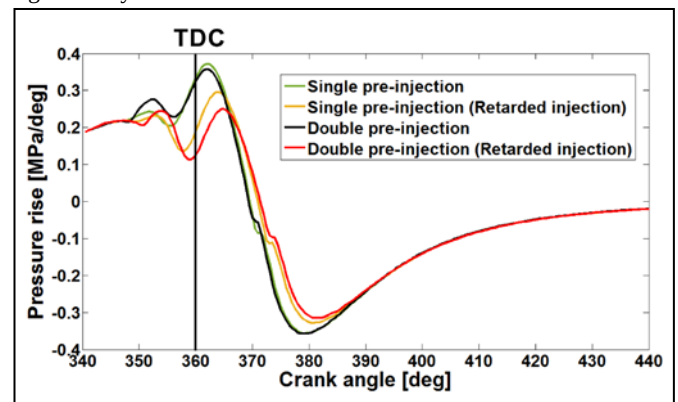


Figure 11. Influence of double pre-injection strategy to pressure

5. Conclusion

Pre-injection strategy can be successfully applied as combustion control strategy due to reducing of maximum pressure rise at low speed and engine load. The study revealed that single pre-injection strategy can reduce pressure rise by 43%. By applying this strategy it is necessary to reduce injection timing in order to obtain the same engine power. Additionally, it can reduce pressure rise up to 55%.

Double pre-injection is more effective. To achieve significant impact on in-cylinder pressure rise it is necessary to increase pre-injected mass and to retard the injection up to 3deg by crank angle rotation for studied operating point. In that case pressure rise reduction by 61,5% was observed.

This study optimized the pre-injection parameters at single engine operating point. The results revealed that pre-injection strategy have to be precisely optimized at whole operating maps taking into consideration the injection system parameters.

Acknowledgment

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