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Збірник наукових праць ІІ міжнародної науково практичної конференції «Розробка та дизайн сучасних матеріалів та виробів». – Дніпро: НТУ «ДП», 2023. – 83 с.

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CONFERENCE PROGRAM

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PREFACE

Scientific society: employees of higher educational institutions and research institutes, including graduate students and students, as well as representatives of organizations and firms engaged in the field of knowledge-intensive business, welcome you to the 2nd International Scientific and Practical Conference "Development and Design of Modern Materials and Products", organized based on the Engineering and Generative Design Department Dnipro University of Technology.

We are organizing a conference in the context of the Russian-Ukrainian war, which changed everything not only in Ukraine, in Europe, but also in the whole world.

We hope that such a conference is another opportunity to gather scientists from different directions and countries of the world, with the aim of preserving global scientific unity in such difficult conditions.

We are sure that the results of our joint work will be interesting and useful for all participants of the conference and will serve to solve modern problems of the world scientific community.

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EFFECT OF STRUCTURES ON THE STRENGTH, FRACTURE TOUGHNESS, CRACK RESISTANCE OF WELDED JOINTS OF HIGH-STRENGTH STEELS AND COMPOSITE COATINGS

Abstract. The work introduces the structurally-analytical technique of estimation of the effect of structures on the most important operational properties of the materials (such as strength, fracture toughness, and crack resistance) has been developed. The role of structural factors in ensuring optimal properties of materials and their operational reliability has been shown.

Keywords: high-strength steel, welded joint, coatings, microstructure, phase composition, dislocation density, mechanical properties, crack resistance, local inner stresses, laser technologies, hybrid laser-arc welding, detonation spraying

Our main idea is to obtain welded joints and coatings in high operational properties by applying advanced technologies. Only these technologies lead to the formation of structures in the joint zone, which positively affects the quality of welded joints and coatings. Such technologies are laser and hybrid laser-arc welding [1], detonation spraying of coating as well [2].

The executed complex of experimental investigations at all the structural levels allowed carrying out analytical evaluations of the specific contribution of different structural and phase factors and parameters, formed in the investigated weld beads and coatings, in change of strength characteristics σ_T and determining the structural factors cardinal influencing on the character and distribution of local inner stresses ($\tau_{L/IS}$), which are the potential sources of incipience and propagation of cracks in the investigated structural microregions [1, 2]. Integral values of hardening ($\Sigma\sigma_T$) were evaluated (according to equation including known dependencies of Hall–Petch, Orowan, etc.) as a sum value consisting of series of constituents:

$\Sigma\sigma_T = \Delta\sigma_0 + \Delta\sigma_{S.S.} + \Delta\sigma_G + \Delta\sigma_{Sg} + \Delta\sigma_D + \Delta\sigma_{D.H.}$, where $\Delta\sigma_0$ is the resistance of type of metal lattice to movement of free dislocations (stress of lattice friction or Peierls–Nabarro stress); $\Delta\sigma_{S.S.}$ is the hardening of solid solution with alloying elements, according to Mott–Nabarro theory; $\Delta\sigma_G$ and $\Delta\sigma_{Sg}$ are hardening due to change of grain and subgrain in accordance with Hall–Petch dependence; $\Delta\sigma_D$ is the dislocation hardening, caused by interdislocation interaction on J. Taylor, A. Zeger, N. Mott and G. Hirsch theory as well as $\Delta\sigma_{D.H.}$ is the dispersion hardening due to dispersion phases by Orowan. Calculation values of fracture toughness factor K_{1c} are evaluated on dependence: $K1c = (2E\cdot\Sigma\sigma_T\cdot\delta c)^{1/2}$, where E is the Young's modulus; $\Sigma\sigma_T$ is the calculation value of hardening; δc is the value of critical crack opening (according to data of substructure parameters). Analysis of different approaches to mechanisms of crack nucleation and fracture of materials was used for selection of an evaluation based on dislocation theory of crystalline solid bodies considering analysis of nature of dislocation structure and its distribution (dislocation accumulations or uniform dislocation distribution). This allows carrying detailed evaluation of a level of internal stresses depending on zones of dislocation accumulations, namely along sub- or intergranular boundaries, in zones and their accumulations, etc., which promote formation of concentrators of local internal stresses, i.e. zones of nucleation and propagations of cracks. A field of internal stresses, developed by dislocation structure (dislocation density) is described by expression $\tau_{L/IS} = G\cdot b\cdot h\cdot\rho/[\pi(1-\nu)]$, where G is the shear modulus; b is the Burgers vector; h is the foil thickness, equal to 2×10^{-5} cm; ν is the Poisson's ratio; ρ is the dislocation density.

Determined correlations concerning the effect of a laser and hybrid laser-arc welding speed on the structure of the weld metal and that of the heat affected zone of welded joints made in high strength steel 14KhGN2MDAFB revealed that the increase in a welding speed was accompanied by the change in the weld metal phase composition, an microhardness increase and the repeated refinement of the grain and subgrain structure. The use of high-speed welding technologies allows obtaining phase composition and structural components that provide high operational properties (strength, fracture toughness and crack resistance) of welded joints. As a result of the action of a high-speed thermal-deformation cycle of laser and hybrid laser-arc welding on the weld metal and the heat affected zone of high-strength steel, a homogeneous dispersed fine-grained lower bainite structure and tempered martensite is formed with a uniform distribution of carbide-type phases in them. The most favorable structure (formation of fine grain lower bainite structures, absence of extended dislocation accumulations, uniform dislocation distribution) in the investigated joints is formed at welding speed 14 mm/s (laser welding) and 20 mm/s (laser-arc welding). This provided the optimum combination of mechanical properties, plasticity and crack resistance (the lack of local stress concentrators - zones of nucleation and propagation of cracks). The surface treatment of metals by the detonation spraying of coatings (Cr_3C_2 –NiCr, Al_2O_3, $ZrSiO_4$) makes it possible to obtain composite surface layers with high operational properties. The matrix of such coatings is characterized by a significant dispersion of the substructure (fig. 1 a), the formation of strengthening phases of nano-scale dimensions (fig. 1 b, c) and a uniform distribution of dislocation density (fig. 1). This ensures a minimum level of local internal stresses (fig. 1 d) and, accordingly, crack resistance of coatings for multichamber detonation spraying.

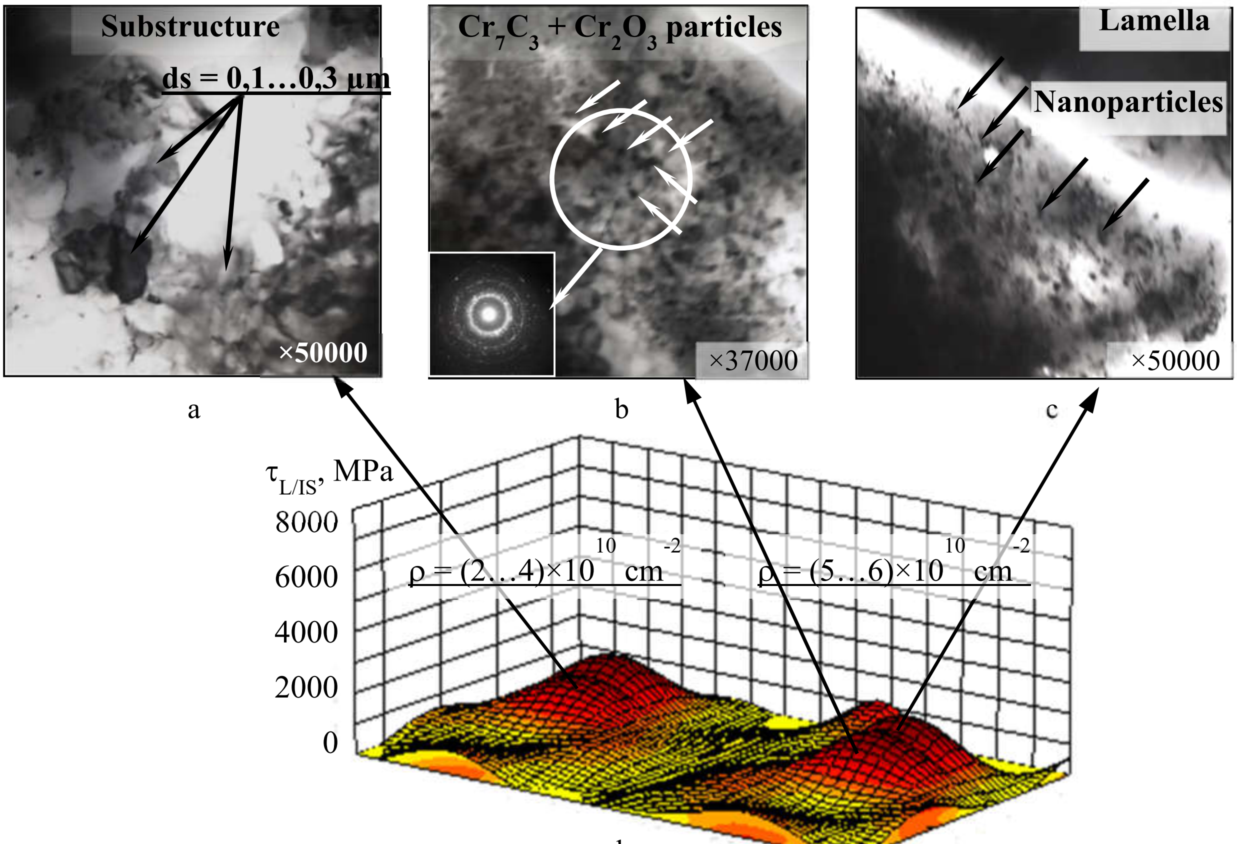

Fig. 1. The formation of a nanostructures (a – c) in Cr3C2-NiCr coatings (transmission electron microscopy) and analytical evaluations local internal stresses $\tau_{L/IS}$ (d).

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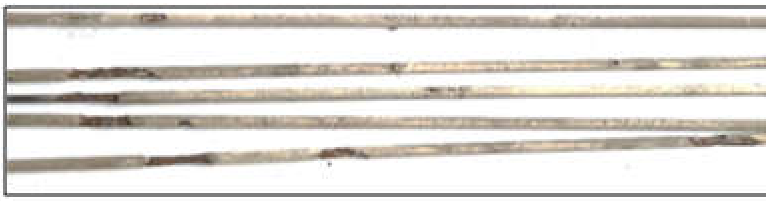
RECYCLING OF WELDING ELECTRODES USING VIBRATION-IMPACT LOADING

Abstract. An innovative method of vibration-impact cleaning of welding electrodes, implemented in a vibratory jaw crusher with an inclined crushing chamber, is considered. The general view and design diagram of the crusher are shown. The results of crushing electrodes in an open cycle at a jaw vibration frequency of 18 Hz and an amplitude of 5 mm are presented. Research has substantiated the reality of 100% separation of the components of welding electrodes in one cycle.

Keywords: welding electrodes, crusher, coating, waste, vibration-impact method.

The production and repair of various types of products is carried out using a significant amount of welding work, an integral part of which are welding electrodes, consisting of a metal rod and coating. The main disadvantages of welding work include the formation of slag and electrode cinders (Fig. 1a). The formation of waste also occurs at the stage of their calcination or poor-quality storage (Fig. 1b).

a



b

Figure 1. Waste welding electrodes: a – cinders; b – destroyed coating

These materials, amounting to thousands of tons, require recycling to convert them into secondary resources, which serve as feedstock for further use in the technological process for the manufacture of new products.

The purpose of the work was to evaluate the efficiency of separation of the constituent materials of the welding electrode using a vibratory jaw crusher with an inclined crushing chamber.

The existing technology for removing the coating is based on its chipping when electrodes pass between two grooved rollers, one of which (the lower one) is driven, and the upper one is adjustable. By vertical movement using screws, a gap is set based on the diameter of the welding electrodes being processed. Such equipment removes up to 90% of the coating, which requires repeated cleaning.

The relatively weak resistance of the coating to impact loads determines the efficiency of recycling electrodes in the developed design of a vibrating jaw crusher (Fig. 2) with an inclined working chamber and an expanded ability to control the disintegration process [1,2,3,4].

In general, the crusher (Fig. 3) includes a passive (lower) jaw 1, mounted on elastic elements 5 and at the same time performing the function of a housing. The active jaw 3 is installed in the racks of the passive jaw by means of the suspension axis 2, relative to which it can perform rotational oscillations. In a given neutral position, the active jaw is held by elastic elements 6. Vibrations of the jaws are generated by a two-shaft inertial vibration exciter 4.

Figure 2. Crusher ВЩДН 130

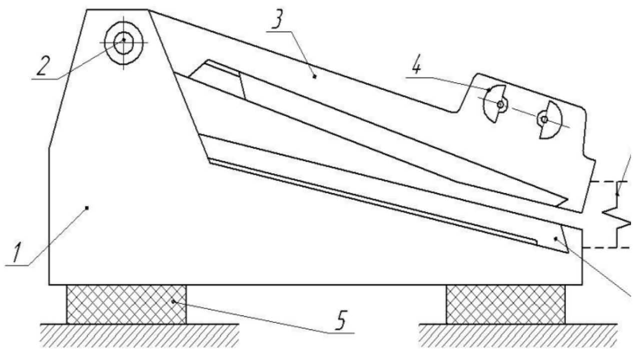


Figure 3. Structural diagram of the crusher

The coating was removed at a vibration frequency of the jaw of 18 Hz and an amplitude of 5mm. At the same time, the task of determining the dependencies between dynamic and technological parameters was not set. A qualitative picture of the cleaning of the metal rod was examined (Fig. 4).

a b

Figure 4. Cleaned rods: a – cinders; b – electrodes

The conducted studies showed the prospects for the effective use of a vibrating jaw crusher for the disposal of welding waste. Complete separation of the constituent materials of the welding electrode will be ensured when operating in an open crushing cycle. At the same time, the quality of separation is practically not affected by the length of the waste and its curvature.

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ABOUT THE INFLUENCE OF THE MODE PARAMETERS OF THE "WHEEL – RAIL" PAIR ON THE CONDITION OF THE SURFACE LAYER OF THE TIRE WHEEL

The interaction of bodies with a moving point of contact (for vehicles, this is primarily the interaction of output links with the external environment, but also during the transfer of motion between links of mechanisms that form kinematic pairs) is the basis of physical processes associated with the movement of loads, and as well as the rolling process, which is accompanied by clutching and the implementation of traction or braking force when performing the main work process [1].

Since the tire of the wheel of rail transport works in a friction pair with the rail, it, first of all, must have high wear resistance, which is determined by its hardness. On the other hand, to ensure the operational reliability of the wheel, it is necessary that the tire has a sufficient supply of viscosity, which in some cases may be associated with the need to reduce strength (hardness). These, to some extent, conflicting requirements regarding mechanical properties and determine the complexity of the problem of ensuring the reliability of the tire wheel. Elastic and plastic deformations (fig. 1, b, c) occur on the support surface of the tire of wheel 1 with rail 2 (Fig. 1, a) under the action of external forces and internal energy of the material, which lead to the formation and detachment of wear particles.

a) b) c)

Figure 1 Conditions of interaction of the wheel – rail friction pair

Operating mode parameters (traction/braking, slipping) are associated with the occurrence of a zone of plastic deformation near the rolling surface and the presence of particles of non-metallic inclusions and areas of corrosion damage to steel formed in the process of interaction. These structural changes cause the appearance of defects of fatigue origin (cracks), which lead to the destruction of the tire (and the undercut of the flange is very dangerous), as well as a change in the wheel profile as a result of the displacement of the metal layers along the rolling surface (Fig. 1, b, c). Thus, the wear mechanism of the rolling surface represents a combination of mechanical, thermophysical and chemical phenomena and is associated with the formation of wear particles and microcracks in places of intense plastic deformation and in areas of the "white layer" near particles of non-metallic inclusions and steel corrosion products. The formation of a "white layer" is facilitated by a large temperature difference during more intensive heating of the rolling surface of the wheel under different mode parameters of operation and its subsequent cooling.

In the paper [1], the authors obtained the dependence of the traction force on the absolute speed of movement and the relative speed of the interacting surfaces of the wheel–rail pair (Fig. 2). This is especially noticeable in the area outside the creep, that is, the movement of rail vehicle in slipping mode.

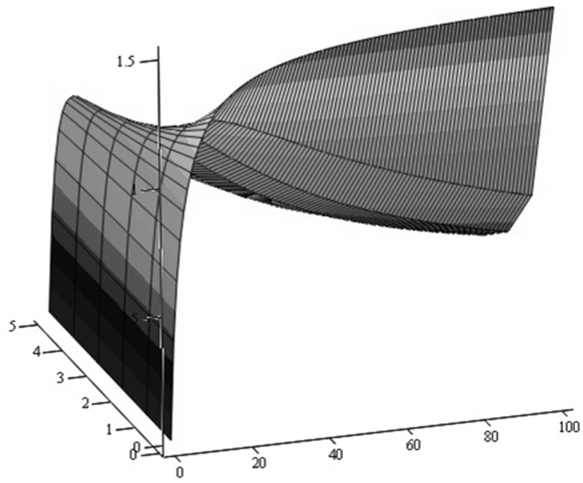

Figure 2 Change in traction capacity of the contact depending on the speed of the rail vehicle

The result of high actual pressures and sliding speeds is a violation of the energetically balanced state of the friction pair, which causes the appearance of significant temperatures in the areas of interaction and leads to significant changes in the properties of the surface layers, causing mechanical and temperature stresses in them. The largest deformation occurs in the center of the contact area, where the pressure is maximum and develops in the direction of wheel slippage (Fig. 1, b, c). The structure of the "white layer" is martensite in a very dispersed form with a large number of dislocations. The hardness of the "white layer" of the skating surface reaches 850 HV. "White spots" cause the appearance of microcracks, which, as they develop, lead to metal staining, and also contribute to the formation of "metal creep" and uneven rolling.

In [2], the dependence of the given modulus of elasticity of the wheel – rail friction pair on the speed of the rail vehicle was obtained. Further studies proved that the repeated heating and cooling causes successively compressive and tensile stresses in the upper layer of the wheel tire, the value of which is higher than the yield point of steel, which leads to the development of plastic deformation. The accumulation of plastic deformation leads to a violation of the integrity of the metal, the formation of cracks. The study of the metal on the surface of the tire showed the presence of two zones of crack development: in the first – the zone of brittle fracture – microcracks appear on the wheel due to high temperatures during slipping and develop deep enough quickly, in the second – the development of cracks occurs more slowly and has a fatigue character. Transverse thermal cracks are also often accompanied by staining of the metal between them on the rolling surface of the wheels.

Conclusion. The study of the mechanism of wear of rail transport wheels includes the study of structural changes occurring in the surface layers of the tire, but also the analysis of wear particles and the establishment of the mechanism of their formation. The variety of operating conditions of friction pairs allows us to claim that a general approach can be an idea of the fatigue nature of the destruction of surface layers. Such an approach is necessary both when choosing the chemical composition of the materials of the wheel-rail friction pair, taking into account their cyclic strength and durability, and when developing new designs of wheels, taking into account their operating conditions.

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FORCE VIBRATIONS OF NONLINEAR MECHANICAL SYSTEM, WITH PARAMETERS DEPENDENCY UPON TIME, AT PRESENT OF NONLINEAR DAMPING AND CASUAL EXTERNAL LOADING

The row of nonlinear stochastic dynamics problems for the mechanical systems with parameters dependency upon time, for example force vibrations of modern machines and vehicles, is taken to the decision of nonlinear heterogeneous singular differential equation of the second order with variable coefficients at the presence of the nonlinear first derivative (functions of damping) degrees of n and accidental external load

$$f''(t) + c(t) f'^{n}(t) + \omega_0^2 \varphi(t) f(t) + \alpha Q(t) f^3(t) = \gamma(t), \quad (1)$$

where c(t) is the damping function, $\omega_0^2\varphi(t)$ – the frequency of natural oscillations of the mechanical system, ω_0 - is a “large” parameter, φ(t) is a given continuous function of time, α is a “small” disturbance parameter of the nonlinear component, Q(t) is a continuously differentiable function with a cubic component, γ(t) is a forcing random force with known characteristics.

In most cases, the exact solution of this equation can be obtained only in individual cases. The paper considers the method of double asymptotic development of the desired function for obtaining the correlation function of a random process.

The initial conditions for this equation are taken in the form

$$f(t_0) = G_0, \quad f'(t_0) = G_1. \quad (2)$$

where , G_0, G_1 – are given constant values.

The solution of equation (1) is sought in the time interval from t_0 to some T, that is, the variable t belongs to a certain segment $[t_0, T]$.The ratio of the thickness to the largest size can be taken as a "small" parameter in the study of vibrations of the given objects, or as a "large" parameter - the value of the frequency of natural oscillations, and others.

Equation (1) describes the forced oscillations of a system with one degree of freedom with a cubic nonlinearity under the action of a random force and is a probabilistic analogue of the Duffing equation with variable coefficients [1]. For example, the solution of problems about oscillations of plates and shells structures under the action of a random load is reduced to this equation by the Bubnov-Galyorkin method. To obtain the instantaneous functions of the initial process f(t), we apply the method of averaging the solution of the stochastic equation (1) over a set of realizations. That is:

$$m_f(t) = \langle f(t) \rangle,$$

$$K_f(t_1,t_2) = \left\langle \overset{\circ}{f}(t_1)\overset{\circ}{f}(t_2) \right\rangle = \langle (f(t_1) - m_f(t_1))\,(f(t_2) - m_f(t_2)) \rangle =$$

$$= \langle f(t_1) f(t_2) \rangle - m_f(t_1) m_f(t_2),$$

$$r_f(t_1,t_2) = \frac{K_f(t_1,t_2)}{\sqrt{D_f(t_1)\cdot D_f(t_2)}},$$

where $m_f(t)$, $D_f(t)$, $K_f(t_1,t_2)$ and $\rho_f(t_1,t_2)$ – respectively, the mathematical expectation, dispersion, correlation function (covariance of the values of the function *f(t)* at time points t_1 and t_2) and the correlation coefficient of the original process f(t), that is, the solution of equation (1); is the centered random function of the original process f(t). Here the operation of calculating the mathematical expectation is indicated by angle brackets.

Equation (1) is presented in the form

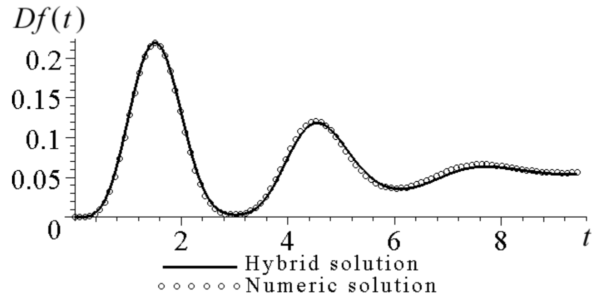
$$f''(t) + c(t)f'(t) + \omega_0^2\varphi(t)f(t) + \alpha F(f^2(t),t) = \gamma(t), \quad (3)$$

where $F(f(t),t) = Q(t)f^3(t)$.

(4)

To obtain an approximate analytical solution of equation (3) and to study the forced oscillations of a mechanical system with damping, the parameters of which depend on time under a stochastic external load, the hybrid asymptotic method of "perturbations-phase integrals (WKB method)-Galyorkin procedure" [3] is used.

Some calculation results for the linear damping function are presented on Fig. 1,2



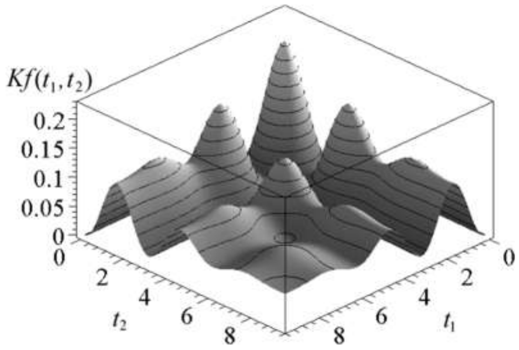


Fig. 1. Dispersion graph of the original process; $\varepsilon = 0{,}5$ ($\omega_0 = 2$); $\alpha = 2$; $T = 3\pi$; $c(t) = t\cdot(3\pi)^{-1}$; $K\gamma(t_1,t_2) = 1$.

Fig. 2. Graph of the correlation function of the original process; $\varepsilon = 0{,}5$ ($\omega_0 = 2$); $\alpha = 2$; $T = 3\pi$; $c(t) = t\cdot(3\pi)^{-1}$; $K\gamma(t_1,t_2) = 1$.

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ANALYSIS OF THE STRESSED-DEFORMED STATE OF A PLAMETIC BODY IN INTERACTION WITH A SOLID OBJECT

Abstract. This study investigates the stress-strain state of a plate-like body during its interaction with a solid object. The research is motivated by the necessity to comprehend and predict the behavior of materials and structures when in contact with external objects, with applications in various engineering and material science fields. The research aims to establish relationships between these parameters and the shape of contact zones that develop during the interaction.

Keywords. STRESS-STRAIN ANALYSIS, PLATE-LIKE BODY, INTERACTION, SOLID OBJECT, DEFORMATION, MECHANICAL BEHAVIOR, MATERIAL SCIENCE.

Main part. The primary objective of stress analysis is to explore how external forces or solid objects induce stress within a plate-like structure. By utilizing analytical and numerical modeling, this study examines how geometric and material parameters influence the resulting stress and deformation characteristics [1].

Investigating the stress-strain state of a plate-like body allows for the study of material behavior during interactions with solid objects, facilitating the optimization of plate-like structures or materials to enhance their strength, stability, and elasticity when interacting with solid objects. This method contributes to the development of new materials with improved mechanical properties.

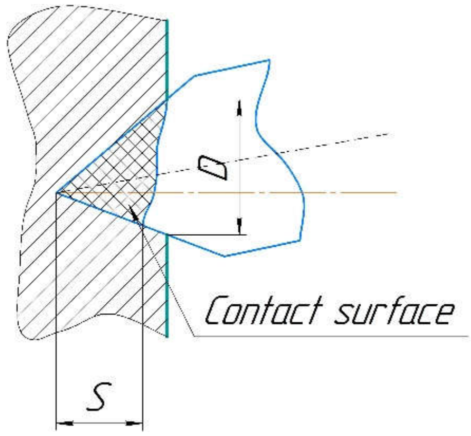

Fig. 1 – Calculation scheme for determining the contact surface area

With the aid of modern computer technologies, detailed modeling of interactions becomes possible, enabling accurate forecasts and structural optimization. The study of penetration into the plate-like body was conducted using Ansys Mechanical, an engineering tool for solving a wide range of problems related to deformed body mechanics, accounting for nonlinear material properties, plasticity, and contact interactions.

Ansys Mechanical provides the opportunity to establish relationships between parameters and contact zones of elements. The distribution of stresses and strains in contact zones depends on several factors, including geometry, material properties, and the force of interaction. Consideration of potential interactions and their effects on materials is crucial in the design process to reduce the risk of damage.

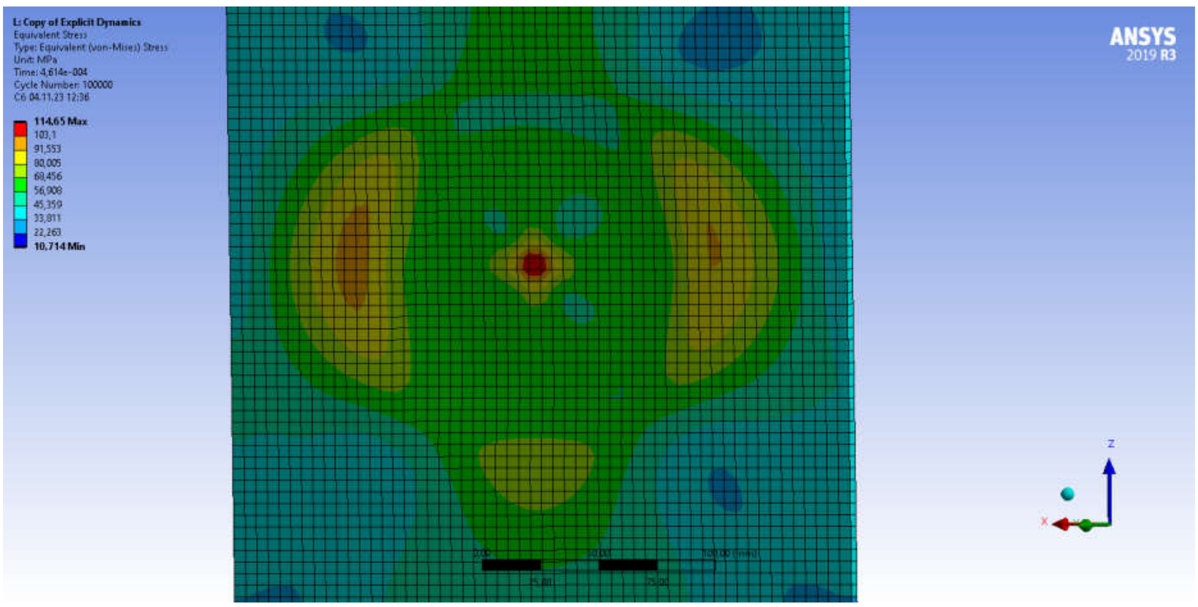

Fig. 2 – Equivalent Stress in a plastic body when interacting with a solid object

From a materials science perspective, the study of steel deformation under load is invaluable for designing armor protection, increasing material strength, and improving structural integrity. The research allows for an understanding of how materials behave under load and how they can be optimized to enhance their properties [2].

Conclusion. In conclusion, the analysis of the stress-strain state of plate-like bodies in interaction with solid objects is a fundamental area of research. By delving into the stress and deformation behavior of plate-like bodies when in contact with solid objects, this analysis contributes to a broader understanding of how materials respond to external forces and provides valuable insights for engineering and design applications.

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DEVELOPMENT OF OPTIMAL TECHNOLOGICAL PARAMETERS OF DEPOSITION OF PLASMA COATINGS

The paper considers the possibility of using ion-plasma sputtering of the surface of molds. This makes it possible to replace scarce steels with other materials. 4X5MFS and 5XNM steels were used in the work. As laboratory tests have shown, the titanium nitride coating applied under optimal technological parameters increases the corrosion resistance of mold parts by 3 times, scale resistance by 2-4 times.

INTRODUCTION

One of the most advanced ways of obtaining castings is injection molding. At the same time, the wide implementation of injection molding in production is held back by the low stability of molds due to their relatively high cost [1-4].

Solving the problem of increasing the stability of the molds can be achieved by affecting only the thin surface layer in order to increase its resistance to cyclic temperature stress and an aggressive environment

The existing methods of processing made it possible to solve the following tasks: weakening the physical and chemical interaction of the mold and the casting, increasing the wear resistance and some others [7], which only partially increases the stability of the molds (by 20-30%) [5-7] .

PROBLEM STATEMENT

The purpose of the work is to create a surface layer that guarantees high wear resistance and corrosion resistance.

At present, the KIB method has found application in the automotive, aviation, and electrical engineering industries. Regarding the use of this method for applying plasma coatings to parts of molds, this issue has not been studied.

In connection with the above, the scientifically based selection of the material of the molds for further processing of the feasibility of the proposed development is an urgent problem.

MATERIALS AND METHODS OF THE STUDY

4Kh5MFS and 5KHNM steels were chosen as materials for copper alloy die casting molds in this work (Table 1).

Table 1

Chemical composition of steels used for the manufacture of injection molding molds

Steel	Content of elements, %				
	WITH	Gold	Mo	V	No
5 KhNM	0.50-0.60	0.60-0.80	0.15-0.30	–	1.40-1.80
4X5MFS	0.37-0.44	4.50-5.50	0.80-1.10	0.80-1.20	–

The coating was applied on the "Bulat-3T" installation

The reaction gas pressure in the installation chamber, the heating temperature of the substrate on which the coating is applied, and the deposition time were selected as the optimal coating parameters. (Table 2).

After applying the coatings, the surface microstructure of the obtained coatings and their microhardness were investigated (Table 3).

Table 2

Effect of nitrogen partial pressure on coating characteristics

Nitrogen pressure, Pa	$3 \cdot 10^{-3}$	$3 \cdot 10^{-2}$	$4 \cdot 10^{-1}$	1
Microhardness, GPa	22	26.0	23.0	18.0
Coating color	gray	yellowish gray	yellow	brown-golden

Table3

Effect of nitrogen partial pressure on the thermal endurance of the coating

Steel brand	Pressure				
	without coating	$3 \cdot 10^{-3}$	$3 \cdot 10^{-2}$	$4 \cdot 10^{-1}$	1
	thermal endurance				
4X5MFS	2000	3000	5000	9500	12000
5 KhNM	2000	3500	5000	9000	11500

Note : 5 μm thick titanium nitride coating applied at a substrate temperature of 500 °°C.

RESULTS AND DISCUSSION

Coatings obtained at different nitrogen pressures differ in the number and size of the droplet phase. The largest amount of droplet phase containing α - Ti is observed in coatings obtained at nitrogen pressures of $3 \cdot 10^{-3}$ Pa, $3 \cdot 10^{-2}$ Pa (Fig. 2 a, 2 b). They have a gray and yellowish-gray color. As the nitrogen pressure increases to 1 Pa, the coating acquires a brownish- golden color, the amount of droplet phase on the surface decreases noticeably (Fig. 2 d).

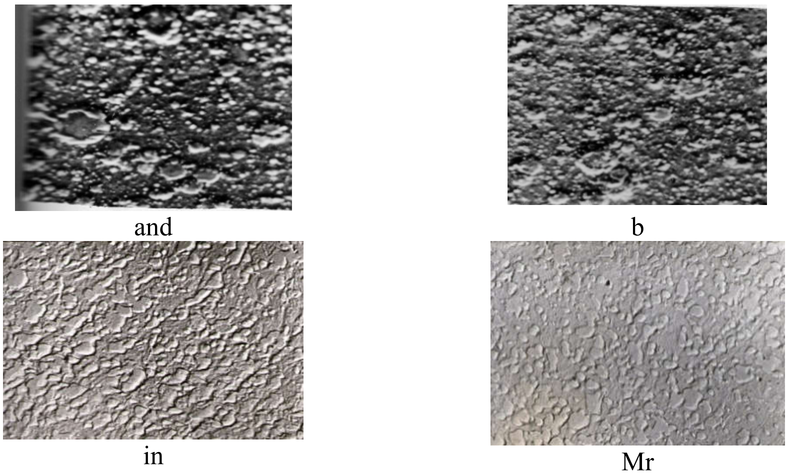

Fig. 2. Microstructure of the surface of titanium nitride coatings obtained under different reaction gas pressures: a – $3{\cdot}10^{-3}$ Pa; b - $3 \cdot 10^{-2}$ Pa; in - $4{\cdot}10^{-1}$ Pa; g – 1 Pa

The presence of a significant amount of droplet phase on the surface intensifies the destruction process.

An increase in nitrogen pressure ($4{\cdot}10^{-1}$ Pa, 1 Pa) significantly reduces the level of microdistortions of crystal lattices in the coating [8]., in this connection, the fragility of the coating decreases with its high hardness.

The titanium nitride coating obtained at a nitrogen pressure of 1 Pa is the most effective in protecting the working surfaces of mold parts from destruction (Table 4).

According to the technical data, the surface temperature of the substrate in the chamber of the Bulat-3T installation during ion bombardment varied from 300 to 800 °C.

Bombardment has the most favorable effect on the substrate made of 4X5MFS and 5XNM steels at a temperature of 500 °C, which corresponds to the best adhesion of the coating to the substrate and, accordingly, the greatest stability of parts with such a coating during operation.

Thus, the coating significantly reduces the adhesive interaction of steels used as material for press forms with molten brass.

As the coating thickness increases, the substrate should be more reliably protected from external factors due to increased hardness, temperature resistance against oxidation and corrosion. coverage. The thickness of the coverage is a parameter to be optimized in each specific case [8, 9, 10].

). Coatings with a thickness of 2-5 microns have the best adhesion. When the coating is more than 5 microns thick, its scaly peeling occurs (Fig.

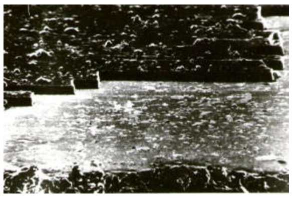

Fig. 4. The initial stage of delamination of a coating with a thickness of 8 μm, ×1000

The conducted studies established that the parts of the molds with a plasma coating applied to their working surfaces have the maximum resistance when the coating settles at a substrate temperature of 500˚C and a nitrogen partial pressure of 1 Pa.

As laboratory tests have shown, the titanium nitride coating applied under optimal technological parameters increases the corrosion resistance of the parts of the molds to which it is applied by 3 times, scale resistance by 2-4 times.

CONCLUSIONS

Summarizing the obtained results, it can be concluded that the maximum stability of parts of molds with plasma coatings is achieved when the working surface is heated during ion bombardment to high temperatures, but not higher than the release temperature of the material of the molds to ensure good adhesion of the coating to the substrate and during subsequent condensation on this heated surface of the coating with a minimum droplet phase content to prevent adhesion of the coating of the casting material.

In the case of applying a titanium nitride coating on the Bulat-3T installation to the working surfaces of parts of molds made of low-alloy steels, the best adhesion of the coating to the substrate, its minimal interaction with molten brass, a significant increase in the thermal endurance of the substrate material is achieved on the road. temperature of 500 C and condensation of the coating at a nitrogen partial pressure of 1 Pa.

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FEATURES DESIGN OF COMPOSITE REINFORCEMENT IN MODERN SOFTWARE

Abstract. The theses compare the design of composite reinforcement in SolidWorks software and Material Desiner with subsequent use in design.

Keywords: Composite materials, matrix, reinforcing fibers, characteristics

Composite materials are increasingly flooding various types of industry. They are made of: wings and fuselages of the aerospace industry; handles and pads in household appliances; in vehicles and equipment. Composites are ideal for applications in corrosive environments, such as chemical processing plants, pulp and paper converting, oil and gas refineries and water treatment facilities. Due to its strong dielectric properties, including arc and track resistance, thermosetting components include substation equipment, microwave antennas, pole line supports and equipment, and printed circuit boards.[1]

Composites consist of a basic material - matrix, and reinforcing fibers (Fig. 1)

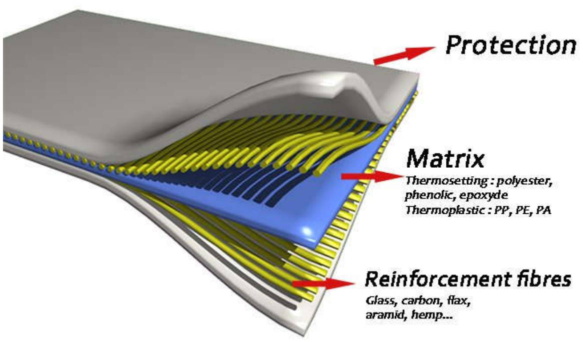

Figure 1.- Composite structure.

Many software products can be used to design composite rebar. In particular, SolidWorks and Material Desiner.

In order to simulate a material in SolidWorks, you need to make a new configuration in the Material tab and select a material based on which the future will be. After that, it is necessary to enter the characteristics of the composite reinforcement (Fig. 2).

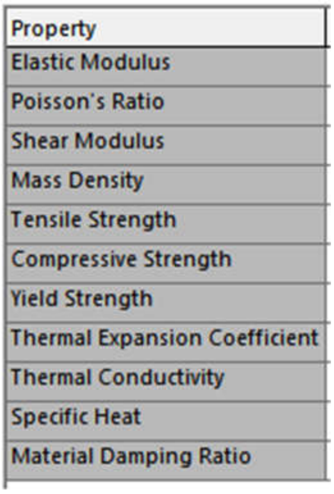

Figure 2. - Material characteristics in SolidWorks.

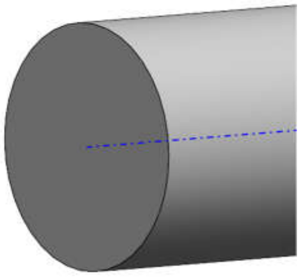

Figure 3. - Apply material to the model.

These characteristics are selected from open sources information. As you can see from Figure 3, the material is applied to the entire model.

To design composite rebar in Material Desiner, select materials from the list of existing materials in the program library (Fig. 4). Materials characteristics are immediately present in the program (Fig. 5).

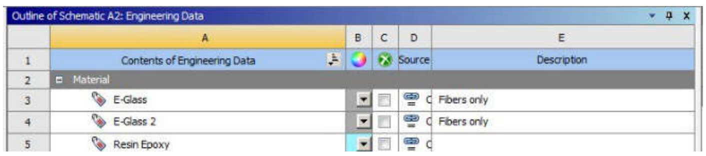

Figure 4. - Materials for composite reinforcement from the library.

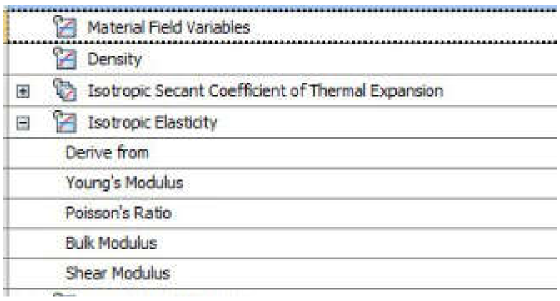

Figure 4. - Materials characteristics in Material Desiner

After that, the type of occurrence of reinforcing fibers in the matrix is selected and the general appearance of the composite is formed (Fig. 6).

Figure 6. - Shape you kind of occurrence of fibers in the composite.

As you can see in Material Desiner, you can see the fibers well and how they disintegrate in the matrix of the composite.

The main differences between the design of composite reinforcement in SolidWorks and Material Desiner:

1. Material selection: SolidWorks - you cannot select multiple materials, Material Desiner - you can.

2. Type of recording characteristics: SolidWorks - you can record the characteristics of the entire composite material at once, Material Desiner - the characteristics correspond to the materials selected for the composite.

3. Display: SolidWorks - does not display different materials, but is used as a single, Material Desiner - showingdifferent materials.

You can use materials designed in SolidWorks in models where you do not need to track how the material behaves inside the composite, but if it is necessary, it is better to use Material Desiner

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AN APPROXIMATE MODEL OF THE DYNAMICS OF AN AIRCRAFT OF TIME-VARYING MASS IN THE PRESENCE OF A MOVING DAMPER AND A COMBINED EXTERNAL LOAD

One of the performance criteria of modern designs of new technology, in particular aircrafts, is the strength associated with dynamic processes in power elements. This especially applies to structures whose mechanical characteristics and external load depend on time and coordinates. Solving the problem of rational design of the specified structures is connected with the need to use modern composite materials and create effective mathematical models based on analytical and numerical methods with the use of modern computer technology, including machine learning (Machine Learning Technology), and approximate analytical approaches. A significant number of publications are devoted to this direction of research on the dynamic characteristics of heterogeneous systems.

This paper discusses an approximate analytical-numerical model of the dynamics of a time-varying mass aircraft in the presence of a moving damper and a bed coefficient dependent on the coordinate, using a hybrid asymptotic approach.

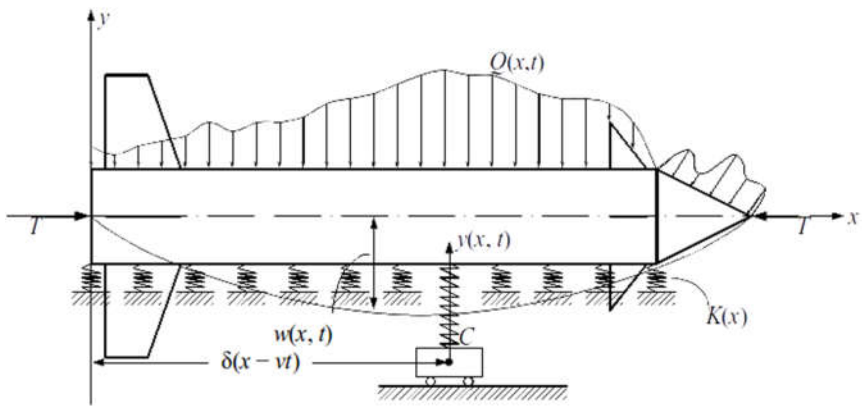


Fig. 1. Scheme of the aircraft and coordinate system

The system of differential equations simulating the oscillations of an aircraft, at a certain point of which a damping system is fixed, is taken in the form:

$$\begin{cases} \dfrac{\partial^4 W}{\partial x^4} + \dfrac{\rho S}{EI}\dfrac{\partial^2 W}{\partial t^2} - \dfrac{T}{EI}\dfrac{\partial^2 W}{\partial x^2} + \dfrac{K}{EI}W - \dfrac{A}{EI}\left(2D\sqrt{cm}\dfrac{dy}{dt} + cy\right)\delta(x - x_1) = \dfrac{Q(x,t)}{EI}, \\ m\left[\dfrac{d^2 y}{dt^2} + \dfrac{\partial^2 W}{\partial t^2}\right]\Bigg|_{x=x_1} + cy + 2D\sqrt{cm}\dfrac{dy}{dt} = 0. \end{cases} \qquad (1)$$

Here $W = W(x,t)$ – the displacement of the beam along the entire axis z, $y = y(t)$ – the displscementt of the damping system, *E*– the modulus of elasticity of the beam material, *I* – the moment of inertia of the cross-section of the beam relative to the axis that passes through the center of gravity, $\rho = \rho(t)$ – the density of the beam material, *S* – the area of the cross-section of the beam, *K(x)* – the coefficient of the elastic base , *T*– the value of the axial force, $Q(x,t)$ – the transverse load distributed along the entire length of the beam, *c* – the stiffness of the spring in the damping system, D– the damping coefficient, *m*– the mass of the damping system.

Entering the notation $\frac{T}{EI} = \overline{T}$, $\frac{K}{EI} = \overline{K}$, $\frac{Q(x,t)}{EI} = \overline{Q}(x,t)$, we obtain a system of equations in the form:

$$\begin{cases} \frac{\partial^4 W}{\partial x^4} + \frac{\rho S}{EI}\frac{\partial^2 W}{\partial t^2} - \overline{T}\frac{\partial^2 W}{\partial x^2} + \overline{K}W - \frac{A}{EI}\left(2D\sqrt{cm}\frac{dy}{dt} + cy\right)\delta(x - x_1) = \overline{Q}(x,t), \\ m\left[\frac{d^2 y}{dt^2} + \frac{\partial^2 W}{\partial t^2}\right]_{x=x_1} + cy + 2D\sqrt{cm}\frac{dy}{dt} = 0. \end{cases} \tag{2}$$

Using dimensionless coordinates

$$\xi = \frac{x}{l},\ \xi_1 = \frac{x_1}{l},\ \hat{A} = \frac{l^4 A}{EI} \tag{3}$$

and multiplying both parts of the first equation by l^4, and the second – $\hat{A}$ by , taking into account

$$a^2(t) = \frac{\rho(t) S l^4}{EI},\ \hat{T} = \overline{T} l^2,\ \hat{K} = \overline{K} l^4,\ \hat{Q}(\xi,t) = \overline{Q}(\xi,t) l^4 \tag{4}$$

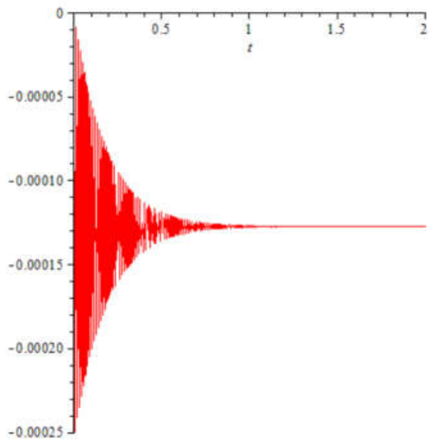
$$C_1 = 2\hat{A}\sqrt{cm},\ C_2 = \hat{A}c\ \ \hat{m} = m\hat{A} \tag{5}$$

the initial system of equations is obtained in the form:

$$\begin{cases} \frac{\partial^4 W}{\partial \xi^4} + a^2(t)\frac{\partial^2 W}{\partial t^2} - \hat{T}\frac{\partial^2 W}{\partial \xi^2} + \hat{K}W - \left(C_1 D\frac{dy}{dt} + C_2 y\right)\delta(\xi - \xi_1) = \hat{Q}(\xi,t), \\ \hat{m}(i)\left[\frac{d^2 y}{dt^2} + \frac{\partial^2 W}{\partial t^2}\right]_{\xi=\xi_1} + C_2 y + DC_1\frac{dy}{dt} = 0. \end{cases} \tag{6}$$

System (6) is a system of inhomogeneous differential equations with time-varying and coordinate-varying coefficients, as well as a Dirac function (which describes the presence of a localized damper), the exact analytical solution of which can be obtained only for individual random ones. Therefore, to obtain an approximate analytical solution, it is proposed to use the Fourier method with the method of phase integrals with the possibility of further refinement of the solution using a hybrid approach, including the principle of orthogonalization according to Galiorkin.

Some characteristic results of the numerical analysis of dynamic characteristics are given in Fig. 2 for specific values of the parameters for the studied system



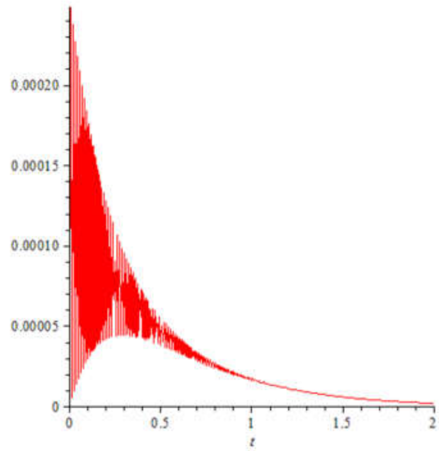


Fig. 2 The nature of the dynamic process according to various parameters of the system and the damping coefficient

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PROSPECTIVE WAYS OF OBTAINING HIGH-STRENGTH SHEET METAL FROM ECONOMICALLY ALLOYED STEELS

Abstract. Rolled sheet makes up almost half of the total amount of rolled products produced at metallurgical plants, and the need for it is constantly growing. With the modern development of technology, the requirements for thick rolled steel are increasing, it must combine high strength and plasticity, withstand dynamic loads, have high wear resistance, cold resistance and corrosion resistance, etc. Specific requirements for a thick sheet depend on its further use.

Key words: rolled sheet, finely dispersed bainite ferrite, low-alloy steel, mechanical properties

The main way of improving the service properties of thick rolled steel for the manufacture of metal products of responsible purpose (including special products) is the creation of high-strength steels that have higher strength characteristics, while maintaining a sufficient level of plasticity and viscosity compared to existing mass-produced steels. Research aimed at the development of technological principles for obtaining high-strength sheet metal from low-alloy steel for the manufacture of metal products of responsible purpose is relevant.

On the basis of analytical studies, it was established that the formation of a structure of finely dispersed bainite ferrite without the release of cementite-type carbides in combination with stable residual austenite is a promising direction for obtaining a high complex strength and toughness of structural steels [1-3]. The formation of such a structure is achieved due to the complex alloying of steel with certain chemical elements, which make it possible to almost completely suppress the processes of carbide formation in bainite ferrite (silicon, aluminum, cobalt, nickel) [2,4,5], and/or appropriate heat treatment.

Thus, the prospects of obtaining high-strength sheet metal from low-alloy steel for the manufacture of metal products of responsible purpose are related to the development of technological principles for obtaining highly dispersed carbide-free bainite.

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ADHESION OF NOMEX COATINGS TO METAL SUBSTRATES

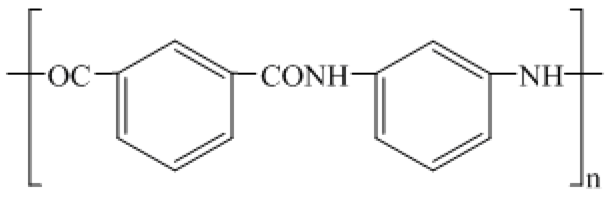
Abstract. The adhesive properties of wear-resistant Nomex coatings to substrates of ferrous and non-ferrous metal materials which are the most common in mechanical engineering were investigated experimentally. The results of measurements of adhesive characteristics taken with the help of such methods as a cross cutting test, a quantitative peel test are discussed in terms of the three most common mechanisms of adhesion: mechanical coupling, molecular bonding, and thermodynamic adhesion.

Keywords: Nomex, Aromatic polyamides, Coatings, Adhesion.

Aromatic polyamides are characterized by high strength and heat resistance, while filling them with traditional solid lubricants (fluoroplastic, graphite, etc.) high anti-friction performance can be achieved.

Perspective representatives of aromatic polyamides are poly (m-phenylene isophtalamide), commonly known as Nomex, and copolymers based on it [1].

Nomex is a linear heterochain polymer whose macromolecules are constructed from aromatic fragments linked by amide bonds (Scheme 1). Nomex is obtained by polycondensation of m-phenylenediamine and isophthalic acid dichloride in emulsion or solution. The molecular weight of the finished Nomex is 20000-120000.



Nomex

Scheme 1

According to the complex of physical and mechanical properties Nomex exceeds the majority of industrial plastics. It is characterized by a high glass transition temperature (270ºC), crystallization temperature (340-360ºC) and melting point (430ºC). Materials based on it combine high heat resistance, frost resistance, strength, stiffness, good ductility, resistance to shock loads, high fatigue strength, stability of dielectric characteristics, high radiation and chemical resistance, high enough (up to 260ºC) temperature of long operation [2].

However, it should be mentioned that along with high rates of tribotechnical properties like other aromatic polyamides Nomex has low adhesion to metals which makes it difficult to obtain high quality coatings.

Therefore, the aim of this work is the detailed experimental study of the adhesive properties of Nomex coatings to various metal materials and identifying the features of interaction of Nomex with the surface of the substrate.

100 μm thick polymer coating was obtained by applying 15-20% Nomex solution to the surface of the metal substrate followed by evaporation of the solvent by means of drying. N, N-dimethylformamide (DMF) was used as a solvent. Drying of the samples was carried out in a drying oven at the temperature of 140-150ºC during 1 h.

Underfeature of the substrate surface was obtained by means of abrasive grinding. Grinding wheels were used as abrasive which provided a surface with the same roughness parameters (Ra 1.4-1.5) for all types of substrates. Before applying the coating the surface of the substrate was cleaned and degreased.

The primary determination of the level of the coating adhesion to the substrate was performed by means of lattice cuts according.

Quantitative evaluation of adhesive properties of coatings was carried out with the help of a peel test.

Testing of coatings on substrates of the most common in mechanical engineering ferrous and non-ferrous metal materials by the method of lattice cuts showed 2 points for samples with a copper substrate and 4 points for all other investigated material substrates.

A relative low mark of adhesion strength can be explained by absence of functional groups in Nomex compound that contribute to the formation of strong chemical bonds between the metal surface and polymer coating.

The research results showed an abnormally high strength of adhesive joint of the Nomex coating with a copper substrate.

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INFLUENCE OF CHANGES IN MECHANICAL PROPERTIES OF ELASTOMERIC SHELL MATERIAL ON A STRESS STATE OF A COMPOSITE TRACTIVE ELEMENT WITH LOCAL STRUCTURAL CHANGES

Abstract. An algorithm for determining a stress state of a composite tractive element with broken structure and a deformation-dependent shear modulus is established by analytically solving a model of a composite tractive element. A character of dependency for a stress state of a composite tractive element on a nonlinear dependency of shear modulus on deformations is determined. A possibility to determine the dependency of a stress state of a composite elastomer-cable tractive element on a nonlinear shear modulus allows considering the effect of this phenomenon on the tractive element strength and ensures an increase of its operational safety.

Keywords: lifting and transporting complex, cable-stayed bridge, composite tractive element, damaged structure, elastomeric shell, stress state, analytical solution.

Main content of paper. Determining a stress-strain state considering the specified character of deformation changes and considering the nonlinear dependency of shear displacements on rubber shear stresses is a complex mathematical problem. Let's simplify it. Assume that the dependency of rubber shear stresses on its deformations is piecewise linear and consists of two parts. As in the studies mentioned above, we assume that the cables deform like rods. Rubber is subjected only to shear stress. The composite tractive element (rope) is infinitely long. It has M cables and is loaded with a tensile force P. The cable numbered j has a continuity breakage. The cross-section with the breakage is at a considerable distance from the rope edges. Rubber shear modulus of layers adjacent to the damaged cable at lengths l_0 is different from the corresponding rubber shear modulus of the remaining layers. The linear size l_0 is much smaller than the rope length, on which the stress state is changed because of a cable breaking. Direct the coordinate axis along the rope. Its beginning ($x = 0$) is located at the point where the cable breaks. Since the cross-section ($x = 0$) is a cross-section of symmetry, the displacements of cables are symmetrical. At the same time, the cross-sections of all cables except the ends of the broken cable do not move. A gap is formed between the ends of the damaged cable. Let's denote the displacement of the end of the damaged cable U_0.

Let's single out a part of length $l_0 \left(0 \le x \le l_0\right)$. Consider it the first one. Consider the part for which $\left(x > l_0\right)$ the second part. The first part of the rope is divided into three stripes with an unchanged number of cables in each. Include stripes that do not have a broken cable into the structure of the two extreme stripes. Give them numbers one and three. The rope part with the broken cable and the cables adjacent to it will be included in the structure of the second stripe (Fig.1).

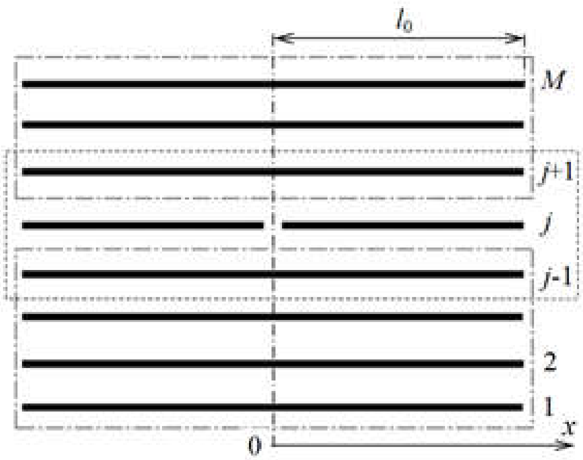

Fig. 1. Rope part with a broken cable

Consider the specified stripes as separate belts. A characteristic feature of such rope stripes is that the properties of elastic material between the rope stripes do not change. Shear modulus of rubber in layers between cables is not variable in our case. This allows using the conditions of their equilibrium and the form of solutions for stripes [1-3], considering the number of cables in stripes and properties of elastic shell. Let's make expressions that allow determining the internal forces in cables and their displacements. Write down the expressions for the extreme stripes in similar forms. In the expressions, we will use additional indices to assign the parameters to one or another rope stripe. Take into account that cross-sections of cables of the extreme stripes do not move when ($x = 0$).

For a rope stripe with cable numbers $\left(1 \le i \le j-1\right)$

$$p_{1,i} = EF\sum_{m=1}^{j-2} A_m\left(e^{\beta_{1,m}x} + e^{-\beta_{1,m}x}\right)\beta_{1,m}\cos\left(\mu_{1,m}(i-0.5)\right) + P, \quad (1)$$

$$u_{1,i} = \sum_{m=1}^{j-2} A_m\left(e^{\beta_{1,m}x} - e^{-\beta_{1,m}x}\right)\cos\left(\mu_{1,m}(i-0.5)\right) + \frac{Px}{EF}, \quad (2)$$

where i is cable number in the first stripe $(1 \le i \le j-2)$; A_m, B_m are integration constants; E, F are, respectively, reduced tensile modulus of elasticity and cross-sectional area of a cable in a rope (belt); $\beta_{1,m} = \sqrt{\frac{2G_0 b}{(h-d)EF}[1-\cos(\mu_{1,m})]}$; h is distance between the cables; b is rope thickness; d is cable diameter; G is shear modulus of elastic (rubber) layer connecting the cables.

For the second rope stripe with cable numbers $(j-1 \le i \le j+1)$

$$p_{2,i} = EF\sum_{m=1}^{2}\left[\left(A_{m+j-2}e^{\beta_{2,m}x} - B_{m+j-2}e^{-\beta_{2,m}x}\right)\beta_{2,m}\cos\left(\mu_{2,m}(i-j-1.5)\right)\right] + P, \quad (3)$$

$$u_{2,i} = \sum_{m=1}^{2}\left(A_{m+j-2}e^{\beta_{2,m}x} + B_{m+j-2}e^{-\beta_{2,m}x}\right)\cos\left(\mu_{2,m}(i-j-1.5)\right) + \frac{Px}{EF}, \quad (4)$$

where $\mu_{2,m} = \frac{\pi m}{3}$; $\beta_{2,m} = \sqrt{\frac{2G_0 bk}{(h-d)EF}[1-\cos(\mu_{2,m})]}$; k is coefficient, which considers the difference in shear modulus of rubber for the second stripe.

For a rope stripe with cable numbers $(j+1 \le i < M)$

$$p_{3,i} = E\ F\sum_{m=1}^{M-j-1} A_{m+j}\left(e^{\beta_{3,m}x} + e^{-\beta_{3,m}x}\right)\beta_{3,m}\cos\left(\mu_{3,m}(i-j-1.5)\right) + P, \quad (5)$$

$$u_{3,i} = \sum_{m=1}^{M-j-1} A_{m+j}\left(e^{\beta_{3,m}x} - e^{-\beta_{3,m}x}\right)\cos\left(\mu_{3,m}(i-j-1.5)\right) + \frac{Px}{EF}, \quad (6)$$

where $\mu_{3,m} = \frac{\pi m}{M-j}$; $\beta_{3,m} = \sqrt{\frac{2G_0 f(t) bk_G}{(h-d)EF}[1-\cos(\mu_{3,m})]}$.

These solutions correspond to the conditions of influence absence of external factors on extreme cables in stripes on the interval $(0 \le x \le l_0)$. The cables adjacent to the broken one are included in two stripes – the extreme one and non-extreme one. In the extreme stripes, there are no disturbances in cables adjacent to the broken one, in accordance with solutions of

(1), (2) and (5), (6). They are loaded with only evenly distributed forces. Cables in the cross-section $x = 0$ are immovably fixed. In a general solution, based on the principle of superposition, we add their displacements as cables, which are part of the middle stripe, to displacements of these cables without considering the force of their external load.

The analytical solution of obtained equations (1-6) allows determining the unknown constants and internal loading forces of cables, and their displacements. The known displacements make it possible to determine tangential stresses in material of the elastic shell located between the cables, which are directly proportional to the tangent of its shear angle.

Stress-strain state indicators are determined for a rope type RCB-3150 consisting of six cables. The sixth of them is broken. The area length l_0 is assumed equal to 0.1 m. Coefficient of change of shear modulus is 0.5. The results of calculations are given below. Figure 2 shows the dependency of a ratio of internal loads in cables to the average load (coefficients of uneven distribution of forces among the cables) along the x-axis. Figure 3 shows the tangents of shear angles of elastic shell between cables with numbers i along the x-axis, relative to its average value.

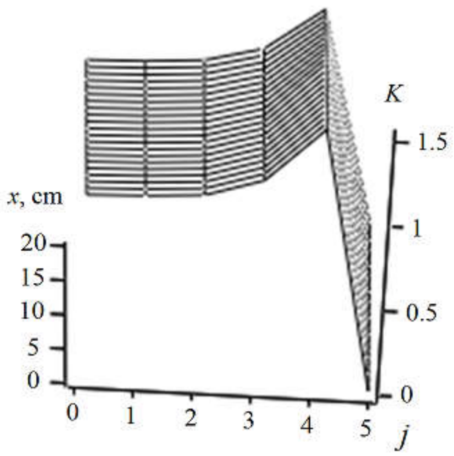

Fig. 2. Dependency of coefficients of uneven distribution of forces among cables with numbers i along the x-axis

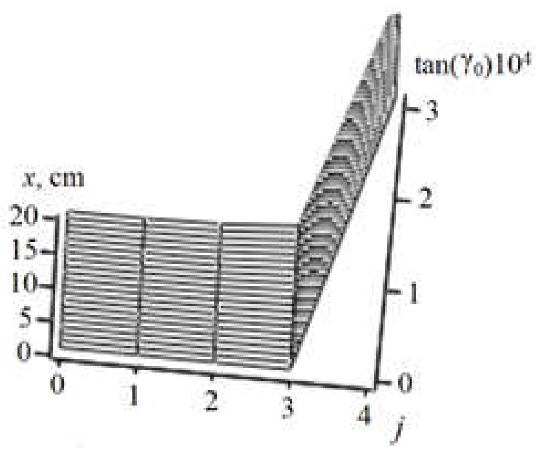

Fig. 3. Dependency of tangents of shear angles of elastic shell between cables with numbers j along the x-axis relative to its average value

Conclusion. By analytically solving a model of a rubber-cable tractive element with a broken structure and nonlinear deformation-dependent rubber shear modulus, the dependencies of changes in a stress state of a rubber-cable tractive element with a broken structure in a form of a cable breakage are established.

In a process of solving the model, an algorithm for determining a stress state of a rubber-cable tractive element with a broken structure is formulated. A mechanism for changing a stress state of a rubber-cable rope is established, considering the nonlinear deformation-dependent shear modulus of rubber.

It is established that an increase in area of action of the reduced shear modulus leads to an increase in the maximum value of a coefficient of uneven distribution of forces between the cables. With infinite growth of area of lower rigidity of rubber layers connecting the broken cable with the adjacent cables, the coefficient of uneven distribution of forces infinitely approaches the corresponding coefficient determined without considering the nonlinear law of the dependency of shear modulus on deformations.

Considering the nonlinear deformation-dependent shear modulus of rubber provides an opportunity to specify the prediction of a rope stress state with a continuity breakage of cables, increase safety and operational reliability of rubber-cable tractive elements.

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STUDY OF STRUCTURE FORMATION OF DEFORMED MAGNESIUM ALLOY MA2-1M WITH DIFFERENT METHODS OF WELDING

The development of solid-phase welding technologies for thin magnesium alloys is an actual task. The experience of obtaining high-quality butt-welded joints from sheets of magnesium alloy 2 mm thick at a constant cylindrical tool rotation frequency of 1420 rpm and various linear welding speeds - 8 m/h, 16 m/h, and 25 m/h is described. The macro- and microstructure of welds, physical and mechanical properties are studied, and it is shown that in the area under the nugget, a local zone with fine grains and a 2-3 times increased hardness and Young's modulus is formed. The TMAZ on the retreating side of the metal flow has a very contrasting plastically deformed texture. Hardening forms as a result of a few thermodynamic processes. This is due to the double pressing from above by the tool to the lower support and the rigid reaction of the lower support, and the plastic flow of the metal at a temperature close to the melting temperature of the magnesium alloy, at which the HAZ recrystallizes. An optimal union of Mg-alloy hardness and thickness and FSW pin geometry in the experiment allowed for obtaining satisfying joints.

Key words: magnesium alloys, friction stir welding, butt joint, microhardness, Young'smodulus, TMAZ, intensive plastic deformation

The development of modern industry cannot be imagined without the use of new structural materials, and above all magnesium alloys. Magnesium and its alloys as structural materials have a unique complex of mechanical, physical and operational properties, which allows them to be used in advanced branches of modern production - aviation, space industry, power engineering, military industry, medicine. Magnesium has a high specific strength, high stiffness and damping characteristics, absolute biological compatibility, therefore it is included in the top ten rating of innovative materials of the future for use in elements of car structures, sports equipment, microelectronics and in surgical implantation [1]. The strength-to-weight ratio of magnesium alloy parts makes them one of many important materials that will replace aluminum [2], [3] and be used in the coming years in the automotive industry to reduce inertial forces and improve performance, handling and fuel economy [4].

In 2020, China proposed global "carbon neutrality" strategies that caught the world's attention, and the widespread use of magnesium and magnesium alloys was identified as one of the best solutions to achieve this goal. However, magnesium alloys still occupy only a small market share compared to aluminum alloys, despite the fact that magnesium, as the seventh most abundant element on earth, can be used in sufficient quantities.

In the aspect of magnesium alloy welding technology, many scientific studies describe the experience of using environmentally friendly and energy-efficient technology - friction stir welding (FSW), which is used for solid-phase joining of parts with a relatively simple geometry. The experience of using the FSW friction stir welding method is considered to be quite successful, since it allows you to avoid melting of the material, its overheating during the welding process, surface deformation and grain coarsening when joining light and ductile magnesium alloys. Therefore, it is of particular scientific interest to study the processes of structure formation and deformation during STP welding in the form of the "slander" effect, in which intense plastic deformation occurs in the HAZ metal by twisting and double pressing of this zone, both from the top of the tool to the bottom support of the tool, and a rigid-elastic reaction lower support equipment.

Therefore, the aim of the research was to try to obtain welded joints from thin plate (3 mm) structural magnesium alloy MA2-1M using different welding methods (diffusion, argon arc and friction stir welding). Also, the task of the research was to determine the thermodynamic mechanisms that act in a complex manner in the HAZ and TMAZ zones during intense plastic deformation of magnesium alloys during welding and form the high-quality and finely dispersed metal structure of the welded joint zone.

The work investigated welded joints of magnesium alloy MA2-1M (AZ31 type), which were performed by various methods of welding in the solid phase (diffusion welding, friction stir welding) and reflow (argon arc welding with a non-fusible tungsten electrode). The research used light (NEOPHOT) and scanning (JSM-840, JAMP 9500F) microscopy methods, micro-X-ray spectral analysis (INCA Energy 350), diffraction (RIGAKU Ultima-IV) analysis methods, nanoindentation methods (microprobe system "Micron-gamma "). The advantages of using the methods of welding MA2-1M magnesium alloy in the solid phase compared to reflow welding have been established, which is associated with the preservation of dispersion-strengthening phases, the absence of structural and chemical heterogeneity, the absence of pores.

For diffusion welding (DW) of MA2-1M magnesium alloy, it was established that the optimal welding temperature is 400...460 ºC, and the holding time should be longer and be 20...30 minutes. At the same time, common grains with a size of 30...60 μm are considered to be formed in the diffusion joint zone, and most of the dispersion-strengthening phases Al11Mn4 (475ºC), Al3Fe(570ºC), Mg2Si (560ºC), Al5Fe2 (610ºC) remain undissolved in the process of diffusion welding. However, the strength of such a connection was not sufficient. In this regard, welding was carried out using intermediate layers (foils) of various metals (Cu, Ni, Ti, Zn) with a thickness of 20...50 microns. The results of metallographic studies showed that when Zn foil is used during diffusion welding of MA2-1M magnesium alloy, a high-quality joint without delamination and cracks is formed at the boundary.

For friction stir welding (FSW) of MA2-1M magnesium alloy, it was determined that the optimal welding speed is in the range of 8...24 cm/s at a pin tool rotation speed of 2000 rpm. The study of the microstructure of welded joints showed a non-uniform distribution of structural components, the formation of elongated ribbons from dispersed phases, the formation of small (1...5 microns) thick grains. Using the nanoindentation method, the inhomogeneity of the hardness distribution was established both along the grain body and in different parts of the welded joint. It was established that the magnesium alloy material is more ductile and the modulus of elasticity is lower in the area of the pin-tool approach than in the area of the tool's departure. At the same time, it was established that microcracks appear in the area of the tool's departure in some welding modes (movement speed greater than 24 cm/s or rotation speed greater than 2500 rpm). In order to determine the causes of the formation of microcracks, a computer simulation of the thermal deformation state of the MA2-1M magnesium alloy during friction stir welding was carried out. The simulation results confirmed the inhomogeneity of the distribution of the elastic-deformed state of welded joints, and determined that the appearance of microcracks is associated with a decrease in the plasticity of the metal in the pin-tool departure zone due to a decrease in the temperature during welding and inhibition of plasticity by clusters of dispersed phases.

For argon-arc welding with a non-fusible electrode (GTAW) of the MA2-1M magnesium alloy, it was shown that, in contrast to STP welding, which ensures the formation of a joint with a minimum level of stress concentration in the places of transition from the seam to the base material, during argon-arc welding due to the action of the processes due to the melting and subsequent crystallization of the metal, a coarse dendritic structure is formed in the seams, as well as defects in the form of pores, microinclusions, and oxide films. These defects significantly reduce the mechanical properties of magnesium alloy welded joints.

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SPECIAL BORDERS AND MULTIPLE JOINTS IN HYPOEUTECTOID FERRITE

Abstract. The In recent decades, methods for describing atomic structure based on the concept of coinciding site lattices, which allows one to evaluate the properties and behavior of high-angle boundaries in various polycrystalline materials, have become increasingly widespread. Experimentally, by direct and indirect methods, it was shown that boundaries exhibiting special properties low surface energy, weak linear tension, low mobility at high temperatures, and others can be classified as special. The structure and properties of special boundaries are considered from the perspective of the coincidence site lattice (CSL) theory and their prevalence in various materials. The existence of special boundaries has also been shown, for example, in gold [1], copper [2], nickel-based alloys [3], aluminum and its alloys [4] and other materials. The experimental results of studies of the structure and properties of special boundaries described in the literature were obtained mainly on ultrapure, rare, less common, or model metals and alloys. Such data regarding industrial materials of wide application are very limited, which makes it difficult to practically use knowledge about special grain boundaries in the development of promising industrial technologies for the production of metal products with the required high range of properties.

Keywords: special borders, multiple joints, hypoeutectoid ferrite.

The In works, the existence of special boundaries with an inverse density of coinciding site lattice $\Sigma = 3^n$ was established for the first time, as well as special structural elements: multiple joints and multiple site lattice in austenitic chromium-nickel stainless steels 03H18N11 and 08H18N10T of industrial production. It has also been shown that low-energy boundaries are formed not only in FCC materials with low stacking fault energy, but also in martensitic and bainitic structures of low-carbon steels, that is, in materials with a bcc lattice. The emergence of special misorientations that ensure the formation of CSL is in this case due to the nucleation and growth of martensite laths in accordance with the Kurdyumov-Sachs orientation relationship [6]. This scheme of formation of slats in a package leads to the emergence of regular orientations between them, corresponding in terms of CSL to special boundaries with an inverse density of coinciding site lattice $\Sigma = 9$, 11, 33 and 129 [5].

There is practically no information about the existence of special boundaries in the bcc iron lattice, although in work [7], devoted to the separation of carbides along grain boundaries in cold-deformed and then annealed alloys Fe-7%Ni, Fe-1%V, Fe-5% Mo, three boundaries were found close to Σ=3 (2° from it) and 3 boundaries close to Σ=11 and Σ=9. The relatively small number of special boundaries in unalloyed α-iron, as well as aluminum, chromium and some other materials is explained by the high values of the energy of their stacking faults and the relatively high specific surface energy of high-angle grain boundaries.

There is no data in the literature on the existence of special boundaries in hypoeutectoid ferrite of low-carbon steels, which are subject to isothermal decomposition of austenite in the diffusion region. At the same time, the available information that during the diffusion nucleation and growth of nuclei with a bcc lattice from a high-temperature FCC phase in a nickel–chromium alloy, the Kurdyumov–Sachs orientation relationship is observed [6], gives reason to believe that in In the ferrite of low-carbon low-alloy steels, in which the FCC–BCC polymorphic transformation also occurs via a diffusion mechanism, there are special boundaries. In this work, the grain boundary structure of the ferrite component of widely used low-pearlite steels in the state after hot rolling and normalization rolling (steel 12GF and steel type 06X1) and after normalization with separate heating (St3) was studied using light microscopy - in order to find low-energy boundaries in the ferrite component of the structure .To detect special boundaries in ferrite, it is recommended to adhere to the following basic identification features, which indicate a special structure and reduced surface energy of the boundary:

– the presence of facets at obtuse angles always indicates that the boundary has orientation sensitivity, that is, a torque, and, therefore, is classified as special;

– the presence of facets at right or acute angles always indicates that the boundary belongs to Σ=3, that is, to the boundaries of annealing twins. If facets can be divided into 2…3 groups with the same direction and a similar degree of etching, then the likelihood that such a boundary is special increases sharply;

– if two segments of the boundary are parallel to each other and limit a relatively narrow layer, and their contacts at two joints have opposite angles equal to almost 180°, then such a boundary belongs to the Σ=3 type, forming a “hanging” annealing twin;

– the boundary can be classified as low-energy, type Σ=3, if in one of the triple junctions the angle opposite to it is close to 180°; this sign is additional, but insufficient;

– if one or both ends of the boundary enter quadruple junctions containing one or more boundaries belonging to the Σ=3 type;

– if the boundary at one end enters a quadruple or quintuple junction, and the other end into a triple junction with the formation of an opposite angle close to 180°, then it belongs to the Σ=3 type.

– if the boundary contains facets or groups of facets, and at one of its triple junctions the angle is close to 180°, then it belongs to the Σ=3 type.

Taking into account these rules, the relative number of special boundaries in the ferrite component of the ferrite-pearlite structure in hot-deformed pipes made of 06H1 steel was calculated and the ratio of special boundaries to the total number of boundaries nspecial/ntotal = 0.08 was obtained.

The decisive influence of special low-energy boundaries in 03H18N11 steel on the resistance to intergranular corrosion (corrosion resistance of grain boundaries and their contribution to the corrosion rate) in highly oxidizing environments was shown. It can be assumed that the seemingly small value of the specific surface of special boundaries (0.08) can also, under the influence of external technological factors, change within significant limits and have a significant impact on the structure and properties of ferritic and low-pearlite steels.

CONCLUSIONS

1. For the first time, the presence of special low-energy boundaries in the ferrite component of low-pearlite steels 12GF, 06X1 and St3 was established - based on studies of their grain boundary structure using light microscopy methods.

2. Typical ensembles with the participation of special low-energy boundaries in the ferrite component of low-carbon low-alloy ferrite-pearlite steels are demonstrated and interpreted.

3. The main identification features are considered that indicate (when examined in a light microscope) that one or another high-angle boundary in ferrite belongs to special ones in the CSL concept, which have a reduced surface energy.

4. For the first time, the relative number of special boundaries in the ferrite component of the structure of hot-deformed pipes made of steel 06H1 was assessed and the ratio of special boundaries to the total number nspecial/ntotal = 0.08 was obtained.

5. Taking into account the results of previously conducted studies of the structure and properties of special boundaries in austenitic stainless steels, it is noted that when developing new technological processes, a promising opportunity opens up to control the structure and properties of metal products from ferrite-pearlite steels by regulating the number of special low-energy boundaries in their structure.

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ASSESSMENT OF THE POSSIBILITY OF REDUCING MATERIAL COSTS IN THE MANUFACTURE OF ENCLOSED GEAR CASINGS

Abstract. The paper presents a method for solving the urgent problem – optimizing metal consumption when producing enclosed gear casings, which find significant applications in the machine-building industry.

It is demonstrated that the reducer housings have low-loaded areas and sizes of their features, such as wall thickness and tails flanges, which determine rigidity, rather than strength, which is required to ensure the functionality of gear engagements, bearings, etc.

Unloaded sections of the housing are proposed to be made of minimal thickness, while the necessary rigidity is ensured by using high-strength cast irons (bainitic, vermicular). Modern casting methods provide the possibility of creating quite complex cast walls of parts with a thickness of up to 3 mm.

Keywords: enclosed gear casings, high-strength cast irons, reducer gear wall thickness, reducer gear housing mass.

At the present stage of intensive development of public production, efficient metal consumption becomes of paramount importance [1]. Optimization of machine metal content as well as increasing the efficiency of metal usage is an urgent issue.

In the machine-building industry, various types of mechanical transmissions have found significant application. The most common ones are gear transmissions (cylindrical, bevel, worm gears), which are structurally implemented in the form of a reducer.

A significant part of the reducer weight (60-80%) is attributed to its housing. Reducing the weight of the housing can lead to substantial efficiency of metal application.

Cast iron housings are the most commonly used. They are typically made from flake graphite cast iron of СЧ grades (grey cast iron).

In [2], it is shown that the housings of reducers have low-loaded areas, and the sizes of their features (wall thickness, tails flanges, etc.) are determined by rigidity rather than strength. The rigidity is necessary to ensure the proper functioning of the kinematic pairs of the reducer, such as gear-tooth systems, bearing parts, etc.

Unloaded sections of the housing can be made of minimal thickness, while the necessary rigidity can be achieved by using high-strength cast irons (bainitic, vermicular).

Modern casting methods make it possible to create component walls with a thickness of up to 3 mm [3]. Fig. 1 depicts a complex cast part with a wall thickness ranging from 3 to 3.5 mm.

Fig. 1. Cast section of a household heating radiator

From the economic perspective, high-strength cast iron costs about 30% more than flake graphite cast iron; however, due to the reduction in the required weight by approximately 30%, it is possible to obtain a housing at the same cost, saving a certain amount of material.

High-strength cast irons are cast irons in which carbon is significantly or entirely in a free state in a compact form resembling spheres (spheroidal graphite). The structure of such cast iron is depicted in Fig. 2.

To increase the strength of cast iron, small additives of alkaline or alkaline earth metals are introduced, with magnesium being the most common choice at concentrations of 0.03% to 0.07%. When treating the molten mass, magnesium vapour contributes to the crystallization of graphite in the form of spheres, resulting in nodular cast iron. Nodular graphite inclusions have minimal interface area with the metal matrix and are not as strong stress concentrators as graphite inclusions in the form of large or small flakes. This, along with the fact that magnesium, by dissolving in the grains and at their boundaries, alters the metal as an alloying element, results in an increasing strength of cast iron, which is why it is referred to as high-strength cast iron.

Usually, when designing the housings of gear reducers, the thickness of their walls is determined using empirical formulas. For example, in [4], the following formula is used to calculate the housing of a single-stage cylindrical gear reducer:

$$\delta = 1{,}3\sqrt[4]{0{,}01T_{2p}^{*}} \geq 6 .$$

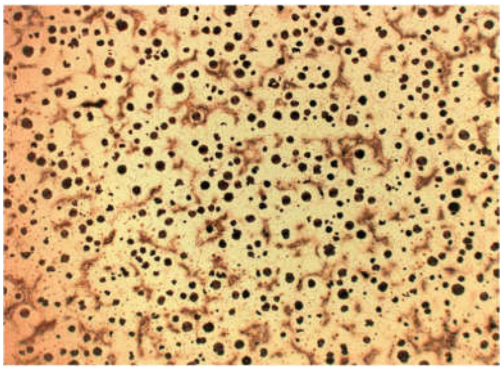

Fig. 2. Structure of nodular graphite cast iron

In this formula, δ is the wall thickness, mm; T_{2p} is the design torque on the output shaft, N·mm. It is important to note that the minimum thickness should not be less than 6 mm.

Previously, the author calculated several single-stage gear reducers of different power ratings. The wall thicknesses of the housings determined for these gear reducers are presented in Table 1.

Wall thicknesses of the cast iron housings of gear reducers

Table 1.

P_{eng}, kW	2.2	2.2	5.5	11	30
T_2, Nm	55	95	150	400	800
δ, mm	6.3	7.2	8.1	10.3	12.3

It is easy to see that reducing the thickness of non-loaded sections of housings to 3-4 mm can have a positive effect. An example of such a 3D model of a 30 kW power reducer housing is shown in Fig. 3.

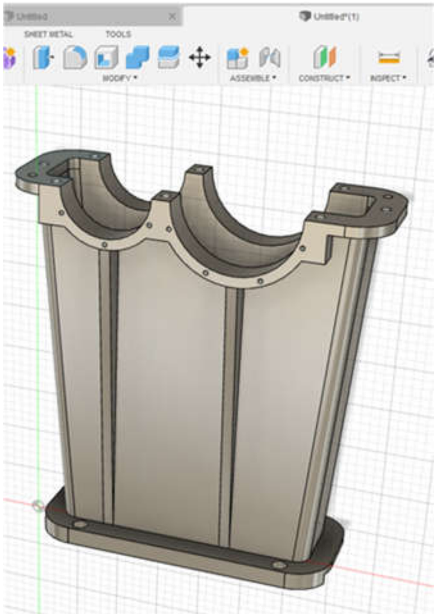

Fig. 3. A 3D model of a reducer housing with 3 mm thick walls.

The initial mass of the gear reducer housing (with 8mm thick walls) was 25.9 kg, and after the new design had been implemented (with 3mm thick walls), it became 21.2 kg. Therefore, the mass reduction amounted to 18.1%.

For higher-power gear reducers, material savings can reach 30% or even more.

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PROPERTIES OF POLYPROPYLENE COMPOSITES FILLED WITH LIGNIN

Abstract. The composites based on a polymer matrix and a natural (renewable) filler can be one of the alternatives to widely used polymers. One of the problems of using natural fillers is their low compatibility with hydrophobic polymer matrices. In order to improve the adhesion between the hydrophilic fibers and the hydrophobic matrix the fillers are usually treated with compatibilizing agents. Compo-sites made by injection molding based on polypropylene and Kraft-lignin, micro-cellulose from hemp waste with filling from 9 to 27 wt % were investigated in the work. To improve the adhesion between the matrix and the polymer, a special chemical treatment of the components was used with the addition of talc as a compatibilizing agent.

Keywords: Hybrid composites, Kraft-lignin, Microcellulose, Polypropylene, Flexural strength, Tensile strength.

Approximately 100 billion tons of lignin are produced per year [1] by the pulp and paper industry and emerging cellulosic biorefineries, with 98% being burned for energy or simply dumped in landfills, posing a major disposal issue [2].

Among the various plant fibers as reinforcing materials lignocelluloses' materials (containing cellulose, hemicellulose, and lignin) and cellulose fibers are most often used. These materials can be obtained from many sources, such as sawdust, cotton, technical hemp, recycled corrugated cardboard, sugar cane, [3] and others. Unfortunately, such raw materials are not always available organizationally, economically and technically. For example, [4], the decomposition of lignin into simpler chemical compounds (phenol, benzene, etc.) is more expensive than their synthesis from oil or gas, compared to the quality of the products obtained. By 2050, the plastics industry may need 20% of crude oil supplies to support plastics production if the trend continues [5].

The potential of lignin is also shown by the continuously increasing number of papers published on the characterization, modification and possible application of lignin. Several review papers were published on lignin blends in the last three decades [9-11] listing numerous combinations of lignin with polymers.

Homogenization and compatibility are important when a larger amount of lignin is added to the polymer to modify mechanical properties [12]. A wide variety of effects were observed on different properties as a result of blending with lignin. Modulus usually increases, because of the stiffness of lignin molecules [13], but strength and deformability often decreases [14]. The conclusions drawn from these results about compatibility are also quite diverse. As mentioned above, Kosikova et al. [16] found good compatibility between organosolv and prehydrolysis lignin and PP, while Jeong et al. [9] claimed outright complete miscibility with several polymers including LDPE and PP. Unfortunately, these claims are rarely supported by real experimental evi-dence and reflect mainly the hopes and belief of the authors.

The following materials were used for the formation samples of composites: virgin polypropylene granule TIPPLEN H 681f, Kraft lignin, cellulose fibers obtained from the technical hemp (see Fig.1), talc. Tetrahydrofuran (≥99.5%) and ethanol (, ≥93.0 wt.%) were used to treat lignin.

The study of mechanical properties (tensile modulus, tensile strength and flexural strength) was carried out according to the EN ISO 527 and to the PN-EN ISO 178 standards. Flexural modulus and strength were investigated. The Charpy impact test were performed on notched specimens by using a machine Zwick HIT5.5P. Study of the structure of composites after impact tests were observed by scanning electron microscopy (SEM) in a JEOL JSN5510LV. The samples were covered with a thin layer of gold.

For the study, compositions were prepared with the ratio of components by mass presented in Table 1. The content of the filler varied from 9 to 27 wt% lignin or cellulose and 6 wt% talc.

The tensile and flexural strength of the composites, Young's modulus and impact toughness were determined, so as to understand interaction different preparation methods and composition impact the properties of the composites.

Thus, analyzing the results of the tensile test, it can be determined that the modulus of elasticity has increased for all compositions. The highest result this characteristic was obtained by composition filling microcellulose, which the modulus of elasticity increased by 32% and the tensile strength increased by 2% only for the composite filled with 9 wt% lignin, for all other compositions a slight decrease in strength was observed up to 5%.

According to the tensile strength results, none composite with anything other than polypropylene had a higher tensile strength than the virgin polypropylene. When the amount of polypropylene was reduced, as microcellulose or lignin was added, the tensile strength gradually decreased, but even at 30% filling, no substantial deterioration of strength was observed. This indicates that composite based lignin or cellulose might be used as an alternative for polypropylene without loss the tensile strength in products. Moreover, based on the results, it wasn't possible prove that the addition of talc positive affect the strength of the composite.

The flexural modulus increased for almost all compositions from 10 to 25%. The best flexural strength and modulus of elasticity were obtained for composites No. 6 (with 27 wt %) lignin. Concerning lignin, the increase in bending strength was from 30 to 33% and was practically independent of the degree of filling, a similar dependence on degree of filling is observed for cellulose, but without an increase in strength compared to primary polypropylene. The obtained results can be explained by good adhesion of the filler to the matrix.

A certain difference can be seen in the structure of the composites in the images containing different amounts of lignin. That is, as a result increasing the among of lignin to the composites, the structure of the composite became less compact and the material more stretched. However, the distribution surface, between the particles of lignin and polymer is quite homogeneous, which is obviously a consequence of the previous chemical treatment of Kraft lignin

The purpose of this study was to investigate and understand the influence of Kraft lignin and microcellulose on the mechanical and interfacial properties of hybrid composites made from polypropylene and paper production waste in Ukraine. A strength-enhancing effect was not expected, but an improvement in stiffness was highly likely. In this work, it was established that lignin-cellulose fillers, both fibrous and dispersed in content up to 30%, do not impair tensile strength and increase bending strength and impact toughness at a certain composition. As a result, it can be stated that lignin in the composition of hybrid composites has good prospects for replacing the exhaustible resource from which polypropylene is polymerized. Of course, further research is needed, as results may have been affected by non-systematic dispersion, but the potential of using lignin in composites has been proven.

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THE INFLUENCE OF THE THERMOPHYSICAL PROPERTIES OF THE MATERIAL OF THE UPPER SUPPORT SHAFTS OF THE PELLET FLUSHING FURNACE ON THE PERFORMANCE CHARACTERISTICS OF THE BEARING ASSEMBLY

The production of iron ore pellets is an extremely important part of the Ukrainian industry, since it is from them that iron and ferrous metals are produced, which make up 1/5 of Ukraine's commodity exports. For heat-strengthening firing of iron ore pellets, Ferrexpo Poltava Mining uses the only technology and equipment in Ukraine and the CIS countries, which works according to the American system "grate - tubular furnace - ring cooler".

One of the most important stages in the production of high-quality pellets is the drying stage. Drying takes place on a moving grid. The 43.967 m long grid is located between the centers of the main and tail shafts. The conveyor chain of the grating is supported by 68 upper support shafts (Fig. 1). Since the grid operates under conditions of sharp and significant temperature changes from 200–1200 °C, a thermal expansion gap of 18 mm is established according to the developer's recommendations. All support shafts are mounted and supported perpendicular to the centerline of the rectangle formed by the properly aligned head and tail shafts of the moving chain rack.

Figure 1 Shafts of the upper support of the pellet blasting furnace

As a result of the violation of the conditions of operation of the movable grate, namely, exceeding the recommended temperature regime, the shaft is elongated by a greater amount than is provided for in the technical documentation. As you know, when the temperature rises, metals undergo thermal expansion, due to which their atoms begin to move faster. This can lead to a change in interatomic bonds and rearrangement of the crystal structure. The study of temperature modes of operation in order to determine changes in physical and mechanical characteristics and structures that arise as a result of high temperature action is one of the tasks of designing metallurgical production equipment.

The Ansys R18.1 software was used to determine shaft temperatures, in particular the shaft surface temperature, and the Steady-State Thermal module [1] was used to determine the temperature flow distribution and thermal deformation parameters. For the most thermally loaded shaft (SUS No. 28), the value of its thermal expansion Δ, subject to the coefficient of thermal expansion of steel 15X28 $\alpha=11\times10^{-6}$ [$°C^{-1}$] (Fig. 2) is:

1) in case of loss of cooling air inside the shaft Δ=29.5 mm;

2) if the air loss at the SUS entrance Δ=30.6 mm;

3) with no air loss according to the measurements Δ=28.5 mm

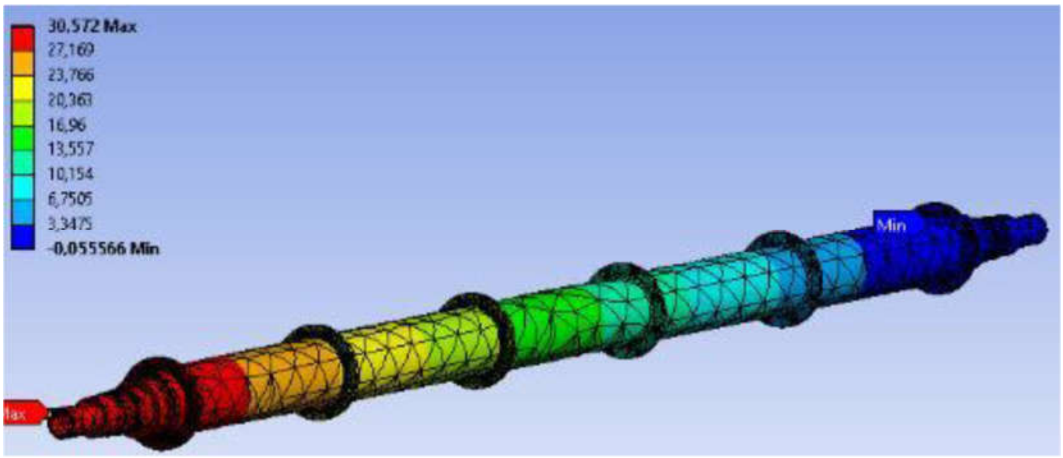

Figure 2 Thermal expansion of SUS No. 28 [2]

The thermal expansion gap is currently insufficient both in the case of air loss in the cooling system of the shafts (damage of the upper support shafts or violation of the tightness of the cooling system) and in the absence of air loss (new SUS, sealed cooling system) [2].

Exceeding the temperature regime leads to unpredictable elongation of the shaft, as a result of which the shoulder of the trunnion presses on the shaft in the axial direction. Since the shaft is not designed for this type of load, it fails. Namely, the shoulder of the trunnion presses on the inner ring of the shaft, which in turn transmits this pressure to the rollers and due to the unusual type of load, the transfer of force from the rollers to the outer ring occurs through a very small contact area, and as a result, local overheating occurs , deformation of the rolling elements and final jamming of the shaft.

The failure of the shaft causes one of the conveyor shafts to stop. As a result of jamming of the shaft, a shock load appears on the half ring, which transfers this load to the flange, as a result of which it fails, that is, it opens and the half ring detaches from the flange. Because of this, the conveyor sags and the load on the main and tail shafts of the grating drive increases. The detected thermal elongation cannot be compensated for by standard roller bearings with axial clearances, since they work in conditions of minor temperature shifts and are not designed for significant axial loads.

When solving the task, it is necessary to use modern means of determining the influence of various factors on operational characteristics, which involve the development of all types of 3D modeling and calculation by the finite element method (FEM), which are effective tools of engineering analysis, for further modernization of the existing support unit in new operating conditions.

Conclusion. Violation of the temperature regime led to overtime elongation of the upper support shafts, as a result of which the existing shaft assemblies jammed, which became the main problem of this production. Temperature fluctuations led to a change in the working loads of the support units, the operational characteristics of the shafts and, as a result, there was a need to review them and develop new technical solutions that should take into account the temperature deformations of the shafts.

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TO THE STRENGTH PROBLEM OF A PIPELINE'S FUNCTIONAL GRADIENT MATERIALS WITH A VARIABLE MODULUS OF ELASTICITY

Abstract. The article is devoted to the problem of rational design of structures under the condition of mathematical modeling of the studied material of structures. The problem is formulated within the framework of a plane problem of elasticity theory, such as the Lamé problem. The basic analytical dependencies are formulated. A mathematical model of the strength problem of a pipeline's multilayer functional-gradient composite is proposed. We review the case when the approximated modulus of elasticity is a function of a coordinate.

Keywords: approximated modulus of elasticity, differential equations with variable coefficients, Lamé problem

The usage of functional-gradient materials in structures of modern mechanical engineering, structural mechanics, gas pipeline systems, aircraft and other industries allows in some cases to solve the problem of rational design, provided that the studied structures are mathematically modeled, in which the mechanical characteristics of the material depends on the coordinates. This leads to the need to integrate the corresponding differential equations and their systems with variable coefficients. In this case, analytical exact solutions can be obtained only in some cases.

Recently, researchers have paid special attention, on the one hand, to finding exact solutions, and, on the other hand, to applying modern approximate approaches, in particular, based on asymptotic methods, not excluding the possibility of computer technology.

The aim of this paper is to formulate the basic analytical dependencies and discuss the mathematical model of the strength problem of a pipeline made of a multilayer functional-gradient composite, whose properties, in particular, the approximated elastic modulus, are a function of coordinate.

The problem is formulated within the framework of a plane problem of elasticity theory, as a Lamé problem [1] with a variable elastic modulus along the radial coordinate. It is believed that the function of change in the elastic modulus of the FGM composite is approximated by the dependence

$$E^* = E^*(r),$$

where r – is the elementary plane normal section pipeline's location radial coordinate.

In accordance with the algorithm for solving the Lamé problem, the main analytical dependencies are given by the following relations, shown in Fig.1.

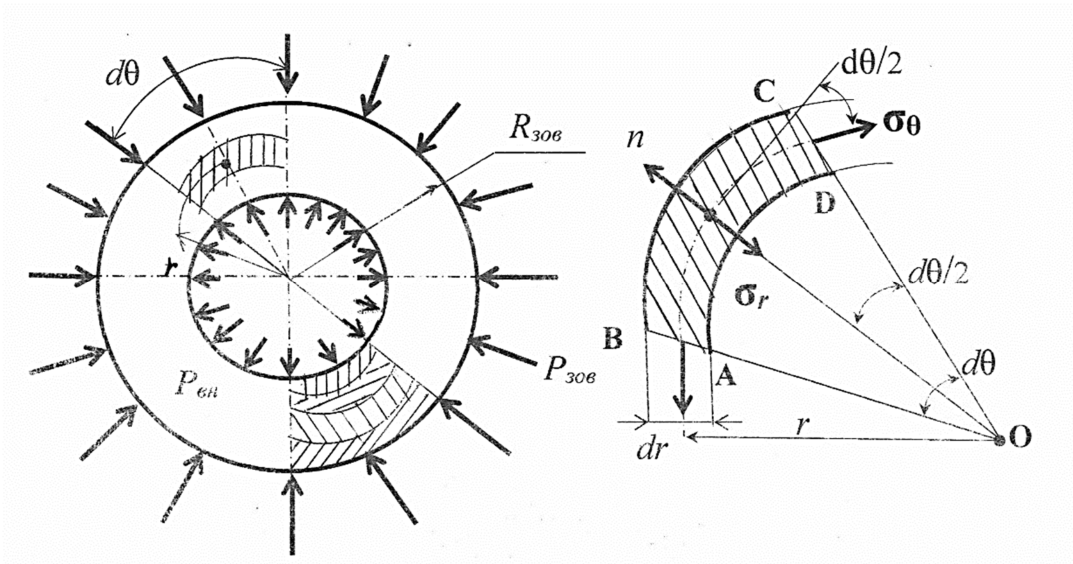

Fig.1. Diagram of the pipe cross-section and acting loads

The static side of the Lamé problem leads to the equation [1]:

$$\frac{d\sigma_r}{dr} + \frac{\sigma_r - \sigma_\theta}{r} = 0, \tag{1}$$

$$\sigma_r = \frac{E^*(r)}{1-(\mu^*)^2}\left(\varepsilon_r + \mu^*\varepsilon_\theta\right), \tag{2}$$

where μ^* – is the approximated Poisson's ratio; it is assumed to be constant.

$$\begin{aligned} \frac{d\sigma_r}{dr} &= \frac{dE^*(r)}{dr}\frac{1}{1-(\mu^*)^2}\left(\varepsilon_r + \mu^*\varepsilon_\theta\right) + \\ &+ \frac{E^*(r)}{1-(\mu^*)^2}\left(\frac{d^2U}{dr^2} - \frac{\mu^*}{r^2}U + \mu^*\frac{1}{r}\frac{dU}{dr}\right) = \\ &= \frac{d^2U}{dr^2} + \left[\frac{\mu^*}{r} + \dot{g}(r)\right]\frac{dU}{dr} - \frac{\mu^*}{r}\left(\frac{1}{r} - \dot{g}\right), \end{aligned} \tag{3}$$

where $$g(r)=\frac{E^*(r)}{1-(\mu^*)^2},\quad \dot{g}(r)=\frac{\dot{g}(r)}{g(r)},$$

(4)

$$\frac{\sigma_r-\sigma_\theta}{r}=\frac{g(r)}{r}\left[\frac{dU}{dr}+\mu^*\frac{U}{r}-\frac{U}{r}-\mu^*\frac{dU}{dr}.\right] \tag{5}$$

Taking into account equations (3-5), expression (1) will be transformed into the following form:

$$\frac{d^2U}{dr^2}+a(r)\frac{dU}{dr}-b(r)U=0, \tag{6}$$

where $$a(r)=\mu^*\left(\frac{1}{r}-1\right)+\left[\dot{g}(r)+\frac{g(r)}{r}\right],$$

$$b(r)=\frac{\mu^*}{r^2}[g(r)-1]-\frac{1}{r}\left[\mu^*\dot{g}-\frac{g(r)}{r}\right]. \tag{7}$$

The differential equation (6) with variable coefficients *a(r)* and *b(r)* is not analytically exactly integrated in general. In this paper, an analytical approach based on the method of perturbation by the "small" parameter μ* [2] is proposed for an approximate analytical solution of equation (6) for given functions *g(r)*.

To refine the obtained approximate solution of the problem, a hybrid asymptotic approach can be used [3]. In specific cases it is possible to compare the function *g(r)* with the method associated with the use of the argument of a function of a complex variable [4].

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EFFECT OF THE USE OF HARD ROUND POLYMER RODS REINFORCED WITH FIBERGLASS ON THE STRENGTH AND DURABILITY OF CONCRETE STRUCTURES

Abstract. The search for and use of corrosion-resistant and durable materials for concrete reinforcement is driven by the rapid development of the construction industry and the need to ensure the durability and reliability of building structures. In this context, the use of solid round polymer rods reinforced with fiberglass is proving to be one of the most promising areas, as they combine high corrosion resistance and significant strength. Achieving these characteristics is becoming increasingly important in the context of the requirements for sustainable infrastructure development and increasing the service life of structures.

Keywords. POLYMER REINFORCING BARS, GLASS FIBER, CONCRETE REINFORCEMENT, CORROSION RESISTANCE, MODERN CONSTRUCTION MATERIALS.

Main part. Construction and infrastructure projects require reliable and durable structures that are resistant to various negative environmental factors. One of the most important challenges is corrosion, which can significantly reduce the service life of concrete structures and increase maintenance and repair costs. The use of corrosion-resistant and durable materials for concrete reinforcement can solve this problem and improve the quality and durability of construction projects.

The main objective of the research is to investigate the effect of using solid round fiberglass reinforced polymer rods on the strength and durability of concrete structures. Specific research objectives include:

- Analysis of the properties of polymer rods and their comparison with traditional metal reinforcement products.
- Study of the effect of polymer bars on the strength of concrete specimens by conducting laboratory tests.
- Investigation of practical applications of polymeric rods in construction projects and evaluation of their durability.
- Identification of the advantages and limitations of using polymer reinforcing bars in construction.

- Draw conclusions about the effectiveness and prospects of using polymer reinforcing bars to improve the strength and durability of concrete structures.

This research work is aimed at expanding the understanding of the importance of selecting appropriate materials for concrete reinforcement and improving the quality of building structures in demanding operating conditions.

Polymer reinforcing bars (fig. 1) are modern reinforcing materials that are distinguished by their unique structure and properties. Rigid polymer bars are designed to reinforce concrete structures and are made of high-quality polymeric materials, such as fiberglass, which give them great strength and corrosion resistance. They usually have a round profile, which ensures an even distribution of the load on the concrete structure.

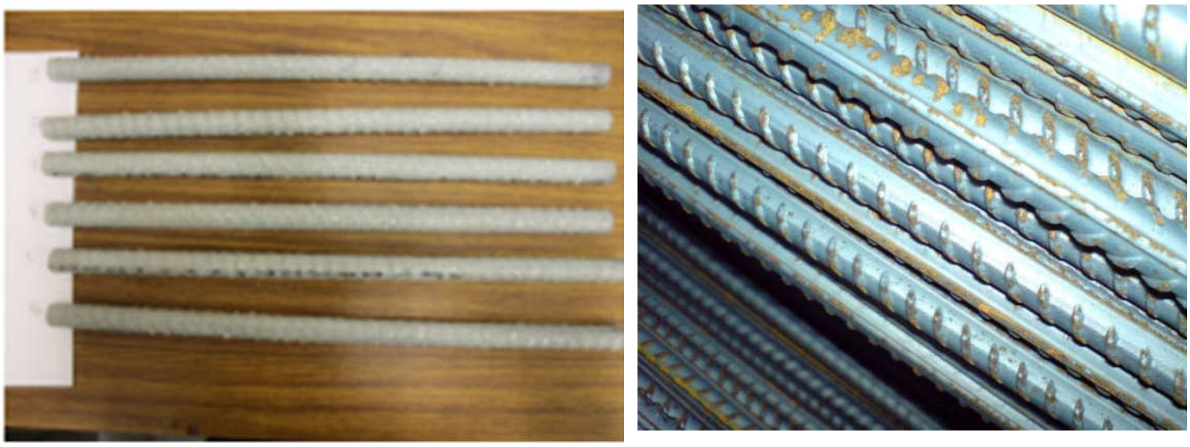

Fig.1 Comparison of polymer reinforcement and metal reinforcement

An important advantage of using polymer rods is their high corrosion resistance. They do not undergo destruction due to oxidation, as can happen with metal fittings, especially in aggressive environments such as salt water or chemical solutions. Polymer rods also have excellent strength and lightness, which makes them easy to install and transport. As a result, they are an attractive solution for construction projects where corrosion resistance and increased strength are important.

Conclusion. Fiberglass-reinforced polymer reinforcing bars are a modern and promising material for reinforcing concrete structures due to their high strength and absolute corrosion resistance. The results of laboratory tests and practical examples of polymer rods confirm their efficiency and durability in construction. The use of polymeric reinforcing bars in construction has prospects and contributes to improving the strength and durability of concrete structures. In general, the use of polymer rods for concrete reinforcement is a promising and reasonable solution, especially in conditions where corrosion is a significant problem.

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INDUSTRIAL DESIGN: ENGINEERING OR ART

Abstract. New world challenges increasingly require designers to solve social problems of humanity, so designers are entrusted with increasingly complex and impressive tasks. In order to meet the needs of industry and bring Ukrainian education to European requirements, the conceptual principles of introducing a new interdisciplinary educational program for training engineers in industrial design in Ukraine, taking into account the experience of the Spanish School of Industrial Design, are proposed.

Keywords: Bachelor of Industrial Design, European Education, Educational Program, Engineering.

In national education, first of all, it is about art design education - which is defined as a direction of educational activity, the result of which is a designer specialist - a person who professionally possesses the skills of design activity and treats the creation of a design product as a work of art [1, 2]. In European education, there are two areas of designer training - the first is with the intensification of engineering training, and the second is with an orientation towards art) [3, 4].

Therefore, the purpose of this article is to find ways to improve the education of applicants in industrial design, taking into account the experience of specialists in this field in Spain, as well as bringing this content into line with the modern requirements of the labor market.

A common feature of European design is learning by doing. That is, designers-practitioners, recognized masters of their field, are involved in the process of professional training of future specialists. Students take an active part in the process of creating design objects, helping designer-teachers. Thanks to such practice, upon graduation, future specialists receive a design portfolio of professional achievements, which helps in future employment and is considered a successful step in a professional career. Practical abilities and skills, participation in real design projects are highly valued by employers, increasing the competitiveness of future specialists, and is a productive stage in building a professional career.

In Ukraine today, industrial enterprises are thinking about the fact that they need designers who know the full cycle of product creation, from the idea to its launch into production and further promotion on the labor market.

Today, 50 higher education institutions train designers in Ukraine, and only 8 of them specialize in Industrial design at the bachelor's level and one at the master's level (Fig. 1). At that time in Spain Grado en Ingeniería en Diseño Industrial y Desarrollo de Productos receive a bachelor's degree in 17 educational institutions, and a master's degree in 6 educational institutions.

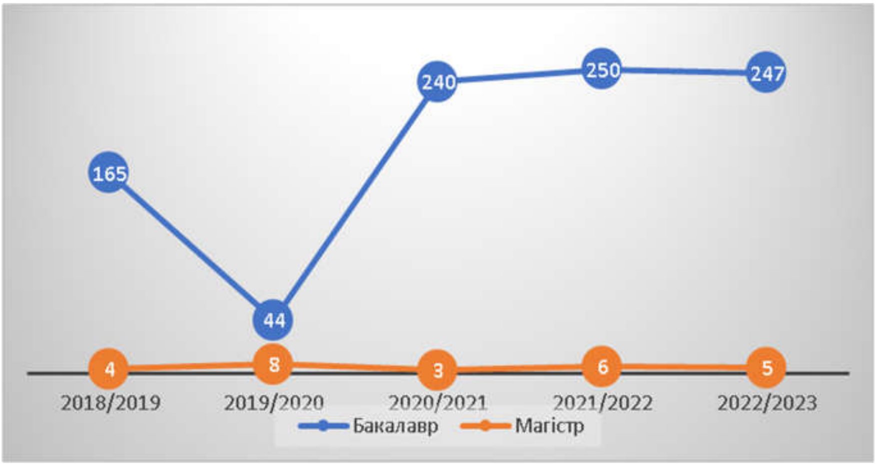

Figure 1. The number of entrants to the Industrial Design specialization (formed according to the data USDE)

The demand for specialization among entrants has been stable for the past three years (Fig. 1), but given that the number of institutions training specialists in industrial design has decreased, the trend indicates a decrease in the number of entrants. The reasons can be different: the consequences of military actions - the number of applicants has decreased, some educational institutions do not have the opportunity to train applicants, as well as the inconsistency of the training content with the requirements of the labor market.

The analysis of educational programs (the analysis was carried out according to programs that are freely available) for the training of specialists in the specialty 022 Design specialization 0224 Industrial design shows the following:

- the competencies proposed by educational standard 022 Design do not cover the entire list of requirements for designers of industrial products and technologies;

- graduates remain ignorant of the design of an industrial model in accordance with functional, technological and economic requirements; calculation of parameters of the designed product, selection of necessary materials and development of technological stages of production, etc.

In terms of the number of loans and the period of preparation, Ukraine and Spain correspond to the Bologna Declaration. Undergraduate studies last at least eight semesters and lead to the training of engineers who are qualified both for professional activities and for access to further study at postgraduate level (master's and doctorate). This type of structure is the most common among engineering schools both in Europe and in Ukraine. However, the training of industrial designers in Spain takes place according to the field of training (Mechanical engineering, industry and construction) Ingeniería, industria y construccióni, the graduate receives an engineering qualification, in Spain it is called Grado en Ingeniería en Diseño Industrial y Desarrollo de Productos. In Spanish higher education institutions, design is understood as a technology, because it connects some intellectual abilities with instrumental ones to achieve a goal. It is obvious that this coordination is subject to appropriate educational components, originating from the formation of analytical abilities, technical knowledge, complemented by cultural sensitivity and creative abilities.

Comparative analysis of the bachelor's engineering program "Industrial aesthetics and certification of materials and products" within the specialty 132 Materials science of the field of knowledge 13 Mechanical engineering in Dnipro University of Technology and training programs Grado en Ingeniería en Diseño Industrial in Desarrollo de Productos в Universidad politécnica de Madrid indicate that programs are focused on technology and broad engineering training.

Conclusions. Design activity and design education have gone through a complex path of formation and development - from learning artisanal production to mastering the art of design and the modern level of development of design culture as a variety of basic forms of a set of design, organizational and transforming human activities. The new European educational program for industrial design engineers in Ukraine should be interdisciplinary and contain two main training focuses: engineering and aesthetics. At the same time, business awareness and environmental awareness when making decisions should become a mandatory component of the training of industrial design engineers.

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PROSPECTS FOR APPLYING ADDITIVE 3D-printing TECHNOLOGY IN CONSTRUCTION

Abstract. The research is directed towards the improvement of existing methods of planning and organization of construction, taking into account the requirements and features of using additive 3Dprinting technologies. For this purpose, the analysis and classification of modern 3D additive technologies was performed. These technologies successfully proved themselves in the world of construction production. The specifications of 3D-printing, technologies, materials, directions for building 3D-printers, and the requirements for the organization of construction sites were considered. The factors that influence widely used 3D-printing technologies in the construction industry of Ukraine are identified. An analysis of the main distinguishing aspects of additive manufacturing for construction allowed us to identify the necessary steps to increase the efficiency of use and highlight promising directions for the development of 3D-printing. Wide use of 3D-printing in construction is a matter of time, it will allow combining the latest scientific developments in the field of engineering, technology, materials science, architecture, design, and construction. Such integration into the new unified innovation system provides for the solution of a whole range of issues and problems which require the improvement methods of planning, organization and management of construction production, allowing the effective use of the latest additive 3D-printing technologies in Ukraine.

Keywords: additive technologies; 3D-printer; 3D-printing; planning and organization of construction production, recycling.

In connection with active hostilities and missile attacks by the aggressor country, the cities and villages of Ukraine, civilian housing and industrial funds have suffered significant damage and destruction. Ukraine needs fast and high-quality reconstruction and restoration. This is possible due to the use of modern construction technologies, such as 3D-printing. Ukraine can become one of the first in the world to build important objects for the country using this technology. This technology can significantly speed up the reconstruction process, because compared to traditional methods, construction using 3D-printers is 10 times faster. Also, the use of construction 3D-printers will allow solving current issues such as environmental protection - reducing carbon dioxide emissions during construction, and solving the issue of using recycling - processing secondary raw materials and materials left after the destruction of buildings and structures.

The conducted analysis shows that in most scientific publications devoted to additive 3D-printing technologies, the priority areas of research are: 1) development of new and improvement of existing 3D-printing technologies [1-3]; 2) improvement of technical characteristics of 3D-printers [4]; 3) determination of rational compositions of working mixtures for 3D-printers, the basis of which are quick-hardening concretes, which can include various additives to improve certain characteristics of building structures, as well as be combined with various types of fibers or with steel reinforcements;

4) improvement and development of modern software that allows you to implement complex 3D models that are designed and simplify the work of operators.

Along with the indicated areas of research, in our opinion, it is important to study the characteristic features of additive manufacturing in construction at all stages of project implementation, including at the design stage.

Research and consideration of the impact of the main factors of 3D-printing on calendar planning, organizational and technological design of construction objects, their complexes, and on the rationalization of methods of organizing construction production using 3D-printing involves the analysis and classification of existing additive technologies in construction, taking into account the experience of leading world leading firms in this market segment. The analysis of publications allows us to claim that research in this direction is appropriate.

In the course of the study, the characteristic features of the use of construction 3D-printers in global practice were highlighted:

1. Advantages of the technology of using 3D-printing compared to classical technologies of construction production: 1) shortening the terms of work on the construction site, improving the quality and accuracy of processes due to software management [5]; 2) savings in labor costs and material costs. Some types of materials, logistics and labor costs for them are excluded from the construction process; 3) reducing the number of personnel involved in construction allows to reduce labor costs 50...80% less man-hours are spent on the construction of 3D-printed objects;
4) 3D-printing fits perfectly into the concept of modular production Design for Manufacturing and Assembly Method [6-8]; 5) increasing safety and improving working conditions; 6) improvement of the ecological situation; 7) topological optimization and acquisition of special properties, change of the design process; 8) variety of forms and simplicity.

2. Economic factors of the effectiveness of the use of 3D-printing in construction: 1) acceleration of the process of developing new products. 3D-printing made it possible to increase speed, reduce cost and risks when obtaining the first versions of the product with various

variations (forms, functionality, etc.) and modifications; 2) change in production strategy. Part of the production facilities will lose their relevance due to the gradual decrease in price, increase in print quality and expansion of 3D-printer capabilities; 3) change of profit generators. Ability to reduce warehouse space and eliminate shipping costs for parts that can be printed on a 3D-printer. The possibility of personalizing the product in design and functionality; 4) new opportunities for designers and architects; 5) competition for possession of innovative technology.

A system of factors influencing the rate of spread of 3D-printing in the construction industry of Ukraine has been determined.

1. Prerequisites for use: 1) low labor productivity in the construction industry. The reserve for its growth is related to the digitalization of the construction process and its automation, including due to construction 3D-printing; 2) the possibility of excluding the "human" factor and errors related to it (they account for up to 70% of defects); 3) the effect due to savings on ensuring the safety of production of construction works, due to the minimization of the presence of personnel on the construction site; 4) the formed developed national ecosystem ("green construction") is ready for active work, having entered the field of strategic investors; 5) the possibility of maintaining a strong scientific school in the field of construction materials science and engineering [8].

2. Difficulties in implementing 3D-printing: 1) general weakness in the development of mechanical engineering and the chemical industry, the high cost of imported components and complex modifying additives; 2) need for further research using nanotechnology to develop new materials and mixtures necessary for effective 3D-printing; 3) weak interest and lack of support for 3D-printing projects from the construction industry and the state as a whole; 4) complex normative and regulatory framework; 5) lack of incentive to increase the efficiency of the construction industry due to the availability of cheap, low-skilled labor [6-8].

CONCLUSIONS

1. The performed analysis of the main characteristic aspects of additive manufacturing for construction made it possible to determine the necessary steps to increase the efficiency of use and to identify promising directions for the development of 3D-printing.

1.1. The use of 3D-printing at all stages of construction and installation work (turnkey construction of a house), full automation of construction production. To implement this direction, significant organizational and technological changes in the concept of additive construction are necessary, among which we can highlight: 1) printing with different materials or development of several materials; 2) installation of specialized components. Much of the building is made from common interchangeable materials (commodities), but there are many specialized components that are not currently 3D-printable (such as nitrogen-filled triple-glazed windows, electronic door locks, dimmable LED-lighting systems, and etc.); 3) organization of complex and rational supplies of consumables; 4) development of software for production management as a whole. Creation of software for planning, organizing and controlling all production activities on the construction site.

1.2. Construction projects using 3D-printing have the advantage of shortening the duration of construction, as well as the ability to create architectural projects and individual structures that cannot be done in any other way.

1.3. Further research on the development of mixtures used in 3D-printing will allow not only to select ready-made compositions for specific conditions and tasks, but also to use recycling to solve the problem of processing construction waste. Also use local materials as raw materials: hay, soil, sand, etc., with the addition of a binder. The use of mineral additives in concrete solutions will allow solving some environmental problems, for example, reducing the emission of carbon dioxide into the atmosphere by reducing the consumption of cement.

2. Additive manufacturing for construction using 3D-printing allows combining the latest scientific developments in the fields of engineering, technology, materials science, architecture, design, construction and construction. Such integration into a new single innovation system opened up a whole layer of questions and problems related to the need to improve methods of planning, organization and management of construction production, which would allow effective use of the latest additive technologies of 3D-printing for the restoration and reconstruction of Ukraine.

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METALLOGRAPHIC ANALYSIS OF STRUCTURAL STATE OF WELDED JOINT ZONES AFTER ELECTRON-BEAM WELDING

Abstract. Currently, welding is one of the most universal and effective methods of obtaining permanent joints among the widely used types of joints for metal structures. A technological scheme of welding process ensures the structural state of a joint itself, and as a result, a corresponding set of properties. Thus, a metallographic study of structural state of a welded joint is an urgent task from the point of view of determining potential places of fracture initiation under the influence of external load. A structural state of a welded joint of low-carbon low-alloy steel 09G2S after electron-beam welding is studied in the paper.

Keywords: electron-beam welding, weld microstructure, heat input, structural state, grain boundary structure.

Main content of paper. The study of morphological structure of a welded joint is carried out on a basis of literary sources [1-3], and according to the principle of dividing the zones of a welded joint. A schematic representation of control points in a structure is shown in Figure 1 [3].

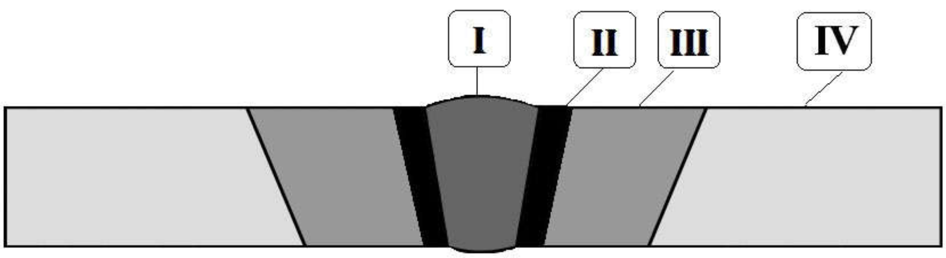


Fig. 1. Zones of welded joint (according to paper [3])

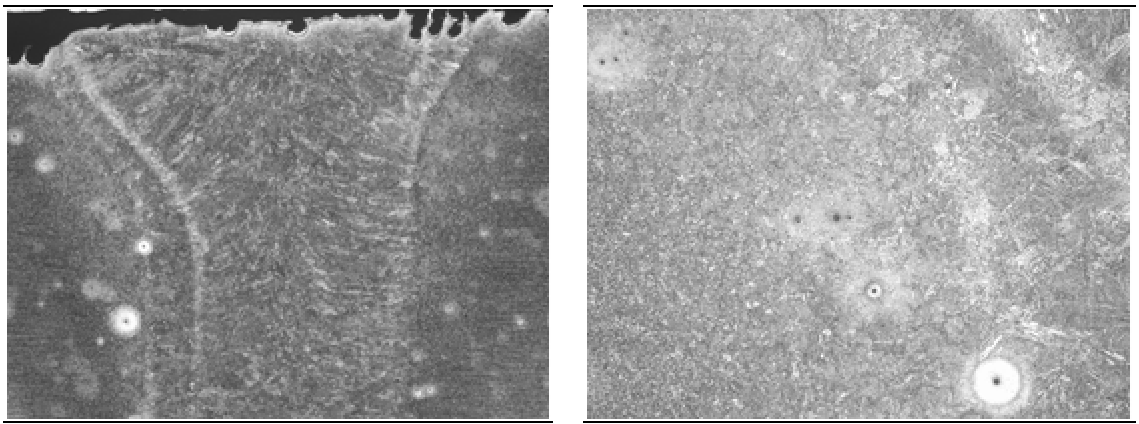
Zone I – the weld metal (WM).

Zone II – boundary of the weld metal (WM) and the heat-affected zone (HAZ).

Zone III – the heat-affected zone (HAZ).

Zone IV – boundary of the heat-affected zone (HAZ) and the base metal (BM) [1-3].

The results of metallographic studies of a welded joint after electron-beam welding are shown in Figure 2.



a (x100) *b* (x200)

Fig. 2. Weld metal microstructure of 09G2S steel after electron-beam welding

The analysis of obtained data shows that formation of a structural state in zone I has a directional nature, which is caused by presence of a temperature gradient. As a result, the structure is columnar crystallites that grow from the surface of molten metal to the joint center (Fig. 2*a*). The appearance of an equilibrium structure is due to the following factors: presence of strong carbide and nitride-forming elements in steels; localization of temperature gradient, which corresponds to conditions of electron-beam welding modes.

Figure 1*b* clearly shows the boundary between zones I and II. According to literature sources [3-5], this element of welded joint structure is called a fusion line or boundary. The formation of fusion boundary is due to the processes of grain boundary migration that occur during cooling after welding. Boundaries are formed during structural transformations directly during the growth of primary crystallites on the WM side and on the BM side. Crystal lattices of the growing phases have an arbitrary orientation, and their combination is accompanied by significant deformation of lattices, which causes the appearance of an increased level of internal microstresses. These processes directly depend on a heat input that occurs during welding, i.e., the more local the source of welding, the smaller the granularity and, as a result, the lower the degree of internal microstresses.

During the formation of structural state of zone II, phase structural transformations occur, which are a consequence of local influence from a heat of the welding source. As a result, the metal of zone II, as well as zone III, has a microstructure different from the BM, which corresponds to the modes of secondary heat treatment of the BM when heated to temperatures above Ac_3 and cooled at different rates.

When approaching zone I, reheating temperatures approach melting temperatures, holding at such temperatures ensures formation of fine-grained austenite, which is further transformed by the bainite mechanism. When distancing from zone I, the heating temperature of metal is significantly lower, but higher than Ac_3, so the size of austenite grain is lower than near the weld joint. Thus, during cooling, an even more dispersed ferrite-bainite structure is formed than in zone II [3, 5].

Metallographic analysis data are summarized and presented in a form of general assemblies, which are presented in Figure 3.

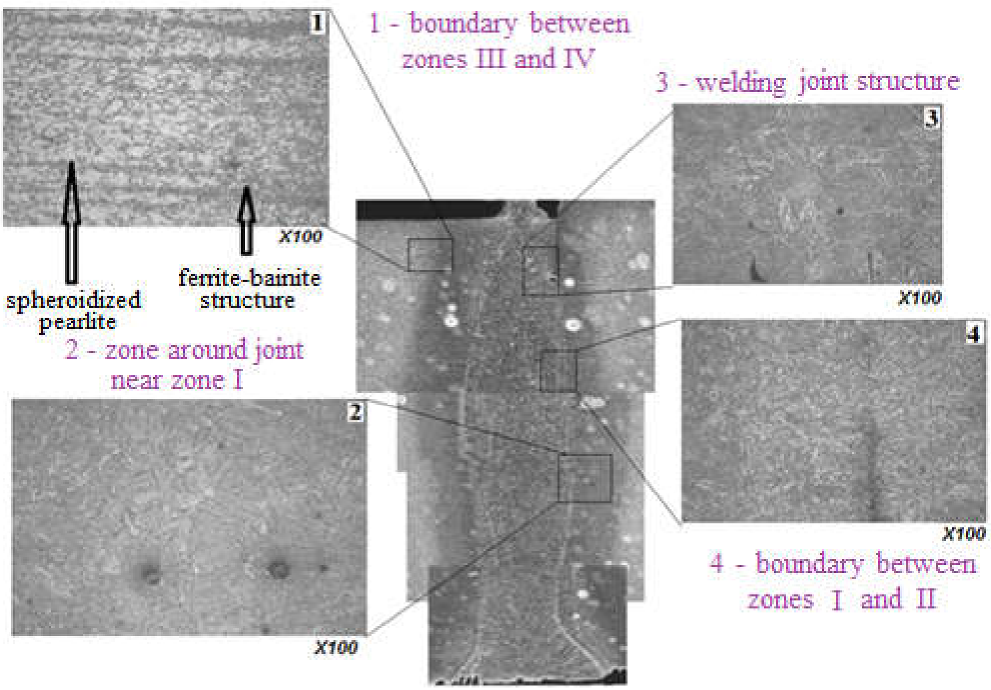


Fig. 3. General appearance and structure of a welded joint of 09G2S steel after electron-beam welding

The analysis of given assemblies shows that during electron-beam welding, the processes occur simultaneously, which are characteristic of both metal crystallization from a liquid phase and phase transformations in a solid state. Due to local heat input, melting of the BM occurs in the upper part of the weld pool, while crystallization of a joint and structural transformations in the solid state are already taking place in the lower part. At the same time, formation of the structural state of zone III is caused primarily by the system tending to reduce the level of free energy. Accordingly, there are changes in the location of grain boundaries, which leads to a decrease in a total length of boundaries, and, as a result, to a decrease in a level of surface energy. Thus, structural state of zones II and III is formed due to the formation of a secondary grain boundary structure and its alignment from the point of view of reducing the total free energy level.

In order to carry out a quantitative analysis of the obtained data, an experimental measurement of a percentage ratio of structural components in zones of the welding joint of the studied steel grade is carried out. The measurement results are presented in Table 1.

Table 1

The percentage ratio of structural components in samples made of 09G2S steel

Welding type	Zone II		Zone III		Zone IV	
	Ferrite	Pearlite	Ferrite	Pearlite	Ferrite	Pearlite
Electron-beam welding	60	40	40	60	60	40

From Table 1, we can see that for samples made of 09G2S steel during electron-beam welding, the percentage content of ferrite component decreases only in zone III compared to zones II and IV; and the content of pearlite component, on the contrary, increases in zone III.

Conclusion

1. Structural state of a welding joint of low-carbon low-alloy steel 09G2S after electron-beam welding is studied in the paper.

2. The conducted set of metallographic studies showed that a structural state is formed in welded joints as a result of local heat input, which is characterized by elements characteristic

of both cast and recrystallized and rapidly cooled rolled metal. As a result, the most dangerous zones (from the point of view of defect initiation) are the boundary zones of the welded joint, namely: the border between zones of WM and HAZ, and the border between zones of HAZ and BM. In these zones, a certain structural heterogeneity is observed, which leads to an increase in a level of internal microstresses, and a resulting increase in a level of internal energy, and a possible initiation of fractures.

3. Quantitative analysis of percentage content of structural components showed that during electron-beam welding, a percentage increase in ferrite component and a decrease in pearlite component are observed in the researched areas. It should be noted that an increase in the percentage content of ferrite component leads to an increase in strength, impact elasticity and plasticity of steel.

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DESIGN OF COMPOSITE MATERIAL OF THE FALSE ROOF OF SKODA CARS

Abstract. Modern technologies require protection of tram electrical equipment on the roof. A false roof can reduce maintenance and snow removal costs in countries with high precipitation. The use of polymer-based composites helps to solve the problem of the complex shape of the equipment profile. The use of technologies for controlling anisotropy and orthotropy is useful for creating materials with improved properties for various industries, including aviation, automotive, and construction.

Keywords. COMPOSITE, ANISOTROPY, ORTHOTROPY, ELASTICITY, POLYMER MATRIX.

General part. Typically, tram electrical equipment is installed on the roof without covering it with additional panels. This makes it necessary to increase the protection class of the equipment, as it is exposed to precipitation and dust. For countries with high rainfall (Finland, Iceland), it is important to install a false roof. This will reduce the time spent preparing for maintenance of electrical equipment by protecting the roof from most of the precipitation in the form of snow. As a result, the personnel who maintain the electrical equipment do not need to spend time removing snow.

It is proposed to use a universal bracket for fastening the false roof panels, the configuration of which can be modified depending on the specific characteristics and requirements of the tram.

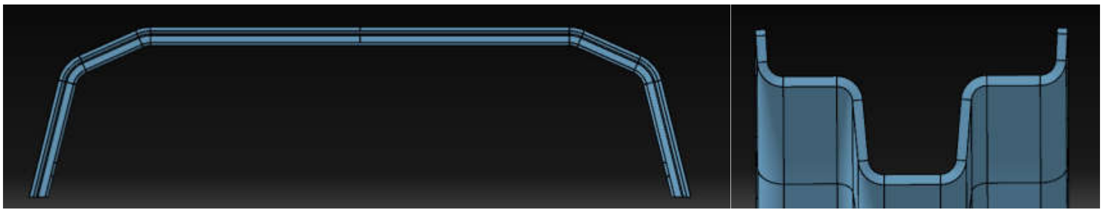

Fig. 1 - Bracket for fixing the tram lining panels

$$\begin{pmatrix} D_{11} \\ D_{21} \\ D_{31} \\ 0 \\ 0 \\ 0 \end{pmatrix} = \frac{1}{0.001} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \sigma_{xy} \\ \sigma_{yz} \\ \sigma_{xz} \end{pmatrix}$$

Using a periodic structure, this is achieved as follows. Let's assume that the RVE occupies the volume $[0, L_x]\times[0, L_y]\times[0, L_z]$.

On the faces normal to the X-axis, the expression is as follows:

$$u_x(L_x, y, z) = u_x(0, y, z) + \epsilon L_x$$

$$u_y(L_x, y, z) = u_y(0, y, z)$$

$$u_z(L_x, y, z) = u_z(0, y, z)$$

On the faces normal to the Y-axis, the expression is as follows:

$$u_x(x, L_y, z) = u_x(x, 0, z)$$

$$u_y(x, L_y, z) = u_y(x, 0, z)$$

$$u_z(x, L_y, z) = u_z(x, 0, z)$$

On the faces normal to the Z-axis, the expression is as follows:

$$u_x(x, y, L_z) = u_x(x, y, 0)$$

$$u_y(x, y, L_z) = u_y(x, y, 0)$$

$$u_z(x, y, L_z) = u_z(x, y, 0)$$

In addition to these periodicity conditions, movements of the solid must also be prevented. This is done through enforcement:

$$u_x(point\ and\ x = 0) = 0$$

$$u_y(point\ and\ y = 0) = 0$$

$$u_z(point\ and = 0) = 0$$

There are alternatives to these periodic boundary conditions. If there is not sufficient symmetry, these alternatives lead to boundary effects. Periodic boundary conditions should be used on periodic structures.

To calculate macroscopic stresses, the forces on the upper faces are integrated. Consider σ_x. The force in the X direction on the face x=L_x is integrated by normalising it with the face area and is obtained in the same way. The entries for D_{11} and the stiffness matrix are easy to obtain.

Repeating the steps for all other load cases (see Periodic Boundary Conditions), all entries for the stiffness matrix are obtained. The stiffness matrix is inverted to obtain the yield matrix:

$$[C] = [D]^{-1}$$

Finally, the engineering constants E_x, E_y, E_z, G_{xy}, G_{yz}, G_{xz}, v_{xy}, v_{yz} are calculated in the ratio:

$$[C] = \begin{pmatrix} \frac{1}{E_x} & \frac{-v_{yx}}{E_y} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} \\ \frac{-v_{xy}}{E_x} & \frac{1}{E_y} & \frac{-v_{zy}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} \\ \frac{-v_{xz}}{E_x} & \frac{-v_{yz}}{E_y} & \frac{1}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} \\ \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{1}{G_{xy}} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} \\ \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{1}{G_{yz}} & \frac{-v_{zx}}{E_z} \\ \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{-v_{zx}}{E_z} & \frac{1}{G_{xz}} \end{pmatrix}$$

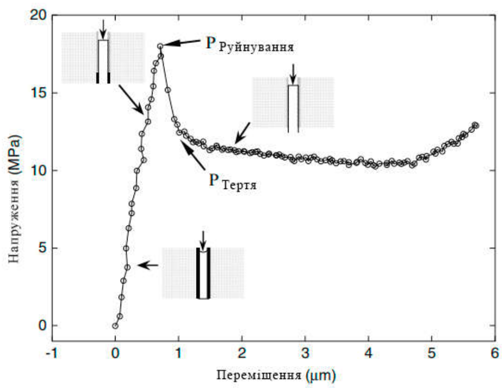

Fig. 3 - Stress-displacement curve. After elastic loading, progressive fibre delamination occurs, followed by interfacial slippage.

Conclusion. The calculations were carried out to determine the mechanical properties of the composite material. The calculations help to obtain a stiffness matrix and a yield matrix for the material. These constants allow us to predict how the material will respond to different types of loads and deformations. The data obtained can also be used to optimise the design of the tram's false roof and cladding panels to ensure maximum strength and minimum weight.

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