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Content

UDC 669.184

ANALYSIS OF THE EFFICIENCY OF CARBON REMOVAL FROM THE MELT AT DIFFERENT STAGES OF STEEL PRODUCTION

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In modern conditions, iron-carbon melts, and in particular steel, is one of the most widespread structural materials in the world. The production of steel is associated with the removal of excess impurities in the iron-carbon melt, in particular carbon. At the same time, there are significant number of technological solutions for the production of steels of various assortments, from ultra-low carbon to carbon-alloyed. The main method of production of structural steels of ordinary quality remains the oxygen-converter process, which is carried out according to the scheme with the supply of oxygen through the top blowing lance and neutral gas through the bottom blowing blocks. The production of high-carbon steels is based on the use of electrosmelting technology using induction heating or arc heating schemes, which is associated with the low oxidation potential of these processes. The production of steels with a carbon content below the critical concentration (0.01%) is associated with the complexity of organizing the supply of carbon to the place of oxidation. Therefore, technical solutions have been developed with the additional introduction of mass transfer intensifiers into the bath (GKR and AOD technologies), as well as carbon oxidation at low pressure. The specified processes require special complex equipment and do not allow the production of low-carbon steels at existing metallurgical enterprises without significant modernization of equipment and changes in production technology.

According to existing views on the mechanisms of carbon oxidation in a metal bath, three links of the specified process are distinguished: 1) introduction of the oxidizer into the melt; 2) the course of the chemical oxidation reaction; 3) bringing carbon to the site of the chemical reaction. In the case of a concentration of carbon in the melt at a level close to the critical level, the speed of the chemical reaction is limited precisely by the supply of carbon to the place of its flow. Thus, to ensure an effective process of removing carbon from the melt at concentrations below the critical one, it is necessary to apply methods of intensification of mass transfer processes in a metal bath. At the same time, there are the following methods of intensification of the mass exchange of millets: forced mixing, influence of an external electromagnetic field, purging with a neutral gas. Among the specified methods of intensification of mass exchange processes, the most technological is purging with neutral gas.

Based on the above, it is proposed to carry out the production of steels with a carbon concentration below the critical one according to the following scheme: oxidation of carbon to the critical concentration by standard methods of oxygen-converter melting, oxidation of carbon below the critical concentration in the melt due to blowing the melt with an inert gas-oxygen mixture at the post-bake treatment stage through bottom blowing blocks of a special design.

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ANALYSIS OF CONDITIONS FOR EFFECTIVE ACTIVATION OF NITROGEN-CONTAINING GAS FLOW

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Today, the metallurgical industry, as the main producer of structural material, sets new, increased requirements for the strength of steels and the improvement of their operational qualities, as an indicator

of the reliability and durability of parts and structures. Methods of improving the properties of steels are quite diverse, but alloying occupies an important place among them. Alloying elements give products heat resistance and corrosion resistance, increase mechanical indicators. Among them, nitrogen should be singled out, the introduction of which allows to reduce the content of more valuable elements of nickel, manganese and other austenite-forming elements in alloys while maintaining the specified austenitic or other structure and, accordingly, the level of ferromagnetism of the alloy; increase the content of ferrite-forming elements in alloys, which positively affects the mechanical and corrosion characteristics of alloys; improve the characteristics of technological plasticity due to the expansion of the austenite existence interval in the high-temperature region; increase the thermal stability of austenite and reduce the probability of its disintegration during heating with the formation of nitrides and other phases; increase resistance to pitting and knife corrosion, stress corrosion cracking, intercrystalline corrosion; to increase the strength of alloys by using strain hardening during slander.

Nitrogen is a fairly widespread chemical element and has long been known as an alloying agent, but its limited solubility in iron alloys, especially with a high content of other components, prevents its widespread use. Different methods of gas activation are used to increase the solubility of nitrogen. The authors investigated the option of activation by creating an electric brush discharge.

The research was carried out on a physical stand created at the research site of the Iron and steel Institute of National Academy of Sciences of Ukraine. The section of the nozzle at the outlet for supplying purging gas, in which a closed-type gas activation device was placed (by creating a brush discharge between the metal electrode and the metal tip of the nozzle), was subject to modeling. Two types of devices were investigated: with a submerged non-insulated electrode and a protruding almost fully insulated electrode (discharge between the lance tip and the non-insulated electrode tip). Analysis of the influence of the pressure of the purge gas and the length of the arc (the distance between the electrodes) on the efficiency of the process of ionization of the flow of nitrogen-containing gas (using the air) showed that when using a discharge device with an immersed electrode, the current that forms the activated gas has a quadratic dependence on the distance between the electrodes with a maximum at a distance of about 15 mm and a purge gas pressure of 0.25-0.3 MPa. With a further increase in pressure, the visible discharge disappears and the current decreases.

Under the conditions of using a different type of discharge device, which is characterized by a protruding electrode, much higher indicators of the strength of the ionized current were obtained, and with an increased distance of the discharge, the strength of the current increased. In addition, the discharge was visually visible even at high purge gas pressures (0.6 MPa) (with the highest values at low purge pressures). Thus, it can be concluded that for the activation of nitrogen-containing gas, the most promising is the use of a discharge device with a protruding electrode.

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USE OF ACTIVATED GASES AS A DIRECTION OF INCREASING THE EFFICIENCY OF TECHNOLOGICAL PROCESSES IN METALLURGY

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Technological operations in the production of steel and metal products are based on oxidation-reduction chemical processes (burning of fuel, oxidation and recovery of impurities). The special importance of chemical oxidation processes is established in the processes of steel production, which is associated with the removal of excess content of silicon, manganese, carbon and phosphorus from the composition of the molten metal charge. At the same time, gaseous oxygen is used as the main oxidizer in established technical solutions. In modern metallurgical units, the maximum efficiency of the flow of chemical transformations using gaseous oxygen has been achieved.

The rate of chemical interaction of various elements with oxygen is determined by the activation energy of a certain transformation. In particular, in an activated state, oxygen forms an ozone molecule,

which is more chemically active than a gaseous oxygen molecule. This is caused by the presence of an additional atom in the molecule, which shifts the electron density of the molecule and reduces the activation energy of chemical processes with its participation.

In general, the activation of gaseous substances occurs under the influence of external influences, which include: the influence of ionizing radiation (UV, α, β and γ spectra); the influence of excess heat; the effect of electric discharges. The formation mechanism consists in the destruction of stable molecules of a gaseous substance and the formation of ions, which interact with molecules to form chemical compounds. At the same time, from a technological point of view, the most successful method of activating gaseous substances is the use of electric discharges. The efficiency of substance transfer depends both on the design of the ionizer and on the power of the discharge itself. The specified features make it possible to influence the processes taking place in the volume of the converter within wide limits.

In the course of research, it was found that the use of an activated flow contributes to an increase in the heat level of the under-furrow area, which indicates a greater heating of the bath than on comparative melts, probably due to a more active flow of silicon oxidation reactions at the beginning of purging, carbon in the middle of purging and afterburning formed in the course of purging CO to CO_2 gas - at the end of purging. At the same time, the analysis of the change in the carbon content and its oxidation rate during blowing of the melt revealed an increase in the proportion of oxygen spent on carbon oxidation when using an activated oxygen flow, with a corresponding increase in the rate of carbon oxidation during blowing and a reduction in the duration of blowing until the torch falls. Conducted research on the level of dust emission from the converter on experimental fuses showed a decrease in this indicator when using an activated gas flow by the order of 56.9% relative to in the period of slag introduction and by 69.5%relatively during the period of blowing under the slag. Based on the results of laboratory studies, the analysis of the influence of the amount of ozone in the purge gas on the amount of dust released from the unit showed the presence of an inverse relationship with the minimum level of dust release at an ozone productivity of about 25-30 g/t·min. The results obtained in the work testify to the high significance of the direction being developed for the metallurgical industry, and the established scientific and technical provisions suggest the continuation of research in terms of the design of discharge devices and a deeper study of the interaction of activated jets with a liquid iron-carbon bath.

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STUDY OF THE IMPACT OF HYDROGEN INJECTION INTO THE BLAST FURNACE ON CO_2 EMISSIONS AND COKE CONSUMPTION

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The idea of using hydrogen and posing the problem of its use in industry was formulated in the early 70s of the 20th century after the first oil fuel crisis. It should be noted that at that time domestic researchers were also engaged in the use of hydrogen in blast furnace production. In the world, at the level of public policy, more and more attention is paid to the development of the hydrogen direction, and hydrogen energy is gaining more and more support not only at the corporate level, but also at the state level. Hydrogen energy with its diverse sources, low carbon emissions, high efficiency and wide range of applications is considered the most promising and environmentally friendly energy in the 21st century and is included in the national energy development strategy of many countries. Therefore, the question of using hydrogen in metallurgy in general and the blast furnace in particular, as the most energy-intensive unit in the metal production cycle, is relevant from the point of view of reducing carbon dioxide emissions.

With the use of improved models of heat and energy balances of blast furnace smelting, estimation calculations of the influence of the use of different hydrogen consumption on CO_2 emissions, technical and economic, thermal and energy indicators of blast furnace smelting were performed.

It was established that an increase in hydrogen consumption by every ~50 m^3/t allows to reduce the output of CO_2, taking into account the afterburning of CO outside the blast furnace, by 2,4-2,6%, and the use of hydrogen in the amount of ~600 m^3/t will allow to reduce CO_2 emissions by 33,4-337%. In addition to reducing CO_2 emissions, the use of hydrogen in the blast furnace allows to reduce coke consumption by 0,46-0,48% for every 10 m^3/t of H_2, which is equivalent to reducing coke consumption by 0,22-0,25 kg/m^3 of hydrogen. Thus, for the first time, the coefficient of replacement of coke by hydrogen when using hydrogen in the blast furnace was determined analytically – 0,22-0,25 kg/m^3.

According to the results of the study, it was determined that the joint injection of hydrogen and PCI into the furnace of the blast furnace allows to solve two tasks at the same time: reducing CO_2 emissions (with an increase in the consumption of hydrogen) and ensuring the minimum cost of iron and steel (with an increase in the consumption of PCI).

As a result of the analysis, the critical consumption of fuel additives was determined, at which, according to Gruner's principle, it is possible to expect to achieve full recovery of iron only indirectly, which means the minimum consumption of fuel when reaching rd=0%:

- with consumption of hydrogen 585-600 m^3/t and coke 378-401 kg/t;
- at consumption of PCI 100 kg/t, hydrogen 500 m^3/t and coke ~329 kg/t;
- at consumption of PCI 150 kg/t, hydrogen 485-500 m^3/t and coke 268-289 kg/t;
- at consumption of PCI 200 kg/t, hydrogen 450-485 m^3/t and coke 228-251 kg/t;
- at consumption of PCI 250 kg/t, hydrogen – 421-450 m^3/t and coke 191-212 kg/t.

Injection of preheated hydrogen into the blast furnace opens significant reserves for reducing CO_2 emissions and coke consumption. Heating of hydrogen in the amount of 100-500 m^3/t for every 100°C allows to reduce the predicted output of CO_2, taking into account the afterburning of CO outside the blast furnace, by 0,37-1,35% and to reduce coke consumption by 0,07-1,16%.

Based on the above, it was established that the use of hydrogen in the blast furnace is a promising way to reduce CO_2 emissions and reduce the consumption of coke and other fuel additives in the blast furnace.

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CORRECTION OF SULFIDE CAPACITY OF BUCKET SLAG

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The results calculations changes in the sulphide capacity of slag formed during ladle desulfurization pig iron using co-injection scheme using mixture based on lime and magnesium are presented. Before start of blowing desulfurizing reagents on the surface ladle bath, usually 0.6-1.2% of the mass slag metal, which got into the ladle with cast iron when it was released from blast furnace or when overflowing from mixer, remains. The composition first ("primary") is significantly different from composition of blast furnace slag and is characterized by reduced basicity and insignificant sulfide capacity.

Slag after desulfurization of cast iron consists of primary residues and products of sulfur removal and redistribution reactions, residues of undigested lime (CaO, MgO, CaS, etc.). As a result of mass transfer processes CaO→MgS→CaS→MgO, the chemical composition and physical properties of slag change continuously. Removal of slag after desulfurization is complicated by an increase in its volume, changes in consistency and unreasonable losses of iron, the content of which in the form balls of various fractions reaches 68-80%.

An increase in the content of CaO and MgO in slag increases its basicity, melting point and viscosity, and leads to a change in surface tension. The formation of a more liquid slag in order to create conditions for returning part of slag balls to bath is possible due to use of modifiers (fluorspar, silica, potassium carbonate, sodium chloride, colemanite, nepheline syenite, calcium aluminate, etc.), containing at least one of components of the formed ladle slag of the $CaO-SiO_2-MgO-Al_2O_3$ system.

The report presents results of calculations to determine the possibility of adjusting the basicity, viscosity, melting point, and sulfide capacity of the "primary" and final ladle slags when using steelmaking waste - final desulphurization slags of steel on ladle-furnace units (subject to limiting the content of S in the latter). Positive industrial experience of using such slags as a bucket slag modifier is known.

It is known that the most easily melting eutectics ($CaO{\cdot}SiO_2$+$CaO{\cdot}Al_2O_3{\cdot}2SiO_2$+tridymite; $CaO{\cdot}SiO_2$+$CaO{\cdot}Al_2O_3{\cdot}2SiO_2$+$2CaO{\cdot}Al_2O_3{\cdot}SiO_2$), in contrast to the coating slags of ladle desulfurization of cast iron with the injection mixtures based on CaO and magnesium, melt at a temperature of ~1300 ^{0}C. The mass of sulfur that can be removed with slag (slag sulfur productivity) differs from slag sulphide capacity obtained by calculations based on thermodynamics. Despite existence of various mechanisms and causes of iron loss during bucket desulfurization: removal of Fe in the waste gas stream; flight of Fe drops outside bucket during destruction of floating gas bubbles at the metal-gas interface; drawing slag into the metal bath by currents in the bubbling zone with capture of liquid metal; removal of Fe with the slag that flows from surface of the bath after processing, largest losses (0.4-2.6% of the metal mass) are due to the last option.

The authors of the report investigated conditions of change and characteristics of the slag desulfurization of cast iron on the UDCH in the 230-t pouring ladles of the converter shop of PrJSC "Kamet-Stal". In the technological route of steel production at PrJSC "Kamet-Stal" "bucket-furnace" units (ACP) are involved; steel refining waste, which includes low-oxidized slag ($SHAKP_1$) with a high CaO content and a sulfur content of 0.2 to 0.9%. Composition of $SHAKP_1$ slag, %: 65-68 CaO, 24-26 SiO_2, 4.4-5.3 MgO, 2.21-4.23 Al_2O_3, 0.1-0.13 P_2O_5. The use of $SHAKP_1$ slag as a modifier of "primary" slag will also contribute to solving environmental problems (waste disposal) and reducing the cost of processing and iron losses. In slags with a basicity of CaO/SiO_2 below 0.93 (corresponding to the molar ratio of CaO/SiO_2=1), the formation of CaS is slowed down due to the absence of free O^{2-} ions and requires additional lime consumption. The introduction of $SHAKP_1$ with a CaO content > 60% is able to save precious fluidized lime.

According to the results studies of the mechanism desulfurization of cast iron, it is shown that low-melting slags of eutectic composition have the maximum fluidity, and their adsorptive capacity depends on the degree of structural and chemical arrangement [1]. It is known that MgO and Al_2O_3 additives reduce the melting point of slag in certain intervals of their content.

The authors of the report performed calculations of changes in the chemical composition of the "primary" and final ladle slag of UDCH PrJSC "Kamet-Stal" when introducing $SHAKP_1$ in the amount of 0.05-0.3% of the mass of cast iron, determined their sulfide capacity, melting point and viscosity after modification. The viscosity and melting point of the investigated slags were determined using ternary diagrams.

Prediction of sulphide capacity (Cs) of modified slags was performed using optical basicity (Λ) proposed by Duffy and Ingram. The models proposed by Duffy et al., Tsao et al., Hao & Wang, Sosinsky & Sommerville, Young et al., Znang et al., Shankar et al. were used to calculate the value of Λ. When calculating Λ and determining changes in physical and chemical properties, the main components of slag (CaO, SiO_2, Al_2O_3) and the presence of up to 10% MgO were taken into account. The used models give excellent results (log$C$s values) for slags modified by the introduction of SHAKP1 (range from -2.3 to -5.15), but in general correspond to the data of known studies. Considering the fact that desulfurization slags are usually not homogeneous and contain a certain amount of solid CaS, the prediction of Cs may not be accurate enough for industrial conditions, but it is suitable choosing directions for optimizing the composition of cover slag using CaO and Al_2O_3-containing waste.

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INVESTIGATION OF THE KINETICS OF SOLIDIFICATION OF A 205-TON FORGING INGOT ON A COLD PHYSICAL MODEL

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The main consumers of large forging ingots are the energy and heavy engineering industries. Turbine rotors, parts of reactor bodies, shafts of propellers and rolling mills, parts of chemical equipment are made from such ingots. Based on the operating conditions (dynamic loads, elevated temperatures, aggressive environments), high requirements are placed on the metal of such parts.

The conditions of solidification of large forge ingots (a large volume of liquid metal and a long time of its solidification) lead to a significant development of liquation and shrinkage processes in the metal melt and, as a result, physical and chemical heterogeneity of the cast metal. During further thermomechanical processing, the inhomogeneity of the ingot is inherited by the forging and semi-finished products obtained from it. Therefore, the problem of improving technologies for the production of large forging ingots is still relevant.

Experimental studies of the processes that occur during the solidification of large ingots are very complex and expensive. In these conditions, it is advisable to apply physical modeling methods on cold transparent models with compliance with similarity criteria.

The purpose of this work was to determine the influence of the parameters of electroslag heating (ESH) and feeding the top part of the ingot on the process of solidification of a 205-ton steel forge ingot in the mould and the development of shrinkage defects.

Experiments were conducted on a flat model simulating the longitudinal section of the ingot. The model is made on a scale of 1:15 with geometric similarity to the real object. As a model liquid, a solution of sodium thiosulfate ($Na_2S_2O_3$) was used, which solidify according to the dendritic mechanism. The melting point of sodium thiosulfate is 48.3 °C, and it retains optical transparency until complete solidification, which allows you to visually observe the processes of forming the crystal structure of the ingot. Fixation of the solidification process was carried out with the help of photo and video recording. The temperature of the melt was controlled by thermocouples. To evaluate the thermal processes during the solidification of the ingot, temperature measurements of the surface of the model were carried out during the entire solidification time using a Wintact WT3160 thermal imager.

It was established that the use of ESH leads to the displacement of the heat center to the top part of the ingot and an increase in the angle of inclination of the V-shaped crystallization front, which improves the feeding of the axial zone of the ingot with liquid metal. Under these conditions, the vertical component of the advancement of the solid phase gradually increases, which at the final stage of solidification of the ingot begins to prevail over the horizontal component. This provides favorable conditions for elimination of axial porosity and reduction of liquation processes. At the same time, no noticeable influence of ESH on the structure formation of the lower part of the model ingots (from the bottom part to a height of $0.5...0.6 \times H_{ing}$, where H_{ing} is the height of the ingot) was found. This gives reason to believe that ESH can be started not immediately after pouring the metal into the mold, but after a certain period of time.

It is shown that ESH with the temperature of the slag pool at the level of $1.15 \times T_m$ (where T_m is the melting temperature of the metal) and liquid metal feeding with a temperature of $1.2 \times T_m$ and a volume of 1.5...2 % of the total volume he ingot, ensures the complete elimination of axial porosity and shrinkage shell in the top part of the ingot. In real conditions, this will reduce the volume of the top part of the ingot by 70 % and thereby save up to 25 tons of metal that goes to scrap. At the same time, the total time of solidification of the ingot increases by an average of 15...20 %. On the basis of the conducted studies, the preliminary modes of ESH with liquid metal feeding of a 205-ton forge ingot were recommended.

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RESEARCH OF CHARGE STREAM CHARACTERISTICS IN A BLAST FURNACE

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The use of bell-less top (BLT) on blast furnaces of various volumes, an increase in the design options of the charging device and its distribution chute, require taking into account the parameters of the stream of materials leaving the distributor in the algorithms of the models.

A calculation method has been developed for estimating the density distribution of the stream of burden materials leaving the BLT chute when they are charged into the furnace. To assess the adequacy of the results of the calculations, experimental studies of the charge stream parameters were performed. The experimental method with the use of a sensor measuring probe was improved, which made it possible to check the results of calculations in industrial conditions. The body of the probe is mounted in the furnace space within the cylindrical part of the furnace using a special support structure on the mark corresponding to the charge stock level. It was experimentally established that the width of materials stream that are charged when using the angles of inclination of the chute in the range of 30°-48° differs slightly and at the level of filling the charge of 1.0 m is about 0.8 m, and the distribution of the stream density along its width is uneven - the most the intensive part is shifted in the direction of the furnace center.

A method of experimental assessment of the trajectories of charge materials in the furnace was developed based on the formation of geometric "ridges" by charging portions of charge materials from the specified angular chute positions followed by non-contact measurement of the profile of charge filling in the furnace, a patent was obtained.

New computational and experimental data on the regularities of the stream density distribution of charge materials made it possible to clarify the method of choosing rational angles of inclination of the chute in working angular positions and to improve the mathematical model of the radial burden distribution.

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PRODUCING STEEL WITH USING CONVERTER PROCESS IN THE MODERN METALLURGICAL INDUSTRY OF UKRAINE

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Metallurgy is one of the leading sectors of the economy of Ukraine [1-4], by 2022 it was be the second largest and profit article of Ukrainian exports [2]. Steelmaking production is the second stage in the total production cycle of ferrous metallurgy [3]. In general, Ukraine is one of the leaders of the steel producers in the world [1, 3]. In 2021, Ukraine took 14 place in the global rating of world manufacturers of steel according to World Steel Association (WSA) data [1]. During 2021 year in Ukraine was produced 21366 thousand tons of steel [1].

In the modern metallurgical industry of Ukraine, the main methods of steel making is the oxygen converter process, Marten process and electrometallurgical process [3]. The ratio in the overall production of steel between these of technological processes changes every year [3]. It should be noted that obtaining steel by oxygen-converter technological process is the most common in the world and Ukraine. Already in 2011, the fate of the steel obtained in the converters was approximately 70% from other ways of production of steel in the world. As of 2017, in Ukraine, the fate of steel produced in

converter was 71.7% [6] from total steel produced [5, 6]. Converter process is predominantly using for obtained the common steel marks.

Steel production with converter process has the potential for further development in the country and increasing it is production. According to the data [3-6], produced steel with converter process is the most favorable in cost compared to other basic ways of the steel producing in Ukraine. For example, an electric steel, which is obtained by the process of smelting in arc steelmaking furnaces. The marks of electric steels similar to the converter steel assortment can be more expensive in the range from 7.8 % to 95.6 % [4]. The marten steel is more expensive than converter steel from 24.5 % to 99 % [4]. Such data indicate the expediency of predominant use for the common marks of steels the converter process.

The above testimony and the fact that converter process of steel in Ukraine is the only one that in general does not require fuel resources (natural gas, coke and others). All written above is important arguments for concentration on further development on the converter process in the ferrous metallurgy of Ukraine for producing the common steel marks. Steel from the converter by basic characteristics and quality is not inferior to the electric steel and Marten steel. Converter steel can be better with production by progressive technological process [1-6].

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RESEARCH OF GAS DYNAMICS TWO-PHASE FLOW IN A T-SHAPED LANCE

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The transition to use effective, from point of view increasing intensity input and, accordingly, reducing duration of ladle processing cast iron, ease maintenance, etc., lances with a T-shaped tip led to emergence associated problems, including nozzle clogging and complications in redirecting gas powder flow at the nozzle from working space of the nozzle without loss of energy due to changes in speed and direction of flow, uneven wear refractory protection nozzles along height, especially in areas close to the nozzles, non-stationarity pressure carrier gas in front nozzles, etc.

The report presents results of studies gas dynamics of two-phase flow in working space of T-shaped tip submersible nozzle and formation of gas-powder jets at exit from nozzles. The methods of physical modeling gas dynamics flow using transparent models of T-shaped tip and results of studies macrostructure cross-section nozzle, "clogged" in the process blowing gas-powder jets based on a mixture of lime and magnesium into the molten iron in order to ensure the removal of sulfur, were used.

It has been confirmed that the process uniform and continuous blowing gas powder jets deep into melt in ladle largely depends on the characteristics gas powder flow in the nozzle channel, working space tip and at the exit from the nozzles. The character macrostructure materials "clogging" nozzle indicates possible energy losses of gas-powder flow formed at the outlet latter. This leads to flow metal melt into inner space nozzle with subsequent freezing, a decrease in inner diameter nozzle, an increase in resistance system with formation of obstacles to exit of the desulfurizer mixture into bath. The latter is complicated due to insufficient momentum flow and occurrence pulsations in zone of leakage from nozzles during transition from jet to bubble mode.

According to research results, it has been confirmed that amount of metal melt entering nozzle lance in case of violations calculated blowing mode decreases with an increase in flow rate carrier gas and stops after reaching a certain critical value close to speed of sound. When flow rate carrier gas increases, there is a transition to the jet flow mode, and after its completion, access to nozzle for liquid is stopped, and the jet shredding on bubble occurs at a considerable distance from nozzle.

In this work, influence configuration of the working space (WP) tip on the angle of opening and length horizontal section gas-powder jet is investigated. In order to change configuration WP, different bottom shapes were used in the inner space transparent model T- shaped tip and its depth (distance from bottom to axis of the nozzles). We used shapes bottom surface in the form of a hemisphere and a concave hemisphere, a cone and a cylinder.

The peculiarities gas dynamics of the gas-powder flow in the transparent tip model were studied using high-speed (240 f/s) imaging. By processing results of the experiments, differences and features movement of solid particles of different fractions in working space tip, length, diameter and particle filling of the horizontal section of the flow in the nozzle and formed jet at the exit of the nozzle tip were established. At a high degree of flow loading, small fractions, in contrast to "large" fractions, move at the speed gas flow.

A method of calculating rational angle of inclination of the surface bottom of the WP T-shaped tip is proposed to ensure minimization of energy losses on the redirection of particles gas-powder stream, reflected from bottom, into nozzle.

It was established that with a decrease in the distance between bottom in the WP tip and axis of the nozzles, density gas-powder flow increases proportionally and depends to a small extent on shape of the bottom. The ratio between length horizontal section of the gas-powder jet and its diameter at a distance of 18 cal. from the nozzle section is: 0.9 – for a cylindrical bottom shape, 1.33 – for a “cone”, 2.0 – for a “concave hemisphere” and 2.4 – for a hemispherical bottom, respectively.

It was found that profile of the gas-powder jet can be used to distinguish horizontal and ascending sections, where jet loses its ability to penetrate into the bath. To optimize blowing process, you need reliable information about opening angle gas jet, penetration depth, structure plume, turbulence volumetric flow, which characterize the main parameters jet. According to the data of various researchers, opening angle of the gas jet in air-water system is 20 degrees, in the mercury-air system - 155 degrees. Thus, opening angle depends on properties of the liquid (density, surface tension). For iron-carbon melts, opening angle can probably vary in the above range.

Regarding distribution of particles on the horizontal section gas-powder jet at exit from nozzles, following can be noted. As a result of the significant difference between density of the gas and solid components gas-powder jet, its separation is observed with formation of less concentrated (upper) gas and more concentrated (powder) parts. At the same time, the most uniform distribution of particles along jet profile in the studied conditions was observed when using a cylindrical shape of the bottom. The opening angle gas-powder jets at the exit from the nozzles corresponds to the following values: 10 degrees – for a cylindrical bottom, 12 degrees – for a “cone”, 16 degrees – for a “concave hemisphere” and 22 degrees – for a hemispherical bottom, respectively.

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NEW METHOD OF SUBSTANTIATED ADJUSTMENT OF THE CHARACTERISTICS OF THE BURDEN REGIME ENSURING THE FORMATION OF RATIONAL PARAMETERS OF THE COHESIVE ZONE IN THE BLAST FURNACE

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The results of numerous studies confirm the significant role of the blast furnace burden regime in shaping the cohesive zone and the impact of the burden regime parameters on its characteristics. Using the method developed at the ISI for determining the shape and position of the cohesive zone, research was conducted to establish the relationships between the parameters of the cohesive zone and the gas temperature above the charge surface based on real data from an operating blast furnace. The findings from these studies revealed correlations between the vertical coordinates of the melting line and the gas temperature above the charge surface and the ore burden in equal-area annular zones of the blast furnace, demonstrating the potential for controlling the position and shape of the cohesive zone using thermal measurement probes, as well as adjusting the parameters of this zone by altering the distribution of ore burden within the radial profile of the blast furnace hearth. It was established that the interconnection between the vertical coordinate of the melting line in the annular zone and the ore burden in that zone is characterized by sufficiently high coefficients of approximation by a power function, which is 0.80.

The boundaries of the cohesive zone are determined by the respective softening and melting temperatures. In the context of charging the blast furnace with multi-component burden materials, the softening and melting temperatures of the charge materials in a particular annular zone are determined by the composition of the material mixture in that zone and their individual high-temperature properties. The ratio of the quantity of pellets to sinter in these zones can be used as a controlling parameter in adjusting the temperature level of the softening and melting surfaces in different annular zones of the blast furnace. This is supported by a high coefficient of approximation of the interconnection between the difference in softening and melting temperatures and the specified ratio, which is 0.99.

The control of the parameters of the cohesive zone, the selection of the direction and magnitude of the controlling influence in each specific case should be based on the results of mathematical modeling of the distribution of burden materials across the radial profile of the furnace hearth, the determination of the composition of the mixtures of burden components in different furnace zones, the prediction of their high-temperature properties, and the trends in changes in these properties when altering the component composition of the mixture. To regulate the distribution of a specific component of the mixed iron ore portion across the radial profile of the hearth, the control parameter can be the setting of the location of the dosage of this component in the volume of the portion (feed) on the conveyor or skip. Formulas have been derived to determine this quantity for given component content in the annular zone and its content in the burden for blast furnaces with different charging system structures.

The results of the research allowed for the establishment of interconnection between the parameters of the cohesive zone (determined using the proposed method) and indicators of the distribution of burden materials across the radial profile of the blast furnace hearth. The identified interconnection between the distribution indicators of the burden across the radial profile, such as ore loading and the content of burden components in the annular zones of the hearth, with the parameters of the cohesive zone, serve as the basis for the development of a substantiated adjustment method for the characteristics of the burden regime, ensuring the formation of rational parameters of the cohesive zone in the blast furnace.

UDC 669

PROSPECTS FOR USING CCM FOR CASTING SMALL SECTION BARS AT MINI-MILLS

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Since the end of the last century, there has been a steady trend in the world towards the construction of mini-smelting plants instead of huge steel mills with a full cycle of metallurgical production. Such mini-plants are usually focused on processing scrap metal and metallized raw materials [1]. The introduction of mini-plants is particularly relevant in the context of the transition to green metallurgy. The low productivity of such enterprises (40-2000 thousand tons of steel per year) and small order volumes with often quite different product mixes make it possible to use mini-caster machines, usually of horizontal type, to cast billets with a cross-section equal to or as close as possible to the cross-section of the finished product. Such CCMs reduce the number of finishing stands in a rolling mill, which reduces the energy intensity of production, shop floor space and capital expenditure on construction. The advantages of such CCMs also include lower consumption of auxiliary materials, such as lining, slagging mixtures, cooling water, etc. A characteristic feature of many mini CCMs is the use of graphite molds instead of copper ones as in traditional CCMs, which are cheaper to manufacture.

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UDC 669

PREPARATION AND CONDUCTING OF PHYSICAL MODELING OF THE STUDY OF THE EFFECT OF GAS SUPPLY THROUGH A HOLLOW ELECTRODE ON THE CHANGE IN THE GEOMETRIC PARAMETERS OF THE HOLE

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The operating mode of the ladle-furnace transformer has a direct impact on the length of the electric arc, which forms a hole at the slag-metal interface. The reaction zone, which occurs when the electric arc interacts with the metal bath under the electrode, has the shape of a "meniscus".

To evaluate the combined effect of the electric arc pulse and gas supply through the channel of a graphitized hollow electrode (GHE), preliminary calculations were made on the geometric parameters of this hole. Parameters such as depth and radius depend on the value of the arc length, which was determined in [1].

Then, based on the calculated similarity criteria, an experimental plan was developed and an experimental setup was created to conduct the study. During the experiment, such parameters as the intensity of gas supply through the GPE channel, the height of the slag cover, and the height of the hollow electrode above the level of the metal mirror were changed. Video recording of the data was performed at the front of the metal-slag interface and from below. The following parameters were monitored: diameter and depth of the hole formed, gas pressure, slag thickness, and height of the HPE.

Based on the physical modeling carried out, using the isothermal model, it is possible to obtain analytical expressions showing the joint effect of the electric arc pulse and the gas jet, which affect the heat transfer characteristics.

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BLAST FURNACE: “BE OR NOT TO BE?”

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According to [1], the blast furnace – basic oxygen furnace (BF-BOF) steelmaking process has a significant potential to reduce CO_2 emissions to levels comparable to direct reduction technologies.

The “green deal” requires green steel, in other words, the steel industry needs to decarbonise, but the decarbonisation of other industries also depends on the steel industry. According to ArcelorMittal, the construction of 1 MW of solar power plant capacity requires 35 to 45 tonnes of steel, and a wind power plant requires 120 to 180 tonnes [2]. Therefore, the decarbonisation of the energy and transport sectors, which are the main sources of CO_2 emissions, should go hand in hand with the decarbonisation of the steel industry to enable progress in the same direction. Moreover, low-CO_2 steelmaking technologies have not been widely adopted because they involve higher production costs. Compared to the BF-BOF route, producing a tonne of steel using low-carbon technologies will cost up to 80% more [3]. This argument also points to the need to maintain and upgrade BF-BOFs at least until CO_2 emissions

in the energy and transport sectors are reduced to levels comparable to those in the steel industry. A rational and systematic approach can be demonstrated by the example of the Japanese steel industry.

The development plans of Japan's largest metallurgical corporation, Nippon Steel [4], do not include a rejection of the BF-BOF route, unlike, for example, the Ukrainian metallurgical company Metinvest [5]. On the contrary, the Japan Iron and Steel Federation [6] promotes the idea that even though the blast furnace (BF) for iron ore reduction in steel production has a stronger environmental impact than the method of melting steel scrap in an electric arc furnace (EAF) for steel production, the BF-BOF route creates steel products that result in scrap, which, through recycling, leads to a reduction in CO_2 emissions. Since the effect of scrap recycling compensates for the CO_2 emissions from the BF-BOF process, the environmental impact of the BF-BOF and EAF routes is generally the same as that of repeated steel recycling [6]. This approach is reflected in the Japanese standard JIS Q 20915 "Life cycle inventory of steel products".

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Electrometallurgy

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STUDY OF THE EFFECT OF ANNEALING DURATION ON THE MECHANICAL PROPERTIES AND MICROSTRUCTURE OF TITANIUM-BASED ALLOY SAMPLES MANUFACTURED USING 3-D TECHNOLOGY

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Additive production, in particular selective laser melting (VLP) - a modern method of manufacturing parts and assemblies of complex geometry from metal powder, which is difficult or impossible to reproduce in traditional production. A feature of this technology is the residual stress generated at the stage of production of parts. Since titanium alloys are characterized by low thermal conductivity, the problem of residual stress formation is especially relevant for them, and heat treatment to remove them is mandatory for products made by VLP technology. Since the structural state of products obtained by VLP technology differs from that formed by the use of traditional technologies, it is necessary to study the effect of annealing to relieve residual stresses on the mechanical properties and microstructure of Ti6Al4V alloy obtained by VLP technology. Examined samples after annealing with a holding time of 1… 5 hours at 800° C. It was found that the temporary resistance after heat treatment for 1… 5 hours decreases compared to the initial state after manufacture by 20.55… -23.03%, the relative elongation - an increase of 31.33… + 35.57%. The nature of the change in the values of the relative narrowing is uneven: annealing with a holding time of 1 hour does not cause significant changes; with increasing exposure time to 2, 3 and 4 hours, there is a decrease in this characteristic by 9.03%; 45.97%; 62.56%, respectively, compared to baseline; after 5 hours the value of the relative narrowing increases this characteristic in comparison with the values after 4 hours by ~ 26.12%. According to the results of correlation analysis of the values of mechanical properties and parameters of the microstructure, it was found that the shape coefficient of α-phase plates has a high correlation with the values of temporary resistance, and the amount of α-phase correlates most with relative narrowing values under static stretching.

UDC 668.048: 623.552: 622.23

STUDY OF THE MECHANICAL PROPERTIES OF CO-CR-MO ALLOY SAMPLES MADE BY THE TECHNOLOGY OF SELECTIVE LASER MELTING WITH A TECHNOLOGICAL STOP

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In the modern production of parts from metal powder, the method of selective laser melting - Selective Laser Melting (SLM) - has become widespread. In Ukraine, the company "Additive Laser Technologies of Ukraine" LLC is engaged in the development of equipment for creating parts from metal powders using SLM technology. Currently, an urgent task for this equipment is the development

of a methodology for selecting the parameters of the metal powder melting process, which ensure the necessary mechanical and operational properties of the parts. For the research, three experimental cylindrical samples of Co-Cr-Mo alloy were made for tensile testing according to ISO 6892:2019 - the diameter of the working zone is 5 mm, with a controlled stop at a height of 18 mm from the beginning of the working zone, the total length of which is 28 mm As a result of the analysis of the values of mechanical properties, it was established that the temporary resistance of the test samples with a controlled stop within 24 hours. of the Co-Cr-Mo alloy, produced by SLM technology, undergoes a decrease in comparison with the samples produced without controlled stopping - by ~13%, relative elongation - by ~1%, and relative narrowing - by ~17%. It was found that for the experimental signs with a stop in the construction process, the deviation of values from the average values was: for temporary resistance ~11%, relative elongation ~62% and relative narrowing ~21%. This is caused by the destruction of one of the samples at the stop. The use of parts with a manufacturing defect (stoppage of construction) must be significantly limited, in accordance with the possible significant weakening and embrittlement of the product.

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JUSTIFICATION OF THE MODES OF SLM TECHNOLOGY WITH THE AIM OF REDUCING RESIDUAL STRESSES BY CALCULATION METHOD

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Improvement of the modes of selective laser melting technology based on the calculation model to reduce the level of residual stresses and prevent deviations in the geometry of the part. The results of modeling on a universal voxel structure and a simplified object for predicting metal behavior depending on the specific energy density in the region of the boundaries of a metal part with Inconel 718 are presented. An experiment was conducted to study the influence of different strategies and process modes on the distortion of parts as a result of the influence of residual stresses from in order to minimize them. Printing was carried out on the 3D printer "Alfa-150" (ToV "ALT Ukraine") at a constant power and distance between tracks in each zone (up-skin, down-skin, in-skin) with a change in the speed of the laser beam, and as well as different schemes for building up samples using 3D printing with a 67˚ rotation of each new layer relative to the previous one. In order to determine defects and deviations from the original model to the solid body (sample), metallographic analysis was performed using optical microscopy (Carl Zeiss AXIOVERT 200M). It has been established that the simulation of printing processes, performed on the Magics platform, with the help of dividing the model into a voxel structure, makes it possible to analytically assess stresses and strains. The analysis of the appearance of the experimental samples showed that the best down-skin indicators are formed at a power of 80 W and a specific energy density (40...38 J/mm3). When using a staggered printing strategy with a 67° rotation at an optimal specific energy density, it is possible to minimize the residual internal stresses that lead to product distortion. In the future, the results can be supplemented by studies of the influence of residual stresses of compression forces under the influence of a laser beam at a constant applied power. With the use of a calculation model, which allows you to calculate the residual stresses when applying the next layer, depending on the speed of the laser movement, power and distance between the applied tracks, it is possible to obtain high-precision parts with specified properties. The model has been adapted to obtain a quantitative estimate of the residual thermal stresses depending on the speed of movement and laser power for the heat-resistant alloy Inconel 718. The optimal modes for minimizing these stresses and reducing the distortion of the part have been determined.

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COMPARATIVE STUDIES OF THE MECHANICAL PROPERTIES OF AlSi10Mg SAMPLES PRODUCED BY THE TRADITIONAL METHOD AND BY THE TECHNOLOGY OF SELECTIVE LASER MELTING

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Additive manufacturing technology, also known as 3D printing, has been used more and more recently, and the number of materials and methods that can be used is expanding.

As part of the work, it is necessary to establish rational modes of manufacturing samples from AlSi10Mg aluminum alloy with a layer thickness of 40 microns using the technology of selective laser melting, to study their mechanical properties, and to compare them with samples made by the traditional method of production. To determine the structural state of the alloys, optical microscopy was used, granulometric analysis was performed using a scanning electron microscope, and mechanical properties were determined according to the standard method using a tearing machine.

It was found that when the scanning speed is increased to 1200 mm/s, the distance between the tracks plays a significant role in obtaining high density. From the analysis of mechanical properties, it was established that the samples made by VLP technology have a higher value of temporary resistance by 28%, and lower values of plasticity characteristics (relative elongation and relative narrowing) by 17.4% and 31.7%, respectively, compared to samples, made according to the traditional method of production.

The dependence of the change in the density of the experimental samples made by the VLP technology with AlSi10Mg on the manufacturing parameters was established. It was established that at a scanning speed of 1000...1100 mm/s, the samples have an average pore size of 2...7 μm; samples made at a scanning speed of 1200 mm/s - from 1 to 5 μm.

Application of the obtained results will make it possible to manufacture parts with increased strength characteristics.

UDC 669[017.15+058]

PHASE COMPOSITION OF THE $AlCr_{0.5}FeCo_{1.75}Ni_3W_{0.5}Ti_{0.8}B_{0.6}$ HIGH-ENTROPY ALLOY OBTAINED BY THE ARC MELTING METHOD

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In 2004, a new type of materials was developed - high-entropy alloys (HEA) [1-2.]. Investigation of HEAs have shown that they are promising wear-resistant materials because they simultaneously exhibit high fracture toughness, hardness, high-temperature resistance, and an excellent combination of high strength and ductility. This paper presents the results of research on HEA of the following composition $AlCr_{0.5}FeCo_{1.75}Ni_3W_{0.5}Ti_{0.8}B_{0.6}$.

The investigated alloywas obtained by the arc melting method using metals with a purity greater than 99.5 at% and titanium diboride powder as initial components. In the work, TiB_2 is used as a raw material because the thermal properties and density of boron are significantly different from those of

metals, which makes melting difficult. Melting was carried out with a nonconsumable tungsten electrode on a copper water-cooled hearth. In the first stage, seven metals, namely Ti, W, Cr, Fe, Co, Ni, and Al, were melted in an arc furnace in required ratios. The resulting ingots were mechanically crushed to powder, which was mixed with TiB_2 powder and remelted six times to homogenize the composition.

The XRD analysis data of the as-cast $AlCr_{0.5}FeCo_{1.75}Ni_3W_{0.5}Ti_x$ alloy show that it crystallizes with the formation of simple solid solutions based on BCC and FCC phases whose lattice periods are a=0.2920 and a=0.3615 nm, respectively. After addition of TiB_2 powder to this alloy and repeated remelting, a substantial decrease in the content of the BCC phases occurs, and the presence of boride with a W_2CoB_2-type crystal structure (127 space group) is recorded. Moreover, the BCC solid solution in the boron-containing sample decomposes into two phases, namely BCC_1 and BCC_2, with lattice parameters close to those of tungsten and iron. According to the XRD analysis data, the content of the FCC phase after the addition of TiB_2 remains unchanged, which indicates that boride forms from the BCC phase. It is worth noting that the lattice parameters of the solid solutions based on phases with BCC1 and FCC structures slightly increase after the addition of TiB_2, which may indicate the partial dissolution of boron and titanium in cubic phases.

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NEED FOR STEEL DEGASATION AT PJSC «KAMETSTAL»

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Prospects for the expansion of the quality range of steel produced at PJSC "Kametstal" require the development of out-furnace processing technologies in order to provide opportunities for additional improvement of the quality of the metal. The production of axial and other carbon and high-carbon grades of steel is associated with the probability of the formation of flocs in the continuously cast billet. The reason for this is the content of excess hydrogen and other gases after the processing of the metal melt at ladle-furnace units. The absence of a converter workshop of the equipment for steel degassing reduces the conditions for the production of quality metal, limits the brand list of orders and narrows the potential opportunities of a large manufacturer of metal products.

Modern technological routes of out-of-furnace processing of steel in world metallurgy in the vast majority of cases include vacuuming of liquid metal melt in a steel ladle as one of the important, necessary and penultimate operations before pouring. The availability of appropriate equipment and the implementation of such an operation during the production of steel is determined not only by the possibility of meeting the necessary requirements regarding the content of hydrogen, oxygen, nitrogen and carbon, the final adjustment of its chemical composition, but also by obtaining "clean" metal from non-metallic inclusions.

The variety of existing and applied methods of out-of-furnace (ladle) processing in steelmaking production made it possible to obtain steel with the necessary requirements, ensured more efficient use of expensive energy and material resources, and increased the competitiveness of manufactured metal products.

In recent decades, the development of new grades of steel with specified properties and the regulated content of harmful impurities and alloying elements, so-called "pure steels" [1, 2], which were produced using various out-furnace processing technologies, continued.

The analysis aimed at improving the equipment for ladle processing of steel indicates the preservation of trends in the development and use of multifunctional complexes for the implementation of processes of vacuuming, refining and fine-tuning of steel (composition and temperature) while minimizing the cost components.

In world metallurgical practice, degassing of steel in a steel ladle has become widespread (VD, VOD - chamber methods; DH - batch and RH - circulation methods and their modifications; RM - pulsation mixing (vacuum method)).

Taking into account the analyzed data for the conditions of the converter workshop of Kametstal PJSC, a direct technological route (converter – ladle-furnace unit – vacuum degasser – continuous steel casting machine) of steel production with out-furnace vacuum degassing is recommended for further consideration as an acceptable option.

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DEVELOPMENT OF A CRITERIA FOR EVALUATING THE PROCESS OF DISTRIBUTION OF ELEMENTS IN THE «METAL – SLAG» SYSTEM DURING OUT OF FURNACE STEEL PROCESSING

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Modern expanded views on the physico-chemical processes between metal and slag, the properties of chemical elements and the regularities of the formation of their compounds, the changed conditions of production, the raw material base and the modernization of steelmaking units require taking into account new factors that cause the transition of elements in the «metal-slag» system and simplifying the form of recording and duration of calculations. In the Iron and Steel Institute of Z.I. Nekrasov National Academy of Sciences of Ukraine, the structuring of models to determine the final content of silicon, manganese, sulfur, and phosphorus is carried out on the basis of a combination of the established informative physicochemical parameters of metal, slag melts and additives, their complex ratios and technological parameters, which reflects a new approach to justifying decisions regarding assessment their absorption efficiency. The equilibrium values of sulfur and phosphorus distribution were calculated according to the models of E.V. Prikhodko and D.M. Togobitskaya [1], which are developed based on the analysis of accumulated information in databases. The results of the comparative analysis of the actual distribution with the equilibrium one reflect the degree of remoteness and approach to the rest stage (completion of ion exchange processes) of the «metal-slag» system. As the data analysis shows, part of the data sample of the 09Г2С steel grade and its modifications have approached the equilibrium value for sulfur, but a significant part of the melts is at the stage of significant distance. The evaluation of the efficiency of the element distribution process was carried out according to the following criterion: $\xi = \frac{Le_{кін} - Le_{поч}}{Le_{поч}} \cdot 100\%$, where $Le_{кін}$ – is the value of the distribution of the element between the final metal and slag, $Le_{поч}$ – is the data of the distribution of the element between the initial metal and slag. In the case when the value of $\xi \geq 1$, the process of sulfur removal takes place with its removal from the slag phase, the greater the difference from 1, the more efficiently the desulfurization process proceeds, but in the case that $\xi \leq 1$, segregation of sulfur in the metal melt occurs. The calculation based on the criterion ξ for evaluating the distribution of sulfur showed that its value for the entire data sample is greater than one, with the minimum mark at the level of $\xi min \approx 3.5$, and the maximum $\xi max \approx 730.9$. The values of the ξ criterion depend on the processes of sulfur recharging between metal and slag and are expressed by the interatomic interaction parameter, which is calculated as the difference between the sulfur charge in metal and slag melts: $\Delta Zc\text{^}S = Zc\text{^}Sмет - Zc\text{^}Sшл$. The smaller the values of $\Delta Zc\text{^}S$, the higher the indicators of the ξ criterion and the approach of the system to the equilibrium state, respectively. As a result of the selection of the data most remote in terms of the equilibrium value of sulfur, when expressing predictive models of the type $lgL_{Sфакт} = f(\rho_{шлаку}, \Delta Zc\text{^}S)$ $R^2 = 0,7$, which confirms the continuation of cooperative ion exchange processes in them, in contrast to melts closer to equilibrium on which this parameter has no significant informative value $R^2 = 0,089$. The proposed criterion demonstrates the effectiveness of using the physicochemical apparatus of the concept of directional chemical communication for the description of complex metallurgical processes, in particular, the analysis of the completeness of the flow of physicochemical interactions in the «metal-slag» system, which is a lever of influence for obtaining competitive metal of the quality demanded by metal consumers.

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DEVELOPMENT OF CALCULATION MODELS OF SPECIFIC MAGNESIUM CONSUMPTION AND SULFUR CONTENT IN CAST IRON UNDER DIFFERENT CONDITIONS OF INJECTION DESULFURATION OF CAST IRON

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Ukrainian technology for the process of injection desulfurization of cast iron with granular magnesium was developed by the Institute of Ferrous Metallurgy and the Titanium Institute together with a number of organizations [1,2,3]. The conditions for using extra-furnace desulfurization of cast iron at these enterprises are very different: by the mass of cast iron in the ladles, by the required volumes of desulfurization, by the initial and required final sulfur content. Based on the obtained and available actual indicators and parameters of cast iron desulfurization, a data bank of more than 3000 control treatments of cast iron has been formed - with the sulfur content in the original cast iron, as a rule, being in the range of 0.03-0.06-0.07%. The mass of cast iron in ladles ranges from 40 to 350 tons. The sulfur content in cast iron after desulfurization is mainly in the range of 0.005-0.010%, some of the cast iron is produced with a content of ≤0.002%. In the practice of creating and mastering the process of desulfurization of cast iron by injection of magnesium, reliable prediction of the expected values of the final sulfur content in cast iron is required when varying the initial sulfur content in cast iron, the specific consumption of magnesium and the standard size of ladles in which desulfurization of cast iron is performed. For this purpose, using the obtained array of actual data, models were developed to predict the parameters of the required magnesium consumption for the final sulfur content in cast iron with changing values of the initial sulfur content in cast iron, changing specific consumption of magnesium, and varying mass of cast iron in ladles. These data are presented by the corresponding calculation models:

$q_{Mg} = 0.36 + 8.5*(S_{start} - 0.02) - ((\ln(S_{end}) - \ln(0.015))/11.5)$ – ladles with cast iron weight less than 75 t

$q_{Mg} = 0.206+7.5(S_{start} -0.02)+(\ln (0.02)- \ln (S_{end}))/10.5$ – ladles with a cast iron weight of 80-130 t

$q_{Mg} = 0.200+7.0(S_{start} -0.02)+(\ln (0.02)- \ln (S_{end}))/9.1$ – ladles with a cast iron weight of more than 140 t

The developed calculation models have been tested on almost all operating cast iron desulfurization complexes. Their legitimacy has been confirmed. These results of work and research were an integral part of the technical and technological regulations of existing and newly created capacities for desulfurization of cast iron.

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Automation and modern methods of controlling metallurgical processes and the quality of metallurgical products

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ADAPTIVE CONTROL SYSTEM OF FREE ROLLING SPEED MODE WITH FUZZY CONTROLLER

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The best high-speed mode of rolling mills is the mode of free rolling with loop formation in finishing groups of cages [1]. Stabilization of the loop is carried out by the control system of the rotation frequency of the rolls of rolling cages based on the information of the sensor of the position of the loop.

The increase in the loop depends on the frequency of rotation of the rolls of adjacent cages and the coefficient of extraction of the rolled product in the cage following the adjustable gap.

To set up the system, it is necessary to know the numerical characteristics of the influences that disturb and affect the size of the rolling loop.

The change in the rotation frequency of the main drive of the cages during the stabilization of the size of the rolling loop in the intercellular gap of the cages of the finishing group of the continuous rolling condition was studied [2]. The change in the rotation frequency of the rolls characterizes the total effects of the rolling mode on the size of the loop.

Research have shown that in a non-stationary realization it is possible to single out a trend that is described by a completely deterministic dependence, and to conduct an analysis of a random stationary realization with respect to this trend.

A structural diagram of the circuit for regulating the position of the rolling loop was developed (regulators are calculated according to the method [3]). This scheme includes: an electric wire with a current loop, a speed loop, a speed regulator, a rolling loop, a loop position regulator, a compensator of disturbing influences. The compensator is based on the Fuzzy controller [4] and produces a control effect depending on the inconsistency in the loop control circuit. In this way, the low-frequency disturbance component at the rolling speed, which can reach 10% of the rolling speed, is monitored and compensated.

The obtained data of changes value of the loop without and with a compensating circuit. The size of the loop in the system without a compensating circuit when rolling a thicker rear part of the rolled product reaches the maximum permissible size. This does not happen in a system with a compensating circuit.

It is possible to stabilize the value of the loop in a given range either by increasing the regulator coefficient, thereby worsening the dynamics of the entire multi-link control system of the high-speed rolling mode, or by using the proposed method of adaptive disturbance compensation. The proposed method of compensation with the help of an adaptive regulator significantly improves dynamic processes in the system. When simulating the operation of the high-speed rolling mode control system, the loop length deviation did not exceed 0.02 m.

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THE EXPERIENCE OF RESEARCHING A NATURAL GAS SEPARATOR USING NON-DESTRUCTIVE CONTROL METHODS

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Diagnostics of the equipment allows the customer to find out about the problems in the equipment and take timely measures to eliminate them. Diagnostic works - include a preventive inspection of the equipment and detection of possible defects (or the need for adjustment) of equipment nodes and mechanisms. One-time diagnostic work is carried out in the event of a malfunction. Scheduled diagnostic work is preferred. As a rule, they prevent equipment breakdown and, therefore, its long-term downtime.

Non-destructive testing is a set of properties and methods of objects in which destruction of the research object is not required. That is, the research object fully retains its properties and can be used for its intended purpose.

As part of the research, the following methods are used for diagnosing the non-destructive control of the natural gas separator:

- visual and measuring control;
- ultrasonic control and thickness measurement;
- magnetic powder control method;
- determination of hardness by the impact impression method.

A natural gas separator is a complex technical device designed to clean gas flows from mechanical impurities, water fractions and other foreign inclusions. It is used to equip gas processing enterprises, compressor and distribution stations. An additional function of such equipment is to maintain the pressure in the system at an optimal level.

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MODERNIZATION OF THE SYSTEM OF AUTOMATED ADJUSTMENT OF THE SPEED MODE OF THE SECTIONAL ROLLER GANG OF THE SMALL-ASSORTED REFRIGERATOR

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Accident-free stacking of rolled bars on the cooling table of a continuous bar mill is ensured by the appropriate setting of the speed mode of the approach sectional roller table. The optimal mode is considered to be one in which, at the moment the front end of the next rod arrives at the refrigerator, there is no spatial gap between it and the rear end of the previous rod. In this case, the ejecting device must be raised to a height that guarantees reliable separation of adjacent rods at the cooling table inlet [1].

Technical solutions for the automated adjustment of the speed of the sections of the feeding roller conveyor are based on the assumption of a negligibly small duration of the transition of the rods from one speed to another in the acceleration process [2]. In the work, the justification of such an assumption was verified by means of computer simulation modeling of the operation of the corresponding automatic control system. It has been proven that for certain values of the rolling speed and the length of the rods being transported, neglecting the duration of the transient processes of the acceleration of the rods on the roller table is unacceptable due to the occurrence of emergency situations due to the non-separation of adjacent rods at the entrance of the cooling table.

A multifactorial active experiment was conducted using a computer model of the rods transportation process. The result is a multiple regression equation that relates the length of the spatial gap ΔS between the end of the previous bar and the beginning of the next bar with process parameters such as rolling speed V_0, speed of the first V_1 and second V_2 rolling sections of the roller table and bar length. After determining the significance of the coefficients, the equation took the form

$$\Delta S = 2{,}62 + 0{,}39\overline{V}_1 + 0.42\,\overline{V}_2 + 0.07\overline{V}_1\overline{V}_2 - 1.5\overline{V}_0,$$

in which $\overline{V}_0$, $\overline{V}_1$ and $\overline{V}_2$ are the relative normalized values of the respective velocities.

The modernization of the existing automatic control system (ACS) consists in determining the optimal values of the speeds of the sections of the roller table based on this equation.

Simulation modeling of the modernized ACS for sectional roller table revealed its effectiveness and feasibility of implementation, in particular, at small-grade mills of ArcelorMittal Kryvyi Rih PJSC

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INCREASING THE ACCURACY OF THE CALCULATION OF ENERGY-FORCE PARAMETERS OF ROLLING ON A PLATE MILL

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The research was carried out on one of the thick-sheet mills (TLS) 3600. The program for calculating the energy parameters of rolling is used in the automatic control system of the sheet rolling process. The optimal rolling parameters and product quality depend on the accuracy of the calculations. The existing 3600 algorithm and computer program use so-called "hardness curves", which determine the dependence of hardness coefficients on the deformation temperature for a group of steels. Despite all its simplicity, this approach provides in most cases good results of predictive calculations of energy and temperature parameters of the rolling process. However, this does not take into account a number of important factors, in particular, the change in the chemical composition of steel within the same brand. In addition, the currently existing 25 hardness curves cover about 780 different grades of steel and they are grouped in such a way that in some cases they can lead to a high calculation error.

At Iron and Steel Institute, a program for calculating the temperature and energy parameters of rolling was developed and tested in the conditions of hot strip mills. The developed program takes into account the following additional factors that are not taken into account in the TLS 3600 algorithm:

- the specific content of the main chemical elements in steel (through the carbon equivalent);

- the rate of deformation, which varies from 3 to 50 sec^{-1} and therefore significantly affects the amount of resistance to deformation;

- the influence of friction and non-contact external zones - through the coefficient of stress in the deformation zone, adapted to the conditions of the finishing stand of mill 3600;

- dynamic and static weakening of steel depending on the time of pauses between passes;

- the effect of elastic deformations of the working rolls.

Taking into account the structure of the automation system of the 3600 mill, the only effective method of adapting the existing model is the correction of the coefficients of the hardness curves in the conditions of a specific rolling mode, in which the number of passes, crimping, temperature and power parameters of the process are known. This approach allows you to adapt the hardness curves, both according to our (conditionally accurate) model before rolling the first sheet of the batch, and according to the actually measured temperature-deformation and energy parameters in the second and subsequent passes.

The developed algorithm for adapting the coefficients of the hardness curve at nodal temperature points takes into account the linear interpolation of data provided by the existing algorithm.

Data processing showed that the adapted model made it possible to increase the accuracy of calculations by approximately 1.3 times. Thus, the root mean square deviation of the rolling force when using the existing model was 12.4 MN, and the developed and adapted model was 9.6 MN.

Metal Science and Heat Treatment of Steel

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ANALYSIS OF THE RELATIONSHIP BETWEEN WEAR RESISTANCE, STRUCTURAL CONDITION AND PEARLITE HARDNESS OF HIGH-CARBON STEEL

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The operational properties of railway rails made of structural steels primarily depend on the mechanical properties. It should be noted that the wear resistance of railway rails in the wheel-rail system is one of the most important characteristics of its performance. Wear is considered to be a change in the profile of the surface along the rolling circle of the wheel of the surface of the rail head due to the forces of interaction between the wheel and the rail during operation. Hardness has traditionally been used to evaluate the wear resistance of pearlite rail steels. This does not mean that high hardness is the direct cause of high wear resistance. In pearlitic steels, the wear resistance increases as the carbon content increases and the interlaminar pearlitic distance decreases. Pearlite consists of alternating plates of iron and iron carbide and has a distance between the plates that varies depending on the temperature of formation as the rail cools after rolling. As the cooling rate increases, the distance between the pearlite rails decreases, thus increasing the hardness provided in head-hardened rails. A dislocation-enriched layer with a compacted structure of solid carbide itself probably increases the wear resistance.

Thus, in pearlite steels, wear resistance is provided by the high carbon content and the small distance between the pearlite plates (which is achieved due to the hardening process of the rail head), both of which increase the hardness. To confirm the secondary effect of hardness on wear, Hirakawa and others increased the hardness of samples with a pearlite structure by lowering the tempering temperature, but this statement was not confirmed in laboratory tests (they did not increase wear resistance).

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ANALYSIS MATERIALS BRAKE PADS OF THE ROLLING STOCK

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When choosing a material for rolling stock brake pads, in addition coefficient of friction, occurrence of a temperature gradient along thickness of the pad itself and rim of the railway wheel should be taken into account. Under conditions of intensive braking, the temperature on rolling surface of the wheel can exaggerate value beginning phase transformations in the steel. Based on this, in metal near the rolling surface of the rim wheel, starting from average range temperature, increase degree of the plastic deformation and heterogeneity of its distribution will contribute to the increase of heterogeneity development processes structural transformations of the metal. The random nature of the action a certain number influencing factors on the pair brake pad - rolling surface of a railway wheel practically makes it impossible to predict nature change a set of the metal properties. An additional complication general picture of the structural transformations in the wheel metal is the cyclic nature change heating temperature during operation of the rolling stock. Thus, when determining material of the brake pad, in addition to the coefficient of friction, one should take into account possible changes at properties metal of the railway wheel after each act of braking. Moreover, modern solution to the issues of increasing specific load on the wheel pair, due to the use of railway wheels after thermal strengthening, significantly

complicates the choice of brake pad material. Indeed, during formation of the carbon steel structure without forced cooling of the railway wheel rim, degree super saturation with carbon atoms ferrite layer of the pearlite colony practically does not differ from the ferrite of the steel after annealing. On other hand, use of the accelerated cooling to increase strength of the steel is accompanied not only by an increase dispersion of the pearlite colony, but also degree super saturation ferrite of the pearlite by carbon atoms. In this case, at accordance with increase strength characteristics of the steel, sensitivity of such wheels to heating during braking will increased. As a result, coefficient thermal conductivity (λ) material of the pad will become significant role. Moreover, increase on carbon concentration in general contributes to a decrease in λ of the cast iron. However, this is most likely caused by an increase at volume fraction of the metastable high-carbon phase. Indeed, proportion to the increase volume fraction of the cementite, decrease at coefficient of the thermal conductivity is observed. On other hand, appearance graphite inclusions in structure the cast iron have a qualitatively opposite effect on λ. As a result, the change at ratio between amount graphite and cementite in the cast iron structure can be considered as a factor affecting the value of λ. In addition to the dispersion of structural components, their morphology acquires a certain importance. After replacing graphite inclusions of the gray cast iron by flakes, the thermal conductivity can increase by up to 20%. Compared to cast iron, composite materials with a high level of friction coefficient have been widely used. Numerous attempts at application encounter certain difficulties. In addition to the more complex pad manufacturing technology, composite materials have a very low coefficient of thermal conductivity. As a result, there are restrictions on the seasonal nature of their use. Compared of the cast iron, alloys type of the bronzes with additional phases of the graphite and ceramics are less common. This made it possible to increase coefficient of thermal conductivity several times, compared to the gray cast iron. However, the high hardness of such material increases wear of the wheel and content of the chemical elements increases its cost. The given information can be useful for continuing search optimal structural state and chemical composition of the material for brake pads of the rolling stock.

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ABNORMAL INCREASE OF CONTACT ANGLE OF WETTING OF THE STEEL SUBSTRATE WITH TIN AS A FUNCTION OF TEMPERATURE

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Studying of the temperature dependence of the contact angle of wetting of the solid substrate with a melt drop is of practical interest in many industries. For example, when composite materials are impregnated to ensure better wetting between the structural components, it is necessary to determine the temperature of wetting threshold of the system. Several studies [1, 2] have noted the cases of abnormal increase of the contact angle with the rise in temperature of melt drop - solid substrate systems. The authors of [1, 2] assume that the increase in wetting angles occurs as a result of formation of new chemical compounds between the contacting substances or a change in the surface structure. We studied this phenomenon in the system of tin drop – substrate of steel 12Х15Г9НД.

The contact angle of wetting of the steel substrate with liquid tin was determined with the use of sessile drop method. In order to avoid the formation of unwanted substances, the heating was carried out in the nitrogen atmosphere. To construct each subsequent point of dependence of the contact angle on the temperature, a new individual drop of tin was provided on the substrate and examined. The wetting angle was calculated by scanning digital photographs of the drop using the TLC-manager software. After the experiment, no iron atoms were detected on the surface of the tin drop during the research by the X-ray fluorescence and atomic absorption methods. Insignificant amount of nitrogen oxides was found on the surface of the tin drop by the ion-selective method. However, it could not significantly affect the contact angle dependence on the temperature.

During the experiment, it was found that at the beginning of the study at the temperature of 525 K the value of the wetting angle was 130°. With the increase in temperature the wetting angle decreased, and its value was equal to 55° at 650 K. However, as the temperature increased further to 725 K the wetting angle value became higher again, reaching 112°. We can assume that the increase in wetting angle in the tin-steel system is observed as a result of changing energy of interaction between the melt and substrate atoms. Wetting in the liquid tin–steel substrate systems was previously studied in [3]. However, the phenomenon of abnormal increase of the angle was not found in [3], since the authors investigated the contact angle dependence on temperature by continuously heating the system to high temperatures. Therefore, after a decrease in the contact angle of wetting of the solid substrate by the melt drop in [3], no further increase in the angle was observed as the temperature increased. Regarding our study, a new drop of tin was provided and studied each time to construct each point of dependence of the contact angle on temperature. Thus, at each point of dependence, the wetting angle was formed anew, which did not exclude its higher values compared to the values of wetting angles of previous drops of the substrate at the lower temperature.

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DETERMINATION EFFECT PEARLITE DISPERSITY ON ENDURANCE AT CYCLIC LOADING OF THE CARBON

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According to experimental studies of the carbon steel, thickness ferrite layer of the pearlite has a certain influence not only on endurance of the fatigue, but also on appearance of the cyclic load diagram itself. Conditional distribution of curves on region of the low- and high-cycle fatigue is caused by qualitative changes at mechanism propagation of the plastic deformation in structural components of the steel. As a result, transition from one section of the cyclic load curve to another is quite often accompanied by occurrence significant violations of its monotonous course. Due appearance of the load curve violations, they are often called "break points", with coordinates on the abscissa (N_d) and ordinate (σ_d) axes, although in reality the sector of the violation has a certain size. Moreover, depending on structural state of the carbon steel and conditions of cyclic loading, position specified section on the curve can significantly shift and change size and appearance. Regarding the reasons for their occurrence, there is no unambiguous interpretation. According to various research results, most often, the cause is considered to be violation development processes of structural transformations, the homogeneity distribution of the plastic deformation, or a change at sliding system of the dislocations under cyclic loading. There are assumptions about a change at stress state of the metal material before of the crack front moving. It is believed that under conditions of a relatively low degree of the cyclic overload, the metal is mainly in a flat deformed state. Other conditions of crack growth correspond to area of the low

cyclic fatigue (area high degree of the cyclic overload). This case corresponds to the plane stress state. According to analysis of the cyclic load curves of the carbon steel with a pearlite structure, it was determined that decrease dispersion of the pearlite is accompanied by a shift position of the transition area on direction of the increased endurance, with a simultaneous decrease spread values of the cycle amplitude. To determine nature accumulation defects in the crystal structure during load cycle, depending on the dispersion of pearlite, the ratio $\sigma_a=K(Ni)^{-m}$ was used, where σ_a is amplitude of the cycle , N_i - is endurance at fatigue , K is a constant, and m is an exponent. After converting the specified ratio, it became possible to estimate rate of the change cycle amplitude ($d\sigma_a/dN_i$), which is a tangent of the cyclic load curve at a certain endurance value. For the corresponding thickness ferrite layer of the pearlite colony, measurement density of the dislocation accumulation (ρ) showed existence of the ratio $d\sigma_a/dN_i \sim 1/\rho$. Its use made it possible to substantiate mechanism of the structural transformations under cyclic loading. When σ_a decreases, the density of mobile dislocations decreases proportionally, that is necessary to maintain conditions at constant propagation of the deformation per cycle. The low increase in ρ corresponds to the increased uniformity location of the dislocations in structural components of the steel. As a result, the moment occurrence of the sectors with a non-monotonic location of the dislocations and their transformation into cores of the metal destruction is shifted in the direction increase endurance of the fatigue. When σ_a corresponds of the sector high amplitudes of the curve, the structural changes in the metal have a qualitatively different character. At high increase dislocations to ensure the appropriate high degree of deformation per cycle will accelerate formation of area with a non-monotonic location of dislocations in structure of the steel. Accordingly, moment of formation germ of the destruction at cyclic loading will be shift towards decrease endurance at fatigue.

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INFLUENCE OF ACTIVE MEDIUMS AND NON-METALLIC INCLUSIONS ON THE DURABILITY AND MECHANICAL PROPERTIES OF BEARING STEEL

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The influence of the types of non-metallic inclusions on the level of their activity in the initiation of corrosion damage and the mechanical properties of bearing steels was studied. Accelerated corrosion testing methods were used, which made it possible to cause in a short time the obvious destruction of steels ШХ15 and ШХ15SG from specially prepared melts programmatically contaminated with various types of non-metallic inclusions [1-5]. Low cycle fatigue tests were carried out in the air and in corrosive environments. An accelerated method was used to test the susceptibility of steels to corrosion cracking using the «IM-12» installation. Fatigue strength tests were carried out on a «NU» type machine with base $N=3\cdot10^6$ load cycles.

When testing steel BCr15 and BCr15SiMn for low-cycle fatigue N in the air, the influence of the type of non-metallic inclusions on the fatigue characteristics is observed: the lowest value of N was obtained for steels contaminated with sulfides, then it increases in the presence of corundum and spinels, silicates and, finally, titanium carbonitrides, respectively. The corrosive environment has led to a significant decrease in the durability of steels under low-cycle fatigue, however, the type of inclusions significantly affects this indicator. The coefficients of influence of the environment βc have been determined, which are the ratio of the durability of steel in air to a similar indicator in a corrosive environment. It is shown that the greater the value of this coefficient, the more strongly non-metallic inclusions reduce low-cycle durability. A decreasing series has been established showing the degree of harmful effects of inclusions on the initiation and development of corrosion damage: sulfides (Fe, Mn)S, FeS-MnS → corundum and spinels Al_2O_3, $MgO\cdot Al_2O_3$, $MnO\cdot Al_2O_3$, $(Mn, Mg)O\cdot Cr_2O_3$ → silicates SiO_2, $MnO\cdot SiO_2$, $FeO\cdot SiO_2$ → titanium carbonitrides TiCN.

High-speed tests to determine the susceptibility to corrosion cracking showed that the mechanical properties of steels depended on the type of non-metallic inclusions when tested in air. Tests in corrosive environments led to a redistribution of the relative influence of the type of inclusion on the mechanical properties of bearing steels. The tensile strength of steel σ_B, tear resistance S_c, plasticity characteristics δ and ψ decreased most significantly for melting with sulfides; for other types of inclusions this decrease is less significant.

The most harmful role of sulfides in reducing the durability and mechanical properties of bearing steels in active environments is shown and justified.

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EFFECT OF CARBON CONTENT IN BAINITE GRADE STEELS ON MECHANICAL PROPERTIES AFTER NORMALIZATION AND TEMPERING

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According to current technology, Ukrainian-made rails are inferior to foreign analogues in terms of mechanical properties and, as a result, operational durability. The throughput capacity of rails produced in Ukraine is 0.5 billion gross tons, while a similar indicator in France, Japan is 1 billion gross tons, i.e. 2 times more. It is shown that increasing the strength characteristics of steel due to the development of a new chemical composition and heat treatment leads to an increase in operational characteristics.

From the literature analysis, it was established that the steels used in steel production cannot form a worn surface layer enriched with carbide. Also, since strain hardening is enhanced by the presence of a second phase (such as carbide), low carbon bainitic steels can be expected to deform less than pearlitic steels. The consequence of this is that, although a bainite steel may have an initial higher bulk hardness than a pearlitic steel, the bainite hardened worn surface may be softer than a pearlitic steel. This effect was observed in laboratory wear tests.

After normalization and tempering, it was found that the deviation of the average values of temporary resistance after tempering of all experimental steels 1...4 has a decrease in values by -15.46, -9.55, -7.94 and -2.52%, respectively, compared to the average values after normalization. The yield strength of experimental steels 1...4, in turn, has values of -16.31, +14.62, -12.42 and +29.75%, respectively, compared to the values of experimental steels after normalization. The relative elongation of test steels 1...4 has increased values by +15.12, +1.68, +24.91 and +22.18%, respectively, compared to the average values of test steels after normalization. The relative narrowing of test steels 1...4 has a

value of +28.73, +18.72, -32.74 and +32.15%, respectively, compared to the test steels after normalization.

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INFLUENCE OF LIQUATION ON THE FORMATION OF GRAPHITE IN CAST IRONS

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The emergence of chemical, phase and different levels of structural heterogeneity in condensed media is an urgent scientific problem of the theory of phase and structural transformations during crystallization and in the solid state of metal alloys, the solution of which is necessary for the targeted formation of their properties. Different types of heterogeneity of the initial phases of metal alloys during subsequent transformations determine the regular formation of the final microstructure with its characteristic heterogeneity of chemical composition, type and distribution of defects in the crystal structure, internal stresses and other components of the internal structure and state of substances that affect their properties. It is obvious that in foundry alloys, among which gray irons occupy an important place, the hereditary influence of initial phase heterogeneity on their final structure and properties should be the most pronounced.

The results of analytical studies of the relationship between the chemical heterogeneity of gray cast irons and the structure of graphite are presented.

It is shown that in order to determine the values of chemical heterogeneity caused by liquation during the crystallization of metal alloys, it is necessary to use not calculated values of liquation coefficients based on thermodynamic calculations or analysis of state diagrams, but experimental data obtained by metallographic methods of analysis. The degree and direction of liquation depend on the composition of the alloy and the conditions of crystallization. The greatest influence on the degree of liquation has the carbon content, the increase of which leads to an increase in the liquation of most elements.

Crystallization of high-carbon cast irons (more than 2.8–3.0% C) leads to reverse liquation with silicon concentration in those areas of austenite that were previously separated from the liquid, that is, in the dendrites of primary austenite and in the central areas of eutectic colonies. In low-carbon (1.5–2.0% C) silicon-containing cast irons, silicon leaching is direct: in the core of dendritic branches, silicon is less than in the graphite eutectic matrix and on the periphery of the colonies. In low-carbon cast irons, silicon liquation in eutectic colonies is relatively small and turns out to be more difficult than in high-carbon cast irons.

Graphite formation occurs in liquation areas enriched in silicon and carbon. The reasons for the graphitizing effect in the liquation areas of some chemical elements and the absence of such an effect in other chemical elements remain unclear and require further research.

The most common alloying elements in gray cast iron: Ni, Cr, Mo, Cu, Al do not significantly affect the structure of graphite and eutectic colonies. The main effect of these elements is to regulate the structure of the metal matrix in the solid state. Mn, Cr, Mo and As are prone to direct liquation, i.e. they enrich peripheral areas of dendritic branches and eutectic colonies. Ni, Cu and Al, like silicon, are prone to reverse liquation with concentration in the middle of branches and eutectic colonies. There is no explanation of the reasons for the lack of action of these elements, comparable to the action of silicon and sulfur, on the formation of graphite in the presence of fundamentally identical laws of their liquation.

By affecting the phase-concentration inhomogeneity of crystallized gray cast irons, through a directed change in the chemical composition, the processing of the melt and the conditions of its crystallization can be controlled by the structure of the graphite and the metal matrix in order to achieve the required properties of castings.

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INFLUENCE OF DEFORMATION MODES ON THE FORMATION OF SPECIAL BOUNDARIES IN THE STRUCTURE OF ULTRA-LOW CARBON STEEL

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An urgent problem at the present time is the improvement of the quality characteristics and the ability to deep drawing thin-rolled sheets made of ultra-low carbon steels, which are used for the production of structural parts in the automotive and machine-building industry by the method of cold stamping [1]. A promising method of increasing the complex properties of metal products from polycrystalline materials is the principle of grain boundary construction. This method consists in the development of temperature-deformation regimes that contribute to the formation of a structure with the maximum possible number of special low-energy grain boundaries of the $\Sigma 3^n$ type, and is based on the concept of lattices of coincident nodes [2].

It is of scientific interest to determine the relationship between the regimes of temperature and deformation treatments, the specific surface area of special grain boundaries of the $\Sigma 3^n$ kind and the improvement of the properties of low-alloy and high-alloy steels. For the first time, the presence of special grain boundaries in ferrite with a volume-centered cubic crystal lattice of low-alloy ferritic-pearlite steels was established [3].

In this work, the content of special boundaries $\Sigma 3$ 60° <111> in the structure of 01ЮТ steel deformed in the austenitic and ferritic temperature regions with air cooling was determined using EBSD-analysis. It was established that the content of special boundaries $\Sigma 3$ 60° <111> in the structure of 01ЮТ steel reaches a maximum value of 13,2% after rolling in the austenitic region with a degree of deformation of 32,3%. An increase in the content of special $\Sigma 3$ 60° <111> boundaries in the structure of steel processed in one pass at a temperature of 970-980°C, in comparison with the deformation in two passes and the end of rolling in the ferrite region at a temperature of 730-740°C (degree of deformation 62,9%), contributes to increasing the ability to deep draw hot-rolled steel 01ЮТ. Determination of rational temperature and deformation regimes will allow to control the properties of rolled metal by increasing the content of special boundaries in the structure of ultra-low carbon steel to obtain a high-quality thin sheet capable of deep drawing.

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INFLUENCE OF QUENCHING TEMPERATURE ON STRUCTURE FORMATION OF ALLOY STEEL

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The main mechanical properties of alloy steel products are acquired after heat treatment. Violation of the temperature and time regime of processing and excessive heating of metal products often leads to products with a change in the size of the initial austenite grains. Subsequently, changes in the size of austenitic grains can affect the martensitic structure obtained during the final heat treatment. Changes in the morphology of martensite affect the reduction of mechanical properties: impact strength, yield strength, hardness, etc. Therefore, studies of the effect of increasing the austenitization temperature on the martensite structure of 31CrMoV9 steel were conducted. In the normalized state, the structure of this steel consists of bainite and martensite.

The experimental steel is characterized by the fact that with an increase in temperature from 850°C to 1050°C, the amount of martensite in the structure increases from ~10 to ~50%, respectively, during normalization. This is mainly due to an increase in the total area occupied by martensite without changing its morphology. After heating to 850°C, 950°C and 1050°C, quenching and tempering, the structure of 31CrMoV9 steel consists of tempered martensite and residual austenite.

As the temperature increases, the initial average diameter of austenite grains increases, and the size of blocks and packets in martensite also increase. The size of martensite needles after quenching from a temperature of 850°C is on average 4 μm, from 950°C – 10 μm, and for quenching from 1050°C – 18 μm. The size of the austenite grain affects the martensitic transformation by changing the density of the nuclei and stabilizing the austenitic phase as the transformation progresses. With an increase in the quenching temperature, an increase in the microhardness of the segregation areas is also observed, while the total average microhardness of the steel decreases from 4060 MPa when heated to 850°C, 3960 MPa at 950°C, to 3894 MPa at 1050°C. This change in microhardness is likely due to an increase in the amount of residual austenite, since an increase in the quenching temperature increases the amount and degree of metastability of residual austenite, its beneficiation with carbon and alloying elements, which causes a decrease in the temperature of the onset of martensitic transformation and, as a result, an increase in the amount of residual austenite. When quenching from 1050ºC, the widest interval between the minimum and maximum microhardness values is observed, which may further adversely affect the properties of 31CrMoV9 steel. Therefore, it is recommended to set a quenching temperature of 850°C for the test steel, which will further save resources.

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STUDY OF THE FEATURES OF THE 316 L STEEL MICROSTRUCTURE MANUFACTURED USING SELECTIVE LASER MELTING TECHNOLOGY

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Corrosion-resistant alloys and steels are widely used in the medical, chemical, food, automotive, and aerospace industries. The modern technology of selective laser melting (SLP-technology) provides additional opportunities for the implementation of complex geometry and the design of metal products.

It is known that the method of production significantly affects the microstructure, which determines the complex of mechanical and operational properties. The purpose of the work was to investigate the features of the structural state of stainless steel 316 L, which is formed during production using SLP technology.

From the microstructural studies, it was established that the steel consists mainly of austenite, the average microhardness in the transverse and longitudinal section is 268 kg/mm^2, the presence of a small number of pores with a size of 1-7 μm and hot microcracks was established. When studying the microstructure after etching using the Marble reagent, the boundaries of the primary austenite grains were revealed and the directionality of the formation of the primary austenite grain in the form of an arc-shaped structure of the melt bath, which is characteristic of the repetitive Gaussian distribution of the laser energy during melting, was established. It should be noted that during etching with this reagent, no duplicates of the primary austenite grain were detected.

When studying the microstructure of the samples after etching with Kalling's reagent, an atypical multidirectionally oriented intragranular substructure was found, which is mainly located in the area of the space between the tops of the tracks of the next layer in the area where the tracks of the previous layer overlap. The microhardness in the area of the above-mentioned structure along the direction of construction is 239...251 kg/mm^2, and when checking the cross-section of this section, the hardness was 286...317 kg/mm^2, which indicates anisotropy of properties.

When applying differential interference-contrast illumination and a Nomarsky prism, the presence of elongated columnar grains spreading across the borders of the melt bath and having epitaxial growth in the direction of the maximum temperature gradient was established. It was established that the direction angles of these columnar grains are 15° to the construction direction. This is probably due to the rotation of the next layer of construction relative to the previous one. The length of these grains is 140±μm, which indicates the melting of about 3 layers of applied powder.

Thus, when analyzing the microstructure, it was established that 316L steel, manufactured by VLP-technology, has an arc-shaped austenite structure, which is characteristic of melting with a normal distribution of laser energy.

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LOCALIZATION OF EPY FORMATION OF GRAIN STRUCTURE OF LOW-CARBON STEELS DURING SEVERE PLASTIC DEFORMATION

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Severe plastic deformation is one of the promising methods for obtaining the Ultrafine-Grained structure of metallic materials, which makes it possible to obtain a high-strength state, as well as unique functional properties of these materials without changing the chemical composition. The local processes of structure formation occurring in low-carbon steels near non-metallic inclusions during severe plastic deformation by the method of equal-channel angular pressing have been studied. Samples of steels 08Al, 08Cr18Ni10Ti, 09Mn2Si, having dimensions of ø20x80 mm, were subjected to plastic deformation by the ECAP method in four passes (one pass with a channel intersection angle of 90° and three passes with an angle of 120°), which corresponded to a true deformation of 3.2 [2, 3]. Structural analysis was performed using an Olympus PME 3 optical microscope, as well as JEM 100CX and JXA-50F electron microscopes; the nanohardness of the steel matrix was measured on a Nano Indenter II setup at a load of 10 mN.

It has been established that in the steel matrix, near inclusions and at the inclusion-matrix interfaces, the nature of the stressed and deformed states changes; the increment in deformation is determined by the angle of rotation of the inclusion as it moves in the plastic region. Various options for the spatial development of deformation are realized by changing the position of the shear planes, the nature of which depends on the degree of plasticity of the inclusion. Near the inclusions, zones of localized deformation are formed, containing difficult curved fragmented shear bands, hanging subboundaries, microtwins and

vortex formations due to rotational localization and the formation of discrete misorientations. The deformation mesobands near the inclusions are two-phase; in some zones of the mesobands, the so-called cold dynamic recrystallization develops. In the steels under study, structure formation during severe plastic deformation is associated with the formation of oriented structural elements that have dimensions of 100…260 nm and are separated by high-angle boundaries, which are characterized by the presence of dispersed curved mesobands of deformation, and in steel 08Cr18Ni10Ti also martensitic plates. With an increase in the number of passes, fragmentation of the mesobands of deformation occurred, which led to a significant fragmentation of the grains. Near the inclusions, the grain sizes are significantly smaller than far from them and are 75…100 nm. The nanohardness values of the steel matrix near the inclusions were 25…40 % higher than the similar values far from the inclusions. Near plastic inclusions of sulfides and silicates, the values of nanohardness are lower than near non-deformable oxides and titanium carbonitrides, which is associated with a certain deformation relaxation of stresses in the plastic inclusion-matrix system. In cases of localization of dynamic cold recrystallization near inclusions, the nanohardness of the steel matrix decreased by about 10 %.

The influence of non-metallic inclusions on the local refinement of the steel microstructure is an important effect during severe plastic deformation, which makes it possible to obtain additional nanostructural strengthening near the inclusions during the general refinement of grains to a submicrocrystalline state.

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PROSPECTIVE WAYS OF INCREASE PROPERTIES THICK ROLLED SHEET

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Rolled sheet metal is one of the main types of products of ferrous metallurgy, which is consumed in large volumes by all branches of industry. With the constant development of production, the requirements for the complex of mechanical properties and durability of rolled sheet are constantly increasing.

One of the promising directions for obtaining a high complex of strength and toughness of structural steels for the production of rolled products is the development of low-alloy steels with the structure of lower carbide-free bainite (NBKB), which is a combination of low-carbon bainite ferrite and high-carbon residual austenite [1, 2]. The conditions for the formation of NBKB, the structure of the α-phase, and the morphology of the residual austenite of carbide-free bainite depend on the carbon content, the degree of alloying of the steel, and the transformation temperature [3]. The structure of NBKB provides a unique combination of strength, viscosity and crack resistance [4, 5].

Recently, work has been actively conducted to study the formation of the NBKB structure in workpieces with a fairly large cross-section - up to 100 mm during continuous cooling [6]. It has been

established that the necessary conditions for the formation of the NBKB structure during continuous slow cooling of blanks and parts of a large cross-section are:

- high stability of supercooled austenite in the region of pearlitic and bainite transformation, while the stability in the bainite region should be lower than in the pearlitic region;
- the temperature at the beginning of the bainite transformation should not exceed 400°C to prevent the appearance of upper bainite;
- additional doping with silicon (aluminum), which contributes to the flow of bainite transformation according to the carbide-free scheme.

Thus, the problem of improving the chemical composition and obtaining a certain structural state of low-alloy steels, which are used for the production of high-strength sheet metal in order to improve its mechanical and service characteristics, is extremely relevant for modern metallurgy.

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IMPROVING THE PROPERTIES OF STEEL BY HEAT TREATMENT WITH HEATING IN THE INTERCRITICAL TEMPERATURE INTERVAL (ITI)

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The work investigated the effect on the structure and mechanical properties of steels 20GL, 20GFL, 14G2 of various modes of heat treatment with heating in ITI, which are not usually used for them. It was found that the application of normalization with heating in the intercritical temperature interval compared to the usual normalization allows to obtain a more favorable level of properties. In all studied steels, an increase in both strength and plasticity properties is observed. Plasticity and impact toughness increase most significantly. In addition, carrying out normalization with heating in ITI allows not only to obtain a higher complex of mechanical properties, but also to reduce the costs of the production process. For steel 20GL, normalization with heating in ITI with preliminary and subsequent austenitization was additionally carried out. Short-term austenitization after aging in ITI eliminates the alignment of the austenite composition and ensures its fine grain. The role of preliminary austenitization before aging in ITI is explained by obtaining a fine-grained structure, which facilitates the redistribution of elements in ITI. This option is simpler than doing short-term austenitization after aging in ITI, because it can be done in one furnace. After carrying out these processing regimes, a high level of plasticity and impact toughness was obtained compared to that after normal normalization while maintaining the strength characteristics at the level required for this steel. Tempering with heating in ITI and low

tempering allow to obtain a level of strength properties close to the low tempering state (tempering with heating above Ac_3) with higher plasticity. At the same time, the heating temperature for quenching is much lower. The optimal exposure time in the ITI is 60 minutes. In addition, compared to the improvement, the strength properties after such heat treatment are higher, and the plasticity and impact toughness remain at the same level, and in some cases, even higher. The use of tempering with heating in ITI and high tempering led to an increase in the entire set of properties for steels compared 20GL, 20GFL and 14G2to the improvement.

The use of isothermal tempering with heating in ITI compared to the improvement allows to obtain higher strength in the studied steels, with satisfactory plasticity and impact toughness. The optimal holding time in the bainite transformation interval is 60 minutes. For steel 20GL, a heat treatment regime was carried out and showed a high level of properties, which consists in isothermal quenching with ITI exposure and preliminary austenitization. Strength and impact toughness significantly exceed these characteristics after improvement. The plastic characteristics also increase somewhat.

Thus, the application of tempering and normalization with heating in ITI, which were not previously used for the studied steels, made it possible to obtain a higher level of mechanical properties compared to the properties after typical treatments, but at the same time, the heating temperature is more than 100 ºC lower than is usually used. This allows energy carriers to be saved in production. In addition, the cooling medium during this type of heat treatment is air or water, which simplifies and increases the environmental friendliness of production. Taking into account the positive results of the conducted research, as well as the influence of the scale factor, it is planned to work out new modes of heat treatment with heating in ITI in production conditions, namely: normalization with heating in ITI, normalization with heating in ITI with preliminary austenitization, quenching with heating in ITI and high relaxation, isothermal quenching with holding in ITI, as well as isothermal quenching with holding in ITI with preliminary austenitization.

The work investigated the influence of heating in the intercritical temperature interval, quenching from it with subsequent low tempering on the abrasive wear resistance of steel 60S2A. This treatment was compared with that of this steel after isothermal tempering from a temperature of 860°C and holding for 10 minutes at 350°C, which provides the highest level of wear resistance. According to the data of X-ray phase analysis, ~30% of metastable austenite is present in the structure of the studied steel, which is almost completely transformed into deformation martensite under abrasive action. Approximately the same amount of austenite and wear resistance was obtained after tempering with ITI and low vacation. Such heat treatment is simpler and more environmentally friendly than isothermal hardening.

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COMPARATIVE ANALYSIS OF DIFFERENT METHODS FOR DETERMINING RESIDUAL AUSTENITE AFTER HEAT TREATMENT OF ALLOY STEEL

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Steels containing a significant amount of deficient alloying elements (Cr, Ni, V, Mo) are used during the manufacture of metal products of responsible purpose (rolled rolls, hot forming dies, shafts, rotors, etc.). A certain amount of residual austenite (*RA*) remains in the structure of such steels after heat treatment, which subsequently affects the operational stability of finished metal products. Currently, there are various ways of determining *RA* in alloyed steels, but it should be understood that precisely the accuracy of the latter measurement allows you to reasonably approach the selection of the final parameters of heat treatment in order to increase the reliability of the operation of finished metal products.

The method of X-ray structural analysis in practice is the most accurate, which allows you to reliably determine the content of *RA*. However, with an insignificant *RA* content (≤ 5.0 %) in the steel structure, the relative error of its measurement can be ~ up to 50 %, which corresponds to the sensitivity limit of X-ray structural method, and the main drawback is the significant laboriousness of this method.

The magnetic method of determining the content of *RA*, which is based on measuring the difference between the forces of attraction of a permanent magnet to the test and reference samples, turns out to be unsuitable for determining *RA* in the structure of alloyed steels, since they contain non-magnetic carbides, which affects the accuracy of the measurement results.

An ultrasonic method for determining *RA* is also known, but it is limited and cannot be extended to alloy steels, due to the fact that it was developed exclusively for X12 type steels.

Taking into account the above, the authors of this work have developed a universal ultrasonic method for determining the content of *RA*: first, the speed of ultrasound in ferrite and austenite of reference samples of alloy steel is set, then the thickness of the sample is measured with an ultrasonic thickness gauge at the set speed of ultrasound, then the thickness of the controlled sample is measured with metric devices (caliper), and the amount of Azal is calculated according to the formula. In accordance with the developed method, determination of the content of *RA* was carried out on test samples of steels 38CrNi3MoV, 4Cr5MoV1Si, X37CrMoV5-1, 60Cr2SiV and 80Cr5MoV. In order to confirm the reliability of the obtained results, the content of *RA* was additionally determined by the X-ray diffraction method on the diffractometer «DRON-2.0» in copper radiation with a monochromator.

A comparative analysis of the results of measuring the amount of *RA* in experimental alloyed steels testified that the use of the proposed method provides sufficient accuracy for much less time-consuming than X-ray structural analysis, so it can be used as an express method of quality control of finished metal products. At the same time, the error in determining the content of residual austenite is minimal, since the developed method eliminates the effect of special carbides in the alloy steel structure.

Thus, the proposed method, unlike other analogues, makes it possible to significantly simplify the determination of the amount of *RA* in the structure of alloyed steels and significantly expand the scope of its application with the corresponding assurance of measurement ac curacy.

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ON THE ADVANTAGES AND DISADVANTAGES OF CUBIC BORON NITRIDE POLYCRYSTALS OF THE cBN – Al SYSTEM, DEPENDING ON THEIR PHASE COMPOSITION

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Polycrystalline superhard materials (PCBN) on the basis of cubic boron nitride (cBN) are used in the tool working in rough, semi-finish and finish turning of products made of iron-carbon alloys with a hardness of up to 63 HRC, including those alloyed with chromium, manganese and nickel. Such materials are obtained by high-pressure sintering of cBN powders with various additives, most often with the addition of aluminum [1].

During the reactive sintering of cubic boron nitride powders with aluminum, chemical interaction occurs with the formation of aluminum nitride and borides [2], examples of such interaction are given below:

$$Al + \frac{2}{3} BN \rightarrow \frac{2}{3} AlN + \frac{1}{3} AlB_2 \quad (1)$$

$$Al + \frac{12}{13} BN \rightarrow \frac{12}{13} AlN + \frac{1}{13} \alpha AlB_{12} \quad (2)$$

$$Al + BN \rightarrow AlN(B) \quad (3)$$

The phase composition of the obtained composites will be respectively cBN, AlN, AlB_2 in the first case, cBN, AlN, AlB_{12} in the second and cBN, a solid solution of boron in AlN (Al(NB)). Each of the options has its advantages and disadvantages. Let's list them:

Composite1 of cBN, AlN, AlB_2 composition. **The advantages** are high hardness and crack resistance due to the formation of a strong sBN frame, the pressure and temperature of the production process are not higher than 4.5 GPa and 1450 ºC. **The peculiarity** is that such a phase composition is usually realized during the sintering of relatively large grains of BN (more than 10 μm), this is due to the kinetics of chemical interaction. The disadvantage is reduced heat resistance due to the decomposition of AlB_2 at temperatures above 1000 ºC according to the AlB_2 AlB_{12}+Al scheme.

Composite 2 of the composition cBN, AlN, AlB12. Advantages - very high hardness and heat resistance, acceptable crack resistance. **The disadvantage** is the high pressure and temperature of the production process, not lower than 6 GPa and 1800 °C.

Composite 3 composition cBN, Al(NB). Advantages - high heat resistance, crack resistance, increased damping characteristics, acceptable hardness, pressure and temperature of the production process not higher than 4.5 GPa and 1450 ºC. **The peculiarity** is that this phase composition is usually realized during the sintering of small grains with BN (less than 7 μm), this is due to the kinetics of chemical interaction. **The disadvantage** is that during the sintering of cBN powders with a grain size of less than 3 μm, the formation of hexagonal boron nitride is possible. The reasons are a decrease in pressure in the high-pressure apparatus due to a low initial density and subsequent increased shrinkage of the pressing, as well as impurities on the developed surface of cBN powders.

Controlling technological factors (pressure, temperature and duration of sintering, dispersity of the initial cBN powder) we obtain materials with the desired structure (phase composition) and properties. Composite 1 is best for rough turning of iron-based alloys, composite 3 for finishing.

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DEVELOPMENT OF METHODS FOR DETECTING THE STRUCTURE OF FERRIT STAINLESS STEEL

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Today, the nuclear industry is an ideal option for an ecological source of energy based on the fission of uranium-235. At the same time, the main disadvantage of nuclear power generation is the formation of radioactive waste (spent nuclear fuel during electricity production). After removal from the reactor, these wastes are placed in special containers containing absorption and retention elements. Materials used to manufacture containers must meet certain requirements: stable structural and elemental condition, stable geometry of spent fuel storage assemblies, nuclear radiation safety of criticality. Stainless steel with a high boron content is still a well-known material used when working with spent fuel, which, in addition to absorption capabilities, has other properties that are mandatory for this type of product. The most common material for making containers in Ukraine is steel 04Cr14Ti3B1V, which belongs to stainless steels of the ferritic class and contains 1.1–3.0 % boron. Despite the fact that this steel was developed in the last century, questions related to the processes of structure formation, as well as the improvement of technological and operational properties, are still debatable. Since boron has a low ability to dissolve in both austenite and ferrite, this leads to the formation of various types of borides in the steel structure. In addition, ferrous phases embrittle steel. At the same time, the formation, morphology, and uniformity of the distribution of one or another type of borides in the volume of the finished metalwork determine not only the complex of mechanical properties and the stress state, but also determine the protective properties of the material and the degree of complexity of manufacturing the final products from them.

The conducted informational and analytical research in this direction testified to the limitations of the used metallographic methods of detecting the structure of stainless steels with a high boron content, which is due to the complex phase composition of boride inclusions. The purpose of the work was to determine a reliable methodology for studying the structure of highly alloyed steels of the ferritic class containing a significant amount of boron. On the basis of known methods and practical experience of the authors, a method of surface preparation of the studied samples made of 04Cr14Ti3B1V steel was developed, which simplifies the detection of the structure and microrelief on the surface of the cut, which allows you to reliably assess the quality of the material. The essence of the method consists in the use of two types of reagents with step-by-step immersion of the studied samples in the mordant. At the same time, there is a stable differentiation of boride phases and a clear definition of the border between the steel matrix and the boride phase. During sample preparation, the first reagent dissolves the matrix and some types of borides, and the second reagent allows you to color the borides of each type, which are present in the 04Cr14Ti3B1V steel, in a different shade. With the help of the proposed method of sample preparation, a structure was detected in the 04Cr14Ti3B1V steel, the reliability of which was additionally confirmed by the results of micro-X-ray structural and micro-X-ray spectral analyses.

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DEVELOPMENT OF PROPOSALS REGARDING REQUIREMENTS FOR THE QUANTITY OF NON-METALLIC INCLUSIONS IN RAILWAY WHEELS WHEN CREATING A NEW NATIONAL STANDARD

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Today, the main domestic consumer of railway wheels, JSC "Ukrzaliznytsia" is technically not ready to switch to the use of wheels in accordance with European regulations, but at the same time, the requirements of DSTU GOST 10791 are morally and technically outdated and do not correspond to the modern level of complexity of operating conditions and the significantly increased actual level of quality railway wheels Thus, it is necessary to develop a new national standard for railway wagon wheels, which corresponds to the current stage of development of equipment and technologies.

To develop proposals for the use of additional indicators of the quality of railway wheels (microstructure, chemical composition of the product, etc.) and to increase the level of existing requirements (contamination by non-metallic inclusions, the level of mechanical properties, etc.) in the new version of the state standard for railway wheels in comparison with the existing DSTU GOST 10791:2016 and in the international standard GOST 10791-2011 with Amendment 1, a statistical analysis of the actual level of quality indicators achieved during the production of railway wheels in the conditions of PJSC "INTERPIPE NTZ" was performed.

Non-metallic inclusions can significantly reduce the technological and mechanical properties of steels, contributing to the formation of various types of defects. One of the ways to increase the reliability and durability of heavy-duty steel products is to reduce contamination by non-metallic inclusions. Therefore, strengthening the requirements for limiting their content and increasing the number of controlled products will contribute to increasing the safety of railway traffic.

As a result of the statistical analysis of the distribution of the number of non-metallic inclusions during 2019-2021, it was established that the quality of the metal is significantly superior to the requirements of the current standard. A much smaller amount is observed for such types of non-metallic inclusions as: sulfides, row oxides, plastic silicates, brittle silicates, and point oxides.

Proposals have been developed regarding new stricter requirements regarding the maximum permissible level of pollution by non-metallic inclusions for wheels of category B: point oxides - 2.0 points instead of 2.5; plastic silicates - 1.5 points instead of 2.0; silicates that do not deform - 2.0 points instead of 2.5. In addition, it is proposed to evaluate the purity of steel using DSTU 8966:2019 "Steel. Metallographic methods for determining non-metallic inclusions", which was introduced to replace GOST 1778-70.

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HEREDITY OF GRAY CAST IRONS

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The results of analytical studies on the problem of heredity of gray cast irons are presented. It is shown that the concept of heredity of cast iron and other metal alloys usually means the connection between the properties of the original charge materials and the properties of the castings produced from them. The phenomenon of heredity in gray cast irons is a component of the general problem of heredity in metal alloys, and in a broader sense – metallurgical heredity.

The most important component of the structure of foundry (blast) cast iron is the characteristic of graphite. It is believed that the phenomenon of heredity in gray cast iron consists in the hereditary transmission to castings of the size, morphology, nature of the distribution of graphite inclusions, as well as the structure of the metal matrix (base) of the original cast irons. The negative heredity of cast irons is most strongly manifested in castings due to the coarse lamellar structure of graphite. Cast irons of the same brand, having the same or similar chemical composition, but from different manufacturing plants, have different structures and mechanical properties, which are preserved during subsequent remelting. At the same time, the nature of cast iron is more pronounced with a high carbon equivalent of secondary smelting iron. The difference in the properties of cast irons of the same chemical composition, but from different metallurgical plants, is explained by the presence of different amounts of impurities, non-metallic inclusions and the content of gases (O_2, N_2, CO) and iron oxides (FeO, Fe_3O_4).

The hereditary properties of cast irons are affected by blast furnace production factors: the volume of the blast furnace, temperature and blowing mode, the degree of ore recoverability, features of pouring cast iron in the foundry, etc. Cast iron produced in a particular blast furnace has its own characteristics in terms of sensitivity to shrinkage and porosity, tendency to graphitization and formation of the structure of the metal base. These features are transferred to the castings after remelting the cast iron.

The heredity of cast alloys, and gray cast iron in particular, is also determined by the dependence of their properties and crystallization kinetics on the structural state of the melt from which castings are made. One of the factors influencing the structural heredity in gray cast irons is the degree of dissolution of graphite inclusions in the melt, depending on their initial size, shape, and melt superheat temperature.

The phenomenon of inheritance of foundry alloys, including gray cast irons, is widely covered in literary sources. Despite this, there are few works aimed at establishing the causes of heredity, and the mechanism of its implementation still remains unclear. The above determines the urgency of conducting further research in this direction.

To control the formation of the structure of graphite and the metal matrix of gray cast irons, on which the properties of castings depend and to eliminate their negative heredity, it is necessary to know the mechanism of influence of the main chemical elements, micro impurities, the amount and composition of gases on the structure of the melt and liquid-solid phase transformations of gray cast irons depending on the conditions of their crystallization.

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THERMODYNAMICS OF THE CHEMICAL INTERACTION OF CUBIC BORON NITRIDE WITH ALUMINUM AND REFRIGERANT TITANIUM COMPOUNDS

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Polycrystalline superhard materials based on cubic boron nitride (PCBN) are obtained by high-pressure sintering of cBN powders with additives, among which refractory compounds of titanium and aluminum are most often used. The selection of the composition and quantitative ratios of additives is based on the fact that as a result of their physical and chemical interaction with boron nitride, solid ceramics are formed, which ensures high bond strength along the boundaries of cBN grains.

In [1], the change in Gibbs energy was calculated for toponymic reactions of the interaction of cubic boron nitride with transition metals of groups IVa-VIa, taking into account the effect of high pressure, and in [2] - the change in Gibbs energy during the interaction of cBN with aluminum at high pressures. In this work, similar calculations are performed for the interaction in the ternary system, namely: cBN – a refractory compound of titanium (TiN, TiC, TiB_2) – Al. The situation with aluminum needs an explanation. The sintering of PCBN composites was carried out in two stages: the first - preliminary impregnation of the compressed charge with aluminum at a pressure of 2 GPa and a temperature of 1300 K, the second stage - sintering at a pressure of 4.2 - 7.7 GPa and a temperature of

1750 - 2300 K. Under such conditions, aluminum is in the liquid state, and therefore entropy and molar volume for liquid aluminum were taken for thermodynamic calculations. When choosing possible reactions for consideration, those during which no gas phase is formed (for example, N_2) were selected, in addition, when choosing options for interaction reactions, data from X-ray structural analysis of sintered composites were taken into account.

The calculation of the Gibbs energy was performed in the approximation of $\Delta Cp = 0$. The dependence of the Gibbs energy on pressure $(dG/dp)T = V$ was established taking into account the volumetric effect of aluminum melting $\Delta V = 0.724$ cm^3*mol^{-1}. Phase compression was neglected, as its effect in such reactions is small. Thus, the effect of high pressure on the Gibbs energy for all the indicated reactions was determined only by the volume effect of aluminum melting and the volume effect of the reactions.

$$\Delta V = d(\Delta G)/dp + \Delta V_{плав}\,Al$$

For the Gibbs energy, we obtain the expression:

$$\Delta\, G_T^p = \Delta H_{298} + T\,\Delta S + p\,\Delta V$$

It follows from the given data that, from the point of view of thermodynamics, chemical interaction must take place in the systems we have chosen, and since the entropy and volume components of reactions are negative, the probability of such an interaction increases with increasing temperature and pressure.

Conclusion. A thermodynamic analysis of the chemical interaction at high pressure of cubic boron nitride with refractory compounds of titanium and aluminum was performed. It is shown that such an interaction is possible in the range of temperatures up to 2300 K and pressures up to 7.7 GPa, the isobaric-isothermal potential ΔG (Gibbs energy) is negative for this range of pressures and temperatures. When the temperature increases, the absolute value of ΔG increases, when the pressure increases, the absolute value of ΔG increases, that is, the increase in pressure and temperature contribute to the chemical interaction in the considered systems.

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IMPROVEMENT OF THE TECHNOLOGY OF THE PRODUCTION OF REINFORCEMENT ROLLED ROD OF INCREASED STRENGTH IN COILS

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The availability of rebar (RR) in coils on the domestic market ensures the advantages of its use in the construction industry due to the introduction of industrial methods of manufacturing reinforced concrete structures and a reduction of steel costs by 5-7% during cutting. The most widely used in construction in Ukraine, as well as in European countries, is RR strength class 500 N/mm^2 (A500C according to DSTU 3760, Bst 500/550 according to DIN 488 - Germany, B500B according to BS 4449 - England).

The production of RR with a diameter of 6.0-18.0 mm in skeins in Ukraine is carried out at metallurgical enterprises, where products of strength class A240C, A400C and A500C are manufactured. At the same time, during the production of RR A500S due to thermomechanical strengthening, there is a large inhomogeneity of the yield index along the length of the rod (rolling) in the range of 350-550 N/mm^2, which indicates the presence of three strength classes in one skein of products at the same time. This does not correspond to the technical meeting the requirements of the RR standards. Therefore, in order to eliminate this shortcoming, high-quality RR class A500C is produced abroad using a combined technology, when using hot deformation, a rolled product with a yield level of 350-450 N/mm^2 is produced (thermal strengthening is not used), and with the help of cold deformation, this indicator is brought to 500 - 600 N/mm^2. That is, additional strengthening is carried out. Cold deformation technology is implemented on specialized equipment by stretching a workpiece with a ready-made periodic profile in the process of rewinding it from skein to skein (stretching technology).

The paper [1] considered the possibility of obtaining RR in skeins that meets the requirements of the national standard with an optimal ratio of strength and plasticity indicators by introducing stretching technology. For the implementation of such a technology, rolling of periodic profile of class A400C according to DSTU 9130 from steel grades St3Г, 18Г2С, 20Г2 and 25Г2С with a carbon content of 0.16...0.24% is used as a workpiece, with subsequent production of products of a higher strength class. Experiments in laboratory conditions have shown that when using a periodic profile with a diameter of 8.0 mm from low-alloy steel (wt.%: C – 0.24; Mn – 1.39; Si – 0.76), when it is deformed by additional by stretching (%, Ɛ) by 2.0 and 4.0% at ambient temperature, RR was obtained with a yield strength of 580 and 650 N/mm2, respectively. This indicates that by means of cold tensile deformation from RR of strength class A400 it is possible to obtain RR of higher strength class - A500C and A600C. Additional equipment (technological line) is required for the introduction of stretching technology and the organization of mass production of RR of increased strength in skeins. Such domestic lines do not exist, but there are foreign ones that have been in use for some time and have proven their efficiency and reliability.

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FORMATION OF THE CELLULAR STRUCTURE OF THE INTERPHASE SURFACE DURING STATIONARY α→γ RECRYSTALLIZATION OF FERTITIC IRON ALLOYS

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Studies of steady-state α→γ recrystallization during isothermal carburization of a ferritic iron alloy with a cellular structure of the interphase boundary have been carried out.

Diffusion transfer of carbon through the γ-phase to the interphase surface is the main factor that determines the kinetics of α→γ recrystallization during carburization.

The α→γ phase transformation was represented as a set of successive stationary states. The α→γ transformation process was considered in a two-dimensional approximation, assuming axial symmetry of the cell. An expression for the distribution of carbon in the γ-phase upstream of the flat PI during a steady-state process was derived.

The boundary concentration differences between curved and flat PI were determined by constructing a common tangent plane to the surfaces of thermodynamic potentials G^{α} and G^{γ} for flat and curved PI.

Diffusion processes in the α phase before PI have been described. The average boundary concentration of the α-stabilizer in the α-phase is higher than in the growing γ-phase. An expression connecting diffusion processes in the α-phase before PI with the speed of front advancement was obtained.

Longitudinal sections of cells corresponding to limiting cases of surface tension coefficient σ and microstructures during α→γ recrystallization are presented. The disturbance amplitude φ(x) was approximated by a piecewise continuous function consisting of fragments of second-order curves and straight lines when performing these calculations.

A detailed study of the microstructures of the transformation front shows that PI cells have a pronounced crystalline facet during solid-phase recrystallization. Two or more columnar crystals of the γ-phase can grow from one grain of the α-phase. The growth of the boundary plane occurs at the maximum speed if {111}γ and {110}α are mutually oriented according to one of the variants of the Kurdyumov–Sachs orientation relationship.

The resulting model can be used as a base model for studying the growth of a natural austenite-carbide composite.

Progressive Metal Processing Technologies

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CHOICE OF THE METHOD OF DETERMINING THE ENERGY-FORCE PARAMETERS OF THE PROCESS OF DRAWN OF THE STACK THROUGH A BENDING-TENSIONING DEVICE

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In the practice of manufacturing metal products, shaped profiles of a complex configuration, including thin-walled, strip and periodic cross-section profiles, play a special role. High-quality, high-precision shaped profiles with different ratio of the width to the height of the tape, which are produced in small-tonnage batches abroad and are widely used in machine-building, instrument-building, aircraft-building and other industries. In Ukraine, the production of high-precision shaped profiles is extremely limited, and the production of strip-type profiles is completely absent. Tape-type shaped profiles are usually produced by cold deformation on drawing, flattening or sheet-rolling mills. The use of drawing in roller drawing in comparison with cold rolling and flattening has higher technological flexibility, does not require large capital costs for the organization of production. Compared to traditional drawing with the use of monolithic drags, the drawing process in roller drags has the following advantages: lower energy consumption; higher permissible deformation per pass; higher homogeneity of product properties, expensive drawing lubricants are not used, additional special metal preparation operations for drawing are not carried out (phosphating, oxalate, copper plating, brown coating, etc.). The main drawback of the roller drag method is the presence of traction force. Tensions that stretch the profile in combination with a decrease in plasticity of the metal during the drawing process can lead to the destruction of the rolled product. In order to eliminate the harmful effects of residual tensile stresses, it is necessary to either eliminate them or convert them into compressive stresses that increase the workability of the steel billet. For this purpose, two methods are used in the practice of wire production: thermal and mechanical. The thermal method used in industry requires significant energy consumption. The mechanical method has several varieties, of which the most rational is the process of sign-changing deformation with wire stretching in a bending-stretching device.

The process of cold deformation with the use of a bending-stretching device is carried out with a counter-tension, the value of which is equal to the effort of drawing the workpiece through this device. The counter-tension determines the force of cold deformation and the power of the drive motor of the traction device, the value of the maximum possible deformation during the first pass, the stability of the cold deformation process and other parameters. When working with a large back tension, frequent breaks in the rolling stock are possible. Therefore, it is very important to correctly calculate the force of cold deformation using bending and stretching roller devices.

The purpose of the work: on the basis of the performed analysis, to choose a technique for determining the energy parameters of the process of drawing the staffs through the bending and stretching device.

As a result of the analysis, the method of calculating the force parameters of the process and the change in shape of the wire rod in the bending-stretching roller device with comprehensive consideration of the mutual dependence of the degree of deformation, the tensile strength of the metal, and the changes in mechanical properties during the deformation process was determined. The headquarters in the roller bending-tension device adopted the methodology that was developed earlier in the ISI of the National Academy of Sciences of Ukraine. The chosen methods serve in the future for the development of a mathematical model for calculating energy parameters and shape change parameters of the process of stretching the staffs through the bending-stretching device, which will allow for a reasonable choice of the parameters of the sign-changing bending of the staffs.

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PRODUCTION OF REINFORCING ROLLED PRODUCTS FROM LOWALLOY MODIFIED NITROGEN STEELS

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The actual task in the production of rolled steel from low-alloyed steel grades is to increase the strength without increasing the cost of production. Implementation of methods of modification and micro-alloying allows to increase characteristics of steel products [1, 2] both to strength and operation. New technologies for modifying steel by isolating nanodispersed excess phases under various conditions significantly increase the strength and plastic properties of rolled steel, including reinforcement.

The possibilities of obtaining reinforcing rolled products that meet the requirements of international standards with an optimal ratio of strength and ductility by implementing the technology of carbonitride strengthening of low-alloy structural steels [3, 4] are considered.

The increase in the consumption of reinforcement with the corresponding strength and plasticity indicators leads to high requirements for its manufacture, which is achieved by the technology of carbonitride strengthening of steels containing vanadium and less often niobium. The production of reinforcing rolled products of strength class 500-600 MPa from low-alloy steels modified with nitrogen [5] significantly increases the consumer properties of the finished product, such as endurance, cold resistance, seismic resistance, fire resistance and fire safety. The use of such rolled products in construction in regions with increased seismic activity and large differences in ambient temperatures will have a beneficial effect on the reliability of reinforced concrete structures and structures.

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EXISTING AND PROMISING METHODS FOR COOLING STEELS FOR WELDING PURPOSES IN A ROLLING LINE

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To produce cold-deformed welding wire from alloy steels using modern technology, it is necessary to have high-quality raw materials – wire rod, which must have an improved combination of strength and ductility properties. The microstructure of alloy steel wire rod determines its ability to cold plastic deformation, and the ratio of structural components, their quantity and uniformity of distribution have a significant impact on the process of stable, break-free drawing. Modern technology for producing welding wire using an energy-saving principle, the so-called “direct” drawing, assumes the absence of additional heat treatments during cold plastic deformation of rolled products in metal production conversion. Reducing the strength and increasing the ductility of welding wire rod is ensured by selective requirements for the chemical composition of steel within grade intervals, additional binding of free nitrogen, as well as the use of special modes of softening treatment with an adjustable rate of post-deformation cooling on a roller conveyor.

The theoretical foundations of deformation-heat treatment of wire rod are based on the laws of the kinetics of austenite decomposition and, accordingly, the peculiarities of the course of phase-structural transformations occurring under the influence of hot plastic deformation in alloy steels. When determining the parameters of deformation-heat treatment of wire rod, one should take into account the chemical composition of the steel, the completion temperature of hot rolling, the duration of the post-deformation pause, as well as the temperature-time cooling conditions.

In metallurgical practice, when producing wire rod, «short» and «long» Stelmor lines are used. Cooling of structural and high-carbon steels is carried out on the «short» Stelmor line (conveyor length ~ 70–90 m), and alloy steels for welding purposes are cooled on the «long» Stelmor line (conveyor length ~ 110–150 m). Increasing the length of the conveyor allows you to create different conditions for cooling wire rod over a wide temperature-time range and combine continuous and quasi-isothermal cooling. The main advantage of the «long» Stelmor line is the possibility of cooling the metal under the heat-insulating covers of the conveyor under conditions close to isothermal, which allows achieving the most effective combination of structure and mechanical properties of alloy steels wire rod. Slow cooling of alloy steels under the heat-insulating covers of the conveyor promotes the formation of ferrite-pearlite structures with a minimum amount of bainite-martensite areas, which ensures an increase in its technological plasticity during drawing without the use of additional annealing.

An alternative reserve for ensuring slow cooling of wire rod may be additional sealing of conveyor sections under heat-insulating covers, installation of special circulation fans, as well as thermal imagers. It is obvious that the temperature and speed regulation of the cooling of rolled steel plays a significant role in the formation of its quality, and the general manufacturing process consists of technological operations, each of which makes its own contribution to the formation of the final set of properties. It should be noted that currently the most rational cooling modes in the production of alloy steels wire rod are not fully used, which allows us to offer national metallurgical plants effective technological measures aimed at improving the production process with relatively minimal material costs.

UDC 629.764

METHOD FOR STUDYING THE DEPTH OF PENETRATION OF THE CUMULATIVE JET OF THE PYROTECHNIC DEVICE OF THE LAUNCHER ROCKET SEPARATION SYSTEM

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Pyrotechnic devices play an important role in many rocket and space technology systems, where instantaneous operations are required, in particular, the separation of launch vehicle stages. One of the most effective types of pyrotechnic devices for performing such operations are linear shaped charges (LSC).

The depth of penetration of the cumulative jet (CJ) is one of the main characteristics that determine the efficiency and reliability of the pyrotechnic devices of the separation system. If the penetration depth of the CS is insufficient, then the pyrotechnic device will not be able to effectively destroy the connections between stages or structural elements in rocket and space technology.

The purpose of this work is to develop a methodology for studying the penetration depth of CJ LSC used in launch vehicle separation systems.

The research methodology consists of the following stages: preparation of interference samples; preparation of LSC; establishing LSC on an obstacle; penetration depth measurement; data analysis.

The developed technique makes it possible to study the depth of penetration of CJ LSC with high accuracy and reliability. The research results obtained using this technique make it possible to confirm the performance, efficiency and reliability of pyrotechnic devices at the LSC.

UDC 629.764

DEVELOPMENT OF MEANS OF PRODUCTION OF TECHNOLOGICAL LUBRICANTS FOR PROCESSING METALS BY PRESSURE

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Most technological lubricants for pressure metal processing (OMT) contain graphite. Such lubricants include: OGV-75, GFP, Ukrinol-7, Delta-31, Sumidera, etc. In these lubricants, the graphite fraction has a size of 2-5 microns. Layer mills are widely used at the enterprise for the production of lubricants with these sizes of graphite. The process is time-consuming and energy-intensive. We developed and implemented at the Mariupol Graphite Plant a means of producing fine graphite using a hydraulic dispersant. At the same time, with the help of cavitation jets, large parts of graphite are quickly crushed into size fractions 2 — 5 μm. The obtained samples were verified on an electric microscope. It was established that it is possible to obtain 60% of fine graphite with a fraction of 2 — 5 μm. At the same time, layer mills would require 10 times more time and 5 times more labor. Technological lubricants OGV-75, GFP, Ukrinol-7 were produced using the developed tool, which were tested in forging and stamping shops (Azovmash, Tokmak; YuZhMASh, Dnipro) and showed good results. We consider that the developed tool is promising, environmentally friendly and can be implemented at enterprises that manufacture technological lubricants.

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IMPROVEMENT OF THE ROLLING ROLL FORGING PROCESS

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When forging rolling rolls using traditional technology, ingot sedimentation operation is widely used to ensure the required forging. We have proposed a form of strikers, in the forging of which there is no need for the time-consuming operation of depositing the ingot. The forging shop used three-beam forgings on a hydraulic press to forge a rolling roll weighing 25 tons, which made it possible to obtain a three-beam ingot. The deposition operation was not applied. Further forging of this three-beam ingot was carried out using traditional technology. At the same time, the technical parameters of the roll rolling met all the requirements of the standard (DSTU), and the process itself was 30% faster. Theoretical studies carried out using the slip line method showed that forging with these punches allows good rolling of the ingot over the entire cross-section. We think that the developed and implemented design of the new three-beam form of forging hammers can be widely used in the forging of various forgings, including rolling rolls.

Modeling and optimization of technological processes

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RESEARCH OF CALCULATION METHODS FOR MODELING THE PROCESS OF MELTING MATERIALS

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The mathematical modeling of multiphase media is rooted in the fundamental postulates and principles of continuous media mechanics. However, it is important to note that the equations governing these processes in multiphase media are predominantly intricate and nonlinear partial differential equations, often possessing analytical solutions only in a limited number of cases, typically lacking practical significance.

To extract quantitative insights into the progression of such processes, numerical methods executed via computational devices have become indispensable. This has given rise to the emergence of novel scientific disciplines, including computational physics, computational fluid dynamics, and computational thermal physics.

Automated systems of scientific research are systems in which, in order to increase the efficiency of scientific research, a number of procedures for obtaining, analyzing, transmitting and accumulating information related to the use of mathematical modeling methods in the course of research are formalized and performed automatically.

Within the Department of Systems Software at Dnipro State Technical University, a significant endeavor has been undertaken in the form of developing an automated research system titled "Melting of Materials". This initiative has yielded specialized software tailored to deliver comprehensive and highly precise data regarding the dynamics of heat and mass transfer processes during material melting. These modeling outcomes enable the formulation of recommendations for optimizing the corresponding technological processes.

UDC 004.94

STUDY OF SPEED AND MEMORY CONSUMPTION FOR THE STAR INTERACTION ALGORITHM ON GRAPHICS ACCELERATORS

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It is presented a detailed investigation into the performance aspects of the N-body interaction algorithm when implemented on graphics accelerators. The N-body algorithm plays a crucial role in various scientific simulations, ranging from astrophysics to molecular dynamics. With the increasing reliance on graphics accelerators for scientific computations, understanding the algorithm's behavior in this context is of paramount importance.

The study focuses on two key performance metrics: speed and memory consumption. Through a series of carefully designed experiments, we systematically analyze the algorithm's execution time and memory usage across different configurations of graphics accelerators. The study encompasses a diverse set of scenarios, including varying particle densities and interaction strengths, to provide a comprehensive understanding of the algorithm's behavior under different conditions.

Additionally, we explore the impact of optimization techniques on both speed and memory consumption, aiming to identify strategies that enhance the algorithm's efficiency on graphics accelerators. Our findings not only contribute valuable insights into the performance characteristics of the N-body

interaction algorithm but also offer practical guidance for researchers and practitioners seeking to leverage graphics accelerators for large-scale simulations.
Overall, this research sheds light on the intricate interplay between the N-body algorithm and graphics accelerators, paving the way for improved computational efficiency in a wide range of scientific applications.

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STEAD TORQUE CORELATION FIELDS IN ROLLING CLUTES

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On the basis of numerical pre-production vibrations [1,2] on wide-strip mills, an empirical statistical determination of the maximum dynamic torque Mm when gripping metal with rolls is established at the moment Mc in the old rolling mode. The greater the Ms, the greater the MD. This location has the appearance of a thin correlation field of points Md, Ms, which is approximated by the linear location Md (Ms). The width of the field is determined by the change in static moment when rolling strips of different sizes. On rolling mills, only the electromagnetic moment of the motor and the static moment during the rolling of the leather strip are constantly vibrating. The importance of MD and MS allows you to complete a number of important tasks.

1. Predict the maximum dynamic moment during the mastering of rolling of strips of a new grade size, embossing movement, and changed rolling temperature.

2. Simultaneously changing the moment in 2-3 separate stands of the rolling mill from the daily correlative fields MD, MS by their analysis allows you to follow the passage of drilling through the stands and more accurately and more accurately evaluate them There is a rolling process and a rolling mill.

3. Vary the data of the empirical division of static and dynamic moment in the development of resource ownership.

4. By specifying in a mathematical model the actual values of the moment MC with the regulation of the influx of technological developments and gaps in the way of statistical modeling, the maximum dynamic moments are determined and the tasks are clearly identified. 1 and 2 without carrying out trivial natural experiments.

5. Determine the characteristics of the division of moments Мд and Mc – the average value, the mean square variation and the coefficient of variation according to the method of determining the stability of the technological process and the state of ownership.

6. The way to link grade sizes to correlative fields is to determine the one with which dynamic pressures reach the greatest value and remain stable when correcting rolling modes.

7. By increasing the information content and reliability of assessing the stability of the technology, we will be able to fully obtain before analyzing the additional fields for the spindle section, as well as the field of static tension - metal temperature lu and dynamic navantazhennya – rolling temperature. For this purpose, the required temperature is measured on one of the spindles and the temperature of the metal at the inlet in the monitored cage.

8. The results of pre-trace simulations and statistical modeling show that the formation of correlative fields MD, MS becomes a characteristic feature for broadband and other mills with the expression of the transition process and steel rolling mode.

The formation of a more significant position allows for constant monitoring of the maximum dynamic moment across all cages without interruption and, if necessary, adjusting the rolling parameters in the direction of changing the impact forces.

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OPTIMIZATION OF WRITING CODES FOR MACHINING PARTS ON CNC MACHINES BY THEIR AUTOMATIC GENERATION

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The process of automatic generation of part processing codes on Roland MDX 40A [1] and HAAS VM3 [2] machines was studied. In order to optimize the writing of machining codes, a framework was created in the SRP software.

The first step in automated part code writing is to create a parametric model in Catia V5. After analyzing the code in Catia V5, a set of parameters will be created. Such a set is created for the variables present in the code, which include the depth of cut, position coordinates along the X and Y axes, etc. At this stage, the parameter sets are linked using formulas, resulting in the geometry-code relationship. If an automated method of generating NC codes is used, they are generated automatically. Thus, after analyzing the code for any of the product and/or part dimensions, the operator has the opportunity to generate new codes in case of a change in the model dimension. You can change the model dimension by changing its main parameters.

The code is generated automatically in text format, after which it can be changed to the ".NC" file format for further running on the CNC machine. This approach will also be used for the HAAS VM 3 CNC machine. Using this code leads to a simulation on the display panel of the CNC machine and checks the accuracy of the written code.

The main disadvantage of generating codes manually using CATIA V5 is that if any model parameters or dimensions are changed, the code creation process must be completely carried out from the first to the last stage, i.e., the choice of surfaces and planes, the machining process, etc. Another disadvantage of generating codes from CATIA V5 is that these codes are quite long and contain from 300 to 2500 lines.

The research was conducted for several typical parts, namely: a body with a hole in the center, a hollow cylinder, a body with three holes of different radii, a body with three holes of the same radius, and a pyramid. As a result, the manual method of generating part processing codes was compared with the automated method.

For the housing with a hole, the manual method of machining code generated in CATIA V5 contained 388 lines of code, and the automated method contained 32 lines of code. Machining the hollow cylinder resulted in a reduction of code lines from 267 to 50. A case with holes of different radii - 432 lines of code using the manual method and 53 lines using the automated method. A case with holes of the same radius - 418 lines and 45 lines, respectively. Pyramid - 1206 lines and 142 lines, respectively.

After analyzing the generation of codes for parts by manual and automated methods, it can be noted that this method is more optimal for machining parts, since the code for machining a part by the automated method is reduced several times compared to the code generated in Catia V5 software. In addition, the use of this method has a greater level of flexibility in part processing programs, since when model parameters are changed in the program in which the part geometry was created, the automatically generated part code will change without the intervention of the CNC operator.

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SOFTWARE FOR STUDYING THE HYDRODYNAMICS OF THE MELT IN A TUNDISH

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This research uses a novel software platform designed for the in-depth study of melt hydrodynamics within tundish systems, a crucial component in metallurgical processes. The interactive website provides a user-friendly interface for researchers and practitioners to visualize, and analyze the intricate flow patterns of molten metal during casting operations.

Through the integration of user-defined parameters and customizable scenarios, the website allows users to explore various operational conditions and assess their impact on the melt flow dynamics.
Key features of the web application include simulation outputs, 3D visualizations, and comprehensive data analytics tools. Researchers can gain valuable insights into the thermal and fluidic characteristics of the melt, facilitating the optimization of tundish design for enhanced casting performance. Additionally, the platform fosters collaboration and knowledge-sharing within the metallurgical community by enabling the exchange of simulation models and results.

This paper highlights the significance of the web-based tool in advancing the understanding of melt hydrodynamics, ultimately contributing to the improvement of casting processes in metallurgical industries. The accessibility and versatility of the platform make it a valuable resource for both academia and industrial applications, promoting innovation and efficiency in the field of metallurgy.

UDC 004.94

TECHNOLOGIES OF SOFTWARE DEVELOPMENT FOR HYDRODYNAMICS RESEARCH IN AN AERATION TANK

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The paper explores advanced technologies in software development tailored for the investigation of hydrodynamics within an aeration tank, a critical component of municipal wastewater treatment facilities. The study focuses on the integration of computational tools to model and analyze the complex fluid dynamics within the tank, aiming to enhance our understanding of the aeration process and optimize its efficiency.

The proposed software leverages state-of-the-art programming languages, such as C#, and utilizes powerful libraries like ASP.NET for presenting hydrodynamic simulations. The graphical user interface, developed using ASP.NET MVC, facilitates user interaction, allowing researchers to input parameters and visualize simulation results with ease.
The significance of this research lies in its potential to revolutionize the field of wastewater treatment by providing a comprehensive, virtual platform for hydrodynamics research. By employing machine learning algorithms, the software aims to intelligently analyze data, identify patterns, and contribute to the development of optimized aeration strategies.

It is concluded the paper's relevance in addressing current challenges in wastewater treatment, emphasizing the potential environmental impact reduction, efficient resource management, and the creation of a digital framework for collaborative research in hydrodynamics.

Environmental problems of ferrous metallurgy

UDC 669.712.04

IMPLEMENTATION OF THE BEST AVAILABLE TECHNOLOGIES IN THERMAL FURNACES IN THE CASE OF FOSSIL FUEL SHORTAGES

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In a time of fossil fuel shortage in Ukraine, especially natural gas, the issues of implementing the best available technologies in metallurgy and reconstruction of metallurgical thermal units are becoming relevant [1]. Reducing fossil fuel consumption decreases greenhouse gas emissions and is an important aspect of Ukraine's integration into the European community. The implementation of "Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)" is Ukraine's steps into the future and a way to economic and energy independence of the country.

An important area of greening technologies is the use of renewable energy sources to generate heat for technological processes. Renewable hydrogen and renewable electricity are most often considered promising sources of “green” energy. The conversion of thermal units to hydrogen heating requires the reconstruction of heating systems and process control systems of the units but almost always ensures the required process parameters [1]. The use of electric energy requires either a complete replacement of the heat treatment technology or a significant reconstruction of the existing equipment with the study of issues related to ensuring the necessary quality and performance of heat treatment.

The authors researched the thermal performance of a continuous furnace for pipe heat treatment when the furnace is heated with natural gas. They also developed technical solutions for replacing natural gas with renewable hydrogen or converting the gas furnace to electric one. During the study, authors developed mathematical models of gas and electric furnaces for pipe thermal treatment. They adapted the mathematical model of the gas furnace on the base of experimental results of metal heating when natural gas is used as fuel.

To evaluate the possibility of converting the gas furnace to electric heating without changing the overall dimensions of its chamber, furnace temperature regimes for reference pipe bundles were developed, and the technical and economic indicators of the furnace operation were determined. Based on the results of the calculations, recommendations for the selection of design and operating parameters of the electric furnace were formulated. Namely, the number and length of temperature control zones were changed, and their thermal capacity was determined; the type and size of eclectic heaters were selected, as well as their location in the furnace chamber.

A comparative analysis of the technical and economic performance of gas and electric furnaces led to the following conclusions. The use of hydrogen as a fuel makes it possible to fully implement the required regimes of heat treatment regime and guarantee a required furnace capacity. Without taking into account the investments for reconstruction, the replacement of natural gas with hydrogen is economically feasible at a ratio of natural gas and hydrogen prices not more than 2.9. The conversion of the furnace to electric heating can be achieved if the furnace capacity is reduced by 20 % for certain steels and dimensions of the pipe bundles. The replacement of natural gas with renewable sources of energy like electricity or hydrogen makes it possible to reduce carbon dioxide emissions by 765 kg/t of metal.

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STUDY OF NITROGEN OXIDES EMISSION DURING AIR HEATING IN HOT-BLAST STOVES

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Blast-furnace gas is used for air heating in hot-blast stoves. The combustion heat of blast-furnace gas does not ensure the achievement of the required temperature under the dome of the hot-blast stoves 1300-1350 °C, and therefore blast-furnace gas is usually enriched with natural gas. Another way to achieve the required temperature under the dome is to heat hot-blast stoves with blast furnace gas using oxygen-enriched air for fuel combustion. In this case, process oxygen enriches the air.

The paper considers both methods of increasing the temperature under the dome of hot-blast stoves and studies the impact of these methods on the nitrogen oxides (NOx) gross emission which is generated during fuel combustion. The research was performed for the operation of hot-blast stoves, which are ancillary equipment of the blast furnace with a volume of 1513 m^3. The initial conditions were the following:

- the temperatures under the dome: 1300 and 1350 °C;
- blast furnace gas composition (volume percentage): CO_2=15.95%; CO=22.55%; H_2=3.37%; N_2=44.39%; N_2O=13.74%;
- the calorific value of blast furnace gas and natural gas, respectively: 3.228 and 36.275 kJ/m^3;
- blast furnace gas consumption per one hot-blast stove: 25.000 m^3/h;
- the consumption of blast-furnace air was the same for both considered methods of increasing the temperature under the dome.

It was determined that to obtain the required temperatures under the dome in the hot-blast stoves (1300 and 1350 °C) when they are heated with a mixture of blast-furnace and natural gases, the calorific values of the mixture have to be respectively 4.550 and 5.013 kJ/m^3 and the natural gas contents have to be respectively 4.0 and 5.4 %. If the hot-blast stoves are heated with blast furnace gas and the combustion air is enriched with process oxygen, the required temperatures under the dome can be achieved when the oxygen content in the air is respectively 23.4 and 32.3 %.

For the considered fuel combustion conditions, the concentrations of nitrogen oxides (NOx) were calculated using the equations published in [1]. The results show that the concentrations of nitrogen oxides (NOx) are 44.5 mg/m^3 when the temperature under the dome is 1300 °C and 79.0 mg/m^3 when the temperature under the dome is 1350 °C. The NOx concentration does not depend on the method of increasing the temperature under the dome of hot-blast stoves because the fuel combustion conditions do not change.

Numerical modelling of heat transfer in the checker chamber was performed according to the methodology given in [2] and made it possible to calculate the consumptions of fuel, process oxygen and flue gases per hot-blast stove as well as gross NOx emission. It was determined that in order to obtain the same heat exchange conditions in the checker chamber of the hot-blast stove, it is necessary to ensure the same flue gas flow rate through the checker regardless of the methods of increasing the temperature under the dome. The gross NOx emissions practically do not depend on methods of increasing the temperature under the dome, and they are 50.75 t/year when that temperature is 1300 °C and 94.67 t/year when it reaches 1350 °C. Thus, both methods have the same environmental impact.

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MELTING OF RADIOACTIVELY CONTAMINATED METAL AS A COMPONENT IN SOLVING ENVIRONMENTAL PROBLEMS AT METALLURGICAL ENTERPRISES

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Metallurgical enterprises may receive scrap metal contaminated with radionuclides of both natural and artificial origin. This may cause a real threat of exposure to elevated levels of radiation to the company's personnel and the population in the adjacent areas.

As it is shown in [1,2], one of the most effective ways to prevent unreasonable deterioration of the environmental situation at an enterprise is to melt metal in a furnace which operates in the normal mode, and the incoming raw materials are not decontaminated beforehand.

During the melting process, radionuclides are mixed and distributed evenly in the melt volume. This distribution remains the same for products made from this metal.

Implementation of the proposed approach makes it possible to remove radioactive contaminants from the sphere of their direct contact with humans and, accordingly, to prevent and eliminate the possibility of unreasonable exposure and environmental contamination.

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