NATIONAL ACADEMY OF SCIENCE OF UKRAINE

Iron and steel institute of Z. I. Nekrasov of National Academy of Sciences of Ukraine
Ukrainian State University of Science and Technology of the MES of Ukraine
Dniprovsky State Technical University MES of Ukraine

Conference Proceedings

All-Ukrainian scientific and technical conference

« SCIENCE AND METALLURGY »

dedicated to the 85th anniversary of

Iron and steel institute of Z. I. Nekrasov of NAS of Ukraine

DOI: 10.52150/2522-9117-2024-conferens

19-20 November 2024

Dnipro

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Iron and Steel Metallurgy: Technology, Innovation, Quality

UDC 669.1.061.6

STUDY OF RATIONAL CONSUMPTION OF PULVERIZED COAL WITH DETERIORATION OF QUALITY CHARACTERISTICS OF COKE

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In recent years, the quality of coke in the blast furnace production of Ukraine has been deteriorating significantly. This is primarily due to the shortage of coking coal. For example, in the blast furnace shop of PJSC "KAMET-STEEL", the average annual value of the hot strength indicator of coke CSR over 7 years decreased from 53.37% in 2018 to 41.45% in 2024, the reactivity indicator CRI increased from 32.48% to 41.67%, the sulfur content increased from 0.58% to 0.92%, the content of the +80 mm fraction increased from 7.62% to 9.35%, the amount of ash and the drum strength indicators M10 and M25 did not change significantly [1].

Low quality of coke has a negative impact on both the technical and economic performance of the process and reduces the possibilities of using coke substitutes in the technology: coke nut, pulverized coal (PCI) and natural gas.

The analysis of changes in the specific consumption of coke equivalent, which is the sum of the specific consumption of coke (C), coke nut (k_1·CN) and PCI (k_2·PCI), where $k_{1,2}$ are the coke replacement factors [2] at different specific PCI consumption for the operation period of BF-1M and BF-9 of PJSC "KAMET-STEEL" for 50 days at the beginning of 2024, was performed. The specific consumption of PCI during this period varied from 60 to 120 kg/t of cast iron. In the studied period, PCI consisted of 100% coal of Australian origin (volatile matter – 13.6%, sulfur – 0.63%, ash – 11.68%, carbon – 87%).

The analysis results showed that the minimum specific consumption of coke equivalent for BF-1M was 538 kg/t with a specific consumption of PCI – 78 kg/t; with an increase in the specific consumption of PCI to 120 kg/t, an increase in both the specific consumption of coke and the coke equivalent was observed (552-573 kg/t). The analysis results are similar for BF-9: the minimum specific consumption of coke equivalent was 557 kg/t with a specific consumption of PCI – 81 kg/t; with an increase in the specific consumption of PCI to 110 kg/t, an increase in both the specific consumption of coke and the coke equivalent was observed (563-575 kg/t).

Thus, the obtained results indicate a deterioration in the degree of combustion of PCI when using coke with low quality characteristics, so the CSR of coke in the analyzed period was: 42.6% for BF-1M and 41.6% for BF-9, on average. The value of specific consumption of PCI recommended for the blast furnace shop – 80 kg/t of cast iron, as the most rational, was adopted for further use.

It should be noted that in the second half of 2024, from an economic point of view, the practice of using a coal mixture in the PCI with the addition of long-flame gas (LF) coal was applied. Since LF coal differs from coal close in performance to low-caking coal by a significant amount of volatile substances, low carbon content and high sulfur content, the use of such a coal mixture reduces the completeness of combustion of the PCI and requires measures aimed at improving the drainage capacity of the blast furnace hearth [1].

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UDC 669.1:669.14

SMALL METALLURGICAL PLANTS (SMP) – THE WAY TO RECOVERY THE STEEL INDUSTRY

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New technological processes that meet the modern requirements of energy efficiency and environmental safety, as well as provide the best opportunities for the restoration of the steel industry of Ukraine and overcoming its technical lag are considered. The solution is to prioritise the development of electric arc furnace production at small steel mills (SMPs). Such technologies can be used both in large-scale metallurgy, which produces commercial products, and in small-scale metallurgy in the machine-building sector at minimal material, energy and environmental costs. The development of the small steelmaking concept will help rebuild regional infrastructure, create new jobs, generate revenues for local budgets, etc. SMP's feedstocks are scrap, metallised raw materials and liquid iron (up to 35-40% of the total charge weight). The production of SMP includes mainly thin hot-rolled sheet of foundry-rolled modules, square and round grade blanks or in-demand special rolled profiles, various consumer metal products, in particular, large forging ingots [1].

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UDC 669.02

THE UTILISATION OF CARBON-CONTAINING MATERIALS OF PLANT ORIGIN IN THE PRODUCTION OF STEEL

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Biomass has the potential to be a significant contributor to the decarbonisation of ferrous metallurgy. The utilisation of biomass in metallurgical processes can provide solutions to a number of significant challenges, including the disposal of biomass processing waste, the reduction of hard coal and natural gas consumption in metallurgical processes, the reduction of harmful gas emissions, and the production of carbon materials with superior characteristics compared to existing alternatives [1, 2].

The study examines the potential of utilizing alternative raw materials, including sunflower husks, sunflower stalks, corn, and straw, as steel carburizers. Prior to utilisation for the carburising of steel, all of the aforementioned biomaterials are subjected to a distinct preparation technology. An increase in the proportion of promising high-strength steels in the total volume of steel production, which typically have a higher carbon content than ordinary, low-carbon steels, will lead to an increased utilisation of carburisers and an elevated level of demand for their quality. Furthermore, the utilisation of biomaterials will serve to diminish the emission of carbon dioxide into the environment [3].

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UDC 621.746.07

USE OF GAS PRESSURE TO FORCE THE MELT OUT OF THE SIPHON CASTING SYSTEM OF LARGE STEEL CASTINGS AND INGOTS

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The technological features of the proposed methods are to seal the siphon casting system of large steel castings and ingots from the environment by means of a layer of solidified metal and subsequent gas-dynamic impact.

In one embodiment, gas is introduced in the above device designs using a refrigerator container with a fixed amount of a substance that forms gas when heated. In another embodiment, a regulated gas supply from an external source with the required pressure values is carried out [1]. The developed device designs and the implementation of their operation can be easily integrated into existing technological processes [2]. The device can also be immersed in liquid steel in case of slag ingress into the riser.

On the example of a steel casting of a ‘die plate’, the parameters for the implementation of these technological processes are determined. The cooling of the casting in the mould, the duration of which is ~ 177 hours, was calculated. The calculations of the amount and composition of substances, which, when heated, release a sufficient volume of gas to force the melt out of the riser, showed that to force steel out of a 2.5 m high riser at a pressure of ~ 0.3 MPa, 6.3 g of paraffin is required, and a mixture of calcium carbonate and carbon 13 times more – 80 g. It has been established that the use of a mixture of calcium carbonate and carbon is less technologically demanding and efficient compared to paraffin (a solid boundary hydrocarbon). Its main advantage is the pressure-independence of the thermal decomposition reaction (the decomposition reaction of paraffin is irreversible, which makes the device more stable).

Based on the results of the analysis of the technological features of various designs of devices that ensure gas-dynamic extrusion of steel from the siphon casting system, it was found that for large castings and ingots using siphon refractory supplies, the most acceptable design is a device with a regulated gas supply. In addition to the reliability of solidified layer formation in the siphon casting system, this device design ensures the elimination of possible leaks along the refractory tube connector due to the possibility of liquid metal returning to the riser. After the new metal layer has solidified and the casting system is completely sealed against the environment, the melt is again forced into the casting or ingot.

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UDC 669.162

ANALYSIS OF THE EFFICIENCY OF EXISTING AND PROSPECTIVE TECHNOLOGIES AIMED AT REDUCING CO_2 EMISSIONS FROM A BLAST FURNACE

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The report discusses the results of thermal energy and exergy analysis of the potential of new and existing technologies for reducing carbon dioxide emissions and coke consumption, the possibility of increasing iron production due to the injection of various fuel additives into the furnace: hydrogen, pulverized coal fuel, natural, coke, carbon monoxide and synthesis gas, as well as the use of metal additives, plastic, technical oxygen and nitrogen, increasing the blowing temperature, reducing heat losses, improving gas distribution in the blast furnace.

With the use of the mathematical model of the full energy balance of blast furnace smelting developed at the ISI NASU, an assessment of the impact of the potential of new and existing technologies on the reduction of CO_2 emissions and technical and economic indicators of blast furnace smelting was carried out.

One of the promising directions in modern blast furnace production is the use of furnace gas purified from CO_2, which is a combination of hydrogen, carbon monoxide and nitrogen. In world practice, this mixture of gases is called synthesis gas. According to the literature, synthesis gas is obtained from non-coking coal with a high volatile content, the use of which will allow to reduce the cost of iron production by reducing coke consumption in the blast furnace, and with a large share of hydrogen - to reduce CO_2 emissions in blast furnace production.

It has been established that CO_2 emissions in blast furnace production can be reduced by 25-30% by making changes to blast furnace smelting technology. The implementation of production decarbonization projects is determined by investments, the raw material and energy base of the metallurgical enterprise, and the level of existing blast furnace smelting technology. In the future, the reduction of CO_2 emissions due to the use of hydrogen and hydrogen-containing fuel additives is the most promising, but now it is not economically profitable from the point of view of the increase in the price of metal products.

The use of pulverized coal fuel is the main factor in reducing the cost of production of cast iron in advanced practice today. Therefore, the report provides calculations of CO_2 emissions reduction and changes in coke consumption and pig iron production when using pulverized coal fuel with other fuel additives, and their combinations.

The limiting factors for blowing various fuel additives into the blast furnace are the degree of direct reduction of iron, the theoretical temperature, the presence of oxygen, and the temperature of the blast furnace gas. On the basis of these restrictions, the limit values of hydrogen injection and hydrogen-containing fuel additives are determined.

Increasing the blowing temperature is a powerful reserve for reducing CO_2 emissions by 10% or more and, in general, improving the technical and economic performance of smelting.

The use of pure metal additives gives a significant effect on reducing CO_2 emissions, which is comparable to the injection of pure hydrogen, but is limited by their availability and price. If carbon is used in the production of pure metal additive, the amount of CO_2 emissions at the metallurgical enterprise will not decrease.

The use of plastic in the blast furnace will allow not only to reduce coke consumption and CO_2 emissions from the blast furnace, but also to dispose of it, thereby reducing the negative impact on the Earth's ecology.

UDC 669.17.046.517B.411.001.5

RESEARCH ON THE INFLUENCE OF THE AMOUNT OF ADDITIVE DURING OUT-OF-FURNACE STEEL TREATMENT ON THE HYDRODYNAMIC AND THERMAL CONDITIONS OF THE LAP BATH

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In recent decades, the influence of a number of constant and variable factors on the efficiency of processes occurring in a steel casting ladle during out-of-furnace steel treatment has been actively studied. Among them, the influence of the ladle capacity, the mass of the metal melt, the chemical composition of the steel, the temperature of the metal melt, the method of introducing the additive and its composition, the conditions of mixing the melt, the intensity and method of blowing the bath, and many others have been determined. At the same time, the assessment of the possible influence of the amount of solid lump additives introduced into the steel casting ladle during steel processing, in particular, on the ladle-furnace unit (UFU), is still insufficiently studied. In order to identify the influence of the amount of lump additive on the efficiency of its use at the initial stage of steel processing, the hydrodynamics and thermal state of the liquid metal melt were numerically studied. The research was carried out using specially developed three-dimensional mathematical models and a software product that takes into account the dynamic influence of the solid additives used. The objects of the study were the baths of steel casting ladles with a capacity of 60 and 250 tons, which are used at the Dniprospetsstal electrometallurgical plant (Zaporozhye) and the Kametstal metallurgical plant (Kamensk). Using the example of ferromanganese grade FMn78 in an amount from 0.2 to 3.0 kg/t, the hydrodynamics and thermal conditions of the metal bath were investigated at the time of introduction and during the first 4.5 seconds of the additive's stay in the metal melt. Simultaneous purging of the bath with argon with a flow rate from 50 to 800 l/min through each of the ladle bottom lances was taken into account.

The conducted computational studies assessed the effect of the amount of lumpy ferromanganese additives on the hydrodynamic state of the melt in ladles of different capacities depending on the modes of purging the bath with the metal melt. It was found that although the hydrodynamics in the ladles as a whole (on average) does not change significantly when lumpy additives are introduced, it changes significantly at the qualitative level at the place of their introduction. In this place, the directions and magnitudes of the melt flows change, which determine the location of the introduced materials in the melt and their further dynamics after introduction. Since from the point of view of the assimilation of conductive elements from solid additives of ferroalloys introduced, it is essential for determining rational modes of their use, it is considered advisable to take into account the factor considered as influential [1].

Numerous studies have also studied the effect of the amount of the introduced additive on the thermal state in the contact zone of the slag-metal melt. It was determined that the specific mass of the additive affects the temperature gradient of the liquid metal at the moment of introduction of the latter and during the initial time (4.5 s) studied. It was established that the argon flow rate per lance in the range from 200 to 600 l/min (ladle with a capacity of 250 t) slightly changes the temperature of the metal surrounding the additive. At the same time, in a metal bath of such capacity at the moment of introduction of the additive with argon flows that are practically used, a significant decrease in temperature occurs, which is confirmed by the results of numerical studies [2]. It is also shown that the temperature decreases under the influence of the mass of the additive in the ladle bath of 60 tons with a similar effect of this factor on its thermal state. In the near future, using the developed mathematical models and software product for studying the influence of the number of lump additives introduced into the metal bath of the ladle on the UCP, the thermal conditions will be estimated until the moment of the start of melting of solid additives and the degree of averaging of conductive elements from ferroalloys in the volume of the melt

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UDC 669.184

CURRENT STATE AND PROSPECTS OF OXYGEN-CONVERTER STEEL PRODUCTION IN UKRAINE

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In 2024, in Ukraine, according to evidence of existing and planned production volumes [1] under favorable conditions, steel production may be increased by 17% compared to the volume of 2023 and amount to approximately 7,300,000 tons to 7,500,000 tons at the end of the current calendar year [1, 2], which is a positive manifestation since metallurgy is the second largest export industry of our country. At the same time, it is important to note that today from 65% to 75% [1, 2] of the world's steel production takes place in oxygen converters using top, combined, side and bottom blowing technologies. According to the source [3], since 2017, the share of oxygen converter steel in Ukraine has been over 70% of the total production, however, due to the destruction and damage of certain metallurgical enterprises of Ukraine during the war, there was a certain redistribution in the technological capacities of steel production between the oxygen converter, open-hearth and electric steelmaking methods of steel production. Today, there are three large metallurgical enterprises in Ukraine in the structure of which oxygen converter shops operate: PrJSC "ArcelorMittal Kryvyi Rih"; PrJSC "Dniprovsky Metallurgical Plant"; PrJSC "KAMET-STEEL". It should be noted that the oxygen-converter method of steel production has a number of advantages compared to electric steelmaking and open-hearth steelmaking, namely: the highest productivity; no direct need for external separate fuel and energy resources; faster flow of physical and chemical processes; insignificant capital costs for construction and repair; higher efficiency; conditions for processing a significant amount of scrap metal without the use of external energy resources; provides good control over the course of the technological process; has better environmental performance than the open-hearth process. In accordance with the above advantages, it is advisable in the future perspective of steel production in Ukraine to restore the dominant share in steel production precisely by the oxygen-converter method to indicators in line with world standards, which will require either the reconstruction of previously existing oxygen-converter shops, the expansion of existing ones or the creation of new metallurgical enterprises in the structure of which they will function.

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UDC 669.162.21:669.788.083.133

DEVELOPMENT OF SCIENTIFICLY BASED TECHNOLOGICAL PROVISIONS FOR THE USE OF HYDROGEN IN A BLAST FURNACE

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Ukraine's integration into the world community of developed economies involves the implementation of the principles of decarbonization of production in various industries, including metallurgy. A promising way to achieve carbon neutrality while maintaining the traditional blast furnace method of iron production is to develop and introduce new, breakthrough changes in technology, in particular, those related to the use of hydrogen as a reducing agent and heat source by significantly increasing its content in the blast. In addition to the direct effect of reducing carbon emissions, this also achieves a general reduction in the negative man-made load on the environment by reducing the intensity of extraction of fossil raw materials for the production of reducing agents and coolants.

The use of hydrogen-containing fuel in the production of iron leads to significant changes in blast furnace smelting technology, in particular, thermal and renewable processes that occur in the furnace. Deepening the understanding of these processes when using hydrogen-containing additives in the blast furnace, scientific justification of their rational amount in order to ensure the maximum degree of hydrogen use have determined the relevance and direction of developments that are currently being carried out in the iron metallurgy department.

Adding hydrogen to the blast and increasing its concentration in the gas phase leads to an acceleration of reduction processes, in particular, to an increase in the degree of indirect iron reduction. The results of previously performed studies have shown that increasing the amount of hydrogen supplied to the blast furnace, up to a certain limit, contributes to an increase in the degree of its utilization. Exceeding this limit value leads to the opposite - a decrease in the degree of hydrogen utilization. Therefore, determining the rational amount of hydrogen-containing additives in the blast composition using heat and mass balance calculations is one of the main research tasks.

Decarbonization of the pig iron production process involves increasing its energy efficiency, which can be ensured by the appropriate quality of iron-containing materials and coke, the development and implementation of charge loading modes adapted to new conditions, and the selection of blow mode parameters that allow achieving high values of the degree of hydrogen utilization, taking into account the peculiarities of its behavior in different zones of the blast furnace.

Of particular note are studies of the influence of hydrogen on the mechanism of reduction of the iron-containing part of the charge used at metallurgical enterprises. The results of these experimental studies will allow us to formulate and clarify the requirements for the quality and properties of iron-containing materials and coke under the conditions of using hydrogen in blast furnace smelting, as well as to clarify the requirements for blast furnace smelting under new technological conditions. Calculation and analytical studies and analysis of melting indicators in different zones of the blast furnace, experimental studies of the reducibility of iron-containing raw materials and taking into account the peculiarities of the nature of the distribution of hydrogen along the radius of the furnace create a scientific basis for substantiating and developing technological requirements for the rational distribution of iron-containing materials, as well as determining rational ratios of injected reductants that ensure a high degree of hydrogen utilization.

The result of the research carried out by the Department of Iron Metallurgy will be the development of scientifically substantiated provisions of blast furnace smelting technology (required properties of iron-containing components of the charge, rational modes of their loading, the ratio of the components of the combined blast, the parameters of the thermal and slag modes) in the conditions of using hydrogen and hydrogen-containing additives in the combined blast.

UDC 669.162.215.261.3:51.001.57

USE OF A COMPLEX MATHEMATICAL MODEL OF FORMATION OF MULTICOMPONENT PORTIONS OF BURNING MATERIALS, THEIR LOADING INTO THE BUNKER OF A CONELESS LOADING DEVICE, UNLOADING FROM THE BUNKER AND DISTRIBUTION ON THE SURFACE OF THE FILLING

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Research carried out in recent years has shown the possibilities of using a complex model of distribution of charge components in solving various technological problems. One of the most important results that can be obtained using the model is a quantitative assessment of the mass of each component of the charge entering the considered annular zone during the unloading of charge materials in each involved angular position of the tray of the coneless loading device. This allows you to analyze the influence of the quantitative characteristics of the applied charge materials distribution program on the distribution indicators of individual components, both iron ore and fuel parts of the charge, as well as ore loading, and creates the possibility of selecting and adjusting the program based on the results of predictive calculations before entering it into the loading control system, which significantly reduces the duration of development of rational charge loading modes and reduces the risk of making ineffective decisions. In addition, the result of mathematical modeling is the component composition of mixtures of charge materials in different zones of the blast furnace, which makes it possible to perform predictive calculations of high-temperature properties of melts and assess the rationality of their distribution across the cross-section of the blast furnace, taking into account technological limitations and risks of negative phenomena during melting, such as damage to the furnace lining, the formation of refractory conglomerates, clogging of the furnace, etc.

The results of modeling using a complex model also allow assessing the possibility of implementing technological requirements for the distribution of charge materials and gas flow during the operation of blast furnaces under various technological conditions.

Currently, mathematical modeling of the distribution of charge components in the working space of the blast furnace is used in the development of new methods for the operational determination of the position and parameters of the plastic zone in the blast furnace, which largely determines the technical and economic indicators of smelting, as well as in current studies of the use of hydrogen and hydrogen-containing coke substitutes in blast furnace technology.

Performing computational and analytical studies to determine the melting indicators in different zones of the blast furnace, as well as their analysis, will allow specifying the requirements for the distribution of charge components, flow rates and parameters of combined blowing to ensure the maximum degree of hydrogen use and determine the rational ratios of injected reducing agents: coke oven and natural gas, pulverized coal fuel.

UDC 669.184

ASSESSMENT OF IMPURITY CONTAINMENT DURING PURGE OF A METAL BATH WITH OXYGEN-NEUTRAL GAS MIXTURE THROUGH A BOTTOM PURGE UNIT

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Considering the global need for structural materials, among which steel and cast iron remain irreplaceable, the place and significance of low-carbon steels with a carbon content below 0.01%wt. should be especially emphasized. The main indicator of their service properties is high plasticity in the cold state. The production of such steels is associated with the need to use special technical solutions to remove carbon from the melt below the critical concentration. This process is accompanied by a significant decrease in the yield of liquid steel. In these conditions, the current task for modern metallurgical science is to develop alternative effective technical solutions for the production of steels with a carbon content below 0.01% in the conditions of the material and technical base of domestic metallurgical enterprises with minimal modernization of equipment. A promising direction for solving this problem is the decarburization of the iron-carbon melt by purging the bath with an oxygen-neutral gas mixture, which is carried out outside the steelmaking unit.

In order to establish the technological efficiency of the process, a high-temperature study was conducted, which involved purging carbon steel with an "oxygen-nitrogen" mixture in a ratio of 30 to 70%, respectively, with a flow rate of 0.075 l/h. Melting and purging were carried out in a 1 kg induction furnace. For the research, a steel charge with the initial chemical composition, wt%: C 0.3; Si 0.03; Mn 0.34; P 0.012; S 0.014 was used. The purging was carried out through a ceramic tube that was immersed in the bottom part of the crucible, which simulated one channel of the bottom purging block under the conditions of steel processing in a steel ladle. The purging time was 3 minutes with sampling every 40 seconds. The results of the absolute change in the chemical composition of the steel during the purging:

- the carbon content decreased by 0.153 wt%;
- the silicon content increased by 0.077 wt%;
- the manganese content increased by 0.044 wt%;
- the phosphorus content decreased by 0.002 wt%;
- the sulfur content did not change.

According to the presented data, it can be established that when purging a metal bath with a mixture of process gases containing oxygen in an amount of 30% of the total volume of the purge gas, priority oxidation of carbon and phosphorus is observed without oxidation of other impurities important for the quality of steel - silicon and manganese.

The conducted studies allow us to conclude that the developed technology of purging steel with a mixture of process gases can be implemented in industrial conditions. In this case, the use of a two-stage technology of decarburization of iron-carbon melt (1st stage – oxidation in the melting unit to a content of 0.2-0.3% by weight; 2nd stage – oxidation to the required concentration in the steel casting ladle by purging with a mixture of gases containing oxygen through the bottom purge block) will allow increasing the yield of the usable product by 7-10% compared to classical processes for obtaining low-carbon steels.

UDC 669.184

STUDY OF THE INFLUENCE OF HIGH-VOLTAGE ACTIVATION OF OXYGEN FLOW ON THE PROBABILITY OF CHEMICAL REACTIONS INVOLVING OXYGEN

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Today, the oxygen-converter method of obtaining a liquid metal intermediate product remains the only economically viable method of producing an indispensable structural material – steels of various grades. However, the method itself, in order to maintain competitiveness in the market, requires constant improvement of production efficiency and cost reduction. Traditional ways of influencing the steelmaking bath to improve exchange processes have a number of limitations and have mostly exhausted their capabilities [1]. Therefore, in the practice of world ferrous metallurgy, unconventional methods of increasing the intensity of steel production processes are increasingly being used, which expand the capabilities of existing processes and do not require significant capital investments and cardinal changes in the production cycle.

Among the unusual, but promising methods of intensification of converter production, one can single out a method of electrical activation of the process components, for example, electrical activation of the gas purge flow [2]. This makes it urgent to conduct research on the study of methods of physicochemical influence on the iron-carbon melt by electrically activated gas jets. Due to the activation of the oxygen flow during purging before it enters the liquid metal bath, oxygen ions are formed in the jet. It is known that compared to the activity of molecules, the activity of ions is greater [3]. Accordingly, this should contribute to an increase in the degree of assimilation of the purge gas by the melt and, as a result, cause an intensification of exchange processes in the converter bath with a corresponding reduction in the duration of purging and an increase in the productivity of oxygen converters.

The work carried out an analytical study of the influence of high-voltage activation of the oxygen flow on the course of the carbon oxidation reaction to CO by evaluating the thermodynamic index of the reaction course in the direction of the formation of reaction products - Gibbs free energy [4]. Carbon, as a component for evaluation, was chosen because the process of its oxidation determines the speed capabilities of the oxygen conversion process under conditions of purging from above. The calculation was carried out taking into account the increased number of oxygen ions that are formed on the way to the metal bath in the oxygen jet due to an electric discharge for the conditions of redox reactions, for which the electrode potentials of the components were calculated. It was found that high-voltage activation of the oxygen flow at the nozzle outlet creates a sufficient number of active particles - ions, which are stored in such a quantity at a distance of 40 calibers that a significant increase in the electrode potential of oxygen can be noted. This, in turn, increases the electromotive force of redox reactions involving gaseous oxygen, namely the "carbon - oxygen" system, and, accordingly, an increase in the negativity of the Gibbs free energy compared to the classical version of purging by 3 times was established. The results obtained indicate the corresponding possibility of reducing the time of purging the metal melt to achieve the required carbon content earlier due to a more active reaction with an increased number of oxygen ions.

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UDC 669.184

INCREASED PORTION OF SCRAP METAL IN THE BATCH OF OXYGEN CONVERTERS AS A BASIS FOR IMPROVING TECHNOLOGICAL AND ENVIRONMENTAL INDICATORS OF PRODUCTION

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Today poses new challenges to human civilization in the field of sustainable development and rational use of nature. At the same time, the metallurgical industry has a significant negative impact on the environment in general and the atmosphere in particular. At the same time, the main share of pollution falls precisely on CO and CO_2 emissions accompanying the technological processes of iron recovery from oxides and direct oxidation of excess carbon in the metal charge during steel production.

Taking into account the technological and organizational features, it is most difficult to organize effective capture and utilization of carbon oxides during steelmaking processes using oxygen converters. At the same time, in modern conditions, this method of steel production is the main one in relation to the assortment of metal products of ordinary quality. In world practice, there is an approach to reducing the negative impact of converter steel production, which is based on the capture, purification and averaging of flue gases, their storage in a gas holder system and further use as energy carriers for other production needs. At the same time, the construction of a gas capture system for preparation and a gas holder system for storing and averaging gaseous products is characterized by high cost. There is also another approach to reducing carbon oxide emissions into the atmosphere by using the heat of combustion of carbon monoxide to dioxide in the cavity of the oxygen converter to increase the proportion of scrap metal in the initial charge. At the same time, the amount of excess impurities in the metal bath, in particular carbon, is reduced accordingly with a corresponding reduction in the amount of carbon oxide emissions into the atmosphere.

The purpose of this study is an engineering and calculation assessment of the increase in the proportion of scrap metal in the charge of oxygen converters with top purge by the amount of carbon oxides formed and, accordingly, discharged into the atmosphere. Considering that the composition and amount of flue gases during purging changes significantly, the average indicator was taken for the assessment, calculated taking into account the features of the material and heat balances of steelmaking close to the real conditions of steelmaking in 250-t converters with top purge. For the comparative analysis, the classical design of the oxygen lance, double-circuit and double-deck, was used. The results were evaluated using the integrated indicator of the amount of carbon dioxide entering the atmosphere (the amount of carbon monoxide was converted to dioxide and the same indicator of the total carbon dioxide emission was used for further evaluation).

Thus, according to the results of the conducted studies, it was established that the integrated amount of carbon dioxide for the use of the classical design of the lance, double-circuit and double-deck, respectively, is, m3/t of steel: 2.79; 2.71 and 2.62. The results obtained correlate with the corresponding increase in the proportion of scrap metal in the charge and an increase in the yield of liquid steel.

Based on the above, engineering calculations have confirmed the effectiveness of the impact on the amount of carbon oxide emissions into the atmosphere from converter production by increasing the proportion of scrap metal in the charge. At the same time, increasing the amount of scrap metal in the charge does not lead to an improvement in technological indicators, since this effect is achieved by optimizing the thermal regime of converter melting by increasing the proportion of CO that is burned into the converter cavity by using blow-off lances of progressive design.

UDC.621.184.244.66.669.184.235.083.133

HIGH-TEMPERATURE RESEARCH OF THE PROCESS OF PURGE OF METAL MELTEN WITH OXYGEN JET ACTIVATED BY ELECTRIC DISCHARGE

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The history of converter production began with air purging, then the process was transferred to oxygen as a more active gas [1]. Now the time has come when the need for the use of more active purging gases, such as ozone [2]. However, the complexity and energy intensity of the process of its production, as well as its high instability, are significant obstacles to its widespread implementation on an industrial scale. In this regard, it is relevant to conduct research on the search for rational opportunities for intensification of the oxygen conversion process by using ozone.

The aim of the work was to study the features of the upper purge with an oxygen jet, which was previously activated by an electric discharge to create ozone, on a high-temperature model of an oxygen converter.

A previously conducted study made it possible to establish that the best conditions for purging a metal bath with ozone are to obtain ozone by activating the oxygen jet at the outlet of the purge lance with a high-voltage electric discharge [3]. This is due to both the simplicity of implementing this method and its reliability in operation. The selected type of high-voltage discharge is brush, which causes the formation of ions in the gas jet.

The research was conducted on a high-temperature model of an oxygen converter with upper purge. A 60 kg model was filled with pre-molten cast iron of the composition, wt%: C 3.85-3.95; Si 0.7-0.9; Mn 0.15-0.17; S 0.018-0.021; P 0.086-0.090 with a temperature of 1360-1400 °C, slag-forming components were introduced and the iron-carbon melt was blown through the upper lance with technically pure oxygen for 12 minutes. The studies were carried out both when using an oxygen flow activated by an electric discharge and for comparison under the conditions of the classical blowing option. High-voltage activation was carried out directly at the outlet of the blow-off lance under conditions of supply to the electrodes located in the lance of 25-30 kV, which corresponded to the formation of ozone at a distance of 40 calibers from the lance nozzle of about 25-27 mg/m^3.

According to the results of research, in comparison with the classical conversion variant, it was established that the use of an oxygen flow activated by an electric discharge for blowing an iron-carbon bath contributes to:

- reducing the bath ignition time by 2-3 times and increasing the bath temperature by 100-500 ºC;
- increasing the carbon oxidation rate by 30-40% rel. and reducing the specific oxygen consumption by 9-10% rel.;
- reducing the level of dust emission from the bath by 56.9-69.5% rel.

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УДК 669.162.12.004.67:669.787.001.5

STUDY OF REDUCTION PROCESSES IN A BLAST FURNACE BY USING HYDROGEN-CONTAINING GASES

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One of the promising ways to significantly reduce harmful emissions in the ferrous metallurgy industry is to reduce the use of carbon by replacing it as much as possible with alternative heat sources and reducing agents. Hydrogen has great potential in this regard due to its physical and chemical properties and because its reactions with iron oxides do not result in toxic CO_2 emissions.

Increased use of hydrogen-containing gases has a significant impact on the parameters and efficiency of blast furnace smelting, changes the course of processes in the blast furnace, temperature distribution and gas permeability of the charge. On the one hand, increasing of hydrogen concentration accelerates the reduction processes, on the other hand, it leads to a decrease in the temperature in the furnace shaft, and therefore optimization of the properties of iron ore raw materials, primarily their reducibility and strength, is a necessary condition for increasing the efficiency of blast furnace smelting with using hydrogen-containing gases. It is necessary to have a clear idea of how the composition of gas mixtures, their feed rate, temperature, properties of iron ore raw materials and many other factors affect the reduction processes. However, there is still no unambiguous and generally accepted theory that would generalize all the patterns of hydrogen reduction processes in a blast furnace. Interesting studies of the effect of hydrogen-containing gases on the reducibility of various types of iron ore raw materials have been carried out in recent years by Chinese, Japanese, European and Indian researchers, but the results of studies conducted under different conditions are quite contradictory.

Ukrainian scientists and blast furnace operators have been conducting research in this area for several decades and have very interesting scientific and practical results, but in recent years the blast furnace smelting conditions and the composition and properties of the iron ore raw materials that Ukrainian metallurgical plants work with have changed greatly, so urgently requires further in-depth study of the course of reduction processes when using hydrogen specifically for modern Ukrainian realities.

In laboratory conditions of the Iron and Steel Institute research continues on the influence of hydrogen on reduction processes in blast furnaces for different types of iron ore raw materials produced in Ukraine. The reduction processes were modeled on laboratory equipment of the ISI by using various mixtures of reducing gases, the composition of which was close to industrial conditions. The effect of hydrogen content in the reducing gas, heating rate and gas feed rate on the loss of sample mass was studied, and then the reduction index R was calculated.

It was determined that increasing the hydrogen content in the reducing gas mixture in the temperature range of 900-1000 ºC is accompanied an improvement in the reducibility for all types of charge materials, but the reducing behavior of the sinter and pellets differs significantly and depends on the hydrogen content in the gas mixture and its feed rate. Analysis of the obtained experimental data made it possible to determine the most effective hydrogen concentrations in the reducing gas for these conditions.

The obtained results, on the one hand, confirmed the generally recognized patterns of the reduction processes in a blast furnace with using hydrogen-containing gases, and, on the other hand, revealed some features specifically for these types of raw materials with which Ukrainian metallurgical plants work. This result allows to be used them for planning further research and for developing technological recommendations for the use of hydrogen-containing gases in blast furnace production in Ukraine.

Electrometallurgy

UDC 662.352:621.73

STUDY OF THE INFLUENCE OF MANUFACTURING PARAMETERS USING LPBF TECHNOLOGY ON THE MECHANICAL PROPERTIES OF ALUMINUM-BASED ALLOY

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The work is devoted to the study of the influence of the circulation of the protective medium in the working space of the printer camera during laser powder layer melting (LPBF). According to the results of research in recent years, for materials with a low specific density (light), the influence of the blowing speed and trajectory is especially relevant. The material for the research is vertical samples made of LPBF-AlSi10Mg aluminum-based alloy, evenly spaced over the entire working plane of the construction chamber, manufactured according to rational technological regimes. Tensile tests must be carried out according to the standard method (DSTU ISO 6892-1:2019). Continuity (porosity) was determined metallographically using ImageJ software. It was established that when supplying a constant feed rate and circulation of the protective medium, alloy particles are captured and transferred to the exit nozzle, which affects the final integrity, namely the pore size. The dependence of the mechanical properties on the location of the studied samples in the platform area (the influence of their blowing) is shown.

UDC 662.317:621.88

INCONEL 718 MICROSTRUCTURE DEPENDING ON FOCAL LENGTH CORRECTION IN PARTS MANUFACTURED BY THE METHOD OF LASER MELTING IN THE POWDER LAYER

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Defects in the finished product are one of the main reasons for the destruction of components obtained by laser melting in a powder layer. Many studies have been conducted to control the process of laser melting in the powder layer to achieve high density and the absence of discontinuities. This was achieved by applying a complex of various proposed available known methods of analysis (optical microscopy, computed tomography and transmissive fluoroscopy during the process) and building process maps of the defective structure of production. The majority of research is directed at the analysis of defects, their form and mechanism of formation, which is currently quite well known. Taking into account this research experience, the authors of many works reached the level they needed. Currently, in the industrial sector of production by the method of laser melting in a powder layer, more progressive issues arise: increasing the productivity of the process and the possibility of increasing the volume of printing, both serial and large-scale production of parts while maintaining the high density of the finished product. As for productivity, these issues have a partial solution, namely the use of a dynamically adapted focal spot, the shape of the focal spot, an increase in the thickness of the powder layer, etc. But when the volume of printing is increased, some difficulties arise that are currently being sought for a solution, mainly these problems are related to the impossibility of using the F-Theta lens. Thus, another optical system was applied in the industrial sector, namely a three-axis focusing system (dynamic focusing) to increase the printing area, which allowed to increase the area due to the compensation of the focal length by moving the movable focal lens and the possibility of installing additional optical systems to cover a larger area (above 400 mm). The use of this system can affect the quality of finished products and especially the repeatability of mechanical properties depending on the offset of the focal distance correction from the center. As a result of the research, it was established that when the focal length correction is shifted, the track boundaries are distorted, which indicates a change in the crystallization of the tracks depending on the curvature of the focal spot. When applying different thickness parameters of the deposited layer, when using rational construction parameters, the structure of the samples produced at 40 μm has columnar grains and HAZ thermally affected regions, indicating overheating. Test samples made at a thickness of 60 μm have a characteristic area of curvature of an arcuate track structure with an inclination angle of 14° depending on the focal length correlation. During the analysis of test samples made with a layer thickness of 40 μm, no change in the angle of inclination was observed, which is associated with a smaller layer thickness and the presence of columnar grains, which in turn suppresses the detection of an arcuate structure.

UDC 662.326:624.98

STUDY OF THE INFLUENCE OF MECHANICAL POST-PROCESSING ON THE FINAL MECHANICAL PROPERTIES OF 316 L STEEL SAMPLES MADE BY SLM - TECHNOLOGY

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In the modern additive manufacturing of parts, the SLM method has become widespread - the technology of laser melting of a layer of metal powder, which allows you to significantly expand the possibilities for optimizing the geometry of products. For details of the traditional method of production (casting, deformation), it is known that the surface roughness can significantly affect the level of mechanical properties, since protrusions and depressions are stress concentrators. Parts manufactured using additive manufacturing technologies have increased roughness, but their structural state after manufacturing is significantly different from traditional metal. It is often necessary to operate without subsequent mechanical surface treatment of products manufactured by the SLM method. The purpose of the work: to determine the effect of roughness, the presence or absence of mechanical processing of the working area of the samples on the mechanical properties under static tension conditions. Research material and methodology. Tensile samples with a working zone diameter of 5 mm, 6 mm (allowance for subsequent machining) and a working zone length of 25 mm were made from metal powder of steel 316L on a 3-D printing machine Alfa-150D manufactured by ALT Ukraine LLC in the vertical direction. The mechanical properties were determined during the tensile test according to the standard method on the "INSTRON" machine. Roughness control was performed by two methods: using a DANA-260 roughness meter and microstructural analysis on an AxioVert 200 M Mat optical microscope using specialized ImageJ software. From the analysis of the profilometric curve and the microstructure, it was found that the samples without mechanical processing have periodic protrusions, which is related to the texture that is formed during manufacturing. The average values of mechanical properties do not differ significantly (less than 6.6% for various characteristics) depending on the presence or absence of mechanical processing, but the deviations from the average within the sample for the values of ultimate strength and relative shrinkage for samples without mechanical processing are many times larger compared to interval of fluctuations of values within the sample for samples with mechanical processing.

The results were obtained as part of the Ukrainian-Austrian project "Improvement of heat treatment regimes of AISI316L produced by SLM to reduce residual stresses" (state registration number 0123U103227) under contract M29-2024/KC.0226.24 dated 05/30/2024.

Technologies for step by step processing of cast iron and steel

UDC 669.17.046.517B.083.133

GENERATION OF COMPLEX INDICATORS FOR PREDICTION OF ELEMENTS DISTRIBUTION COEFFICIENTS BETWEEN FINAL MELTS AFTER PROOFING STEEL IN A BUCKET FURNACE UNIT

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Predicting the indicators of the steelmaking process allows for the rational use of additives and improves the physicochemical and performance properties of specialty steels. To enhance the efficiency of steel refining at the ladle-furnace installation, it is essential to develop methods for predicting the composition of final products. The interaction between molten metal and slag is an ion-exchange process within the "metal-slag" system, with results described by interphase distribution coefficients of diffusing elements.

The Iron and Steel Institute of the National Academy of Sciences has accumulated experience in modeling the physical and chemical properties of steels and ferroalloys at the level of interatomic interaction, as well as the processes of the distribution of elements in the "metal-slag" system under renewable conditions [1-2] using complex indicators of materials loaded into the melting unit and metal smelting technology.

To predict the distribution coefficients of sulfur, silicon, manganese and aluminum between the final products of melting after ladle finishing of steel, based on the concept of directional chemical bonding, a methodology has been developed, which includes:

- selection and substantiation of the most significant indicators of the chemical composition of steel and slag to the UCP, additives and technological regime, which ensure obtaining the required chemical composition of the final steel;
- generation of the structure of complex indicators of the "metal-slag" and metal-additive systems, taking into account their chemical composition and physico-chemical properties, using the mathematical apparatus of Harrington's generalized desirability function, which allows various indicators to be "collapsed" into a single generalized indicator;
- development of predictive models for calculating the distribution coefficients of elements using complex indicators in the form of $L_{el} = A \cdot F_{ms}^{\alpha_1} \cdot F_{md}^{\alpha_2} \cdot F_t^{\alpha_3}$, where F_{ms}, F_{md}, F_t are complex indicators, respectively, of the "metal-slag", "metal-additive" systems and the technological mode of melting, A, α_1, α_2, α_3 – coefficients of the equations, which are determined for a specific brand of steel.

The proposed approach differs from the traditional methods of considering the distribution coefficients of charge elements as constant values and lays down the prerequisites for the development of an algorithm for forecasting and directed formation of the chemical composition of the final melts, taking into account the initial composition of the metal and slag fed into the ladle, and the selection of the optimal composition of slag mixtures, alloying and microalloying additives.

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UDC 69.14.018.298:621.789

LOW FREQUENCY VIBRATION DURING SOLIDIFICATION OF Fe-28Mn-12Al-0.9Si-1.4C STEEL AS-CAST INGOTS

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Foundry and metallurgical processes are the first and main stages in metallic materials production, on which the formation of their quality, initial structural-phase state, presence of defects and impurities depends. For a large number of alloys, there are many difficulties associated with obtaining homogeneous ingots with a minimum defect, absence of liquation and favorable structural-phase characteristics. This is especially important for alloys that contain components with simultaneous large differences in thermal conductivity, heat capacity and density. Obtaining high-quality blanks or products from such materials requires the use of methods to influence the crystallization processes of such alloys to provide elimination of undesirable defects. These issues become especially important for complex multicomponent alloys, which are related to advanced structural materials like lightweight high-strength steels with a high content of manganese and aluminum. Preparing of such melt needs taking in account a various number of technological issues like components density, slag forming ability, overheating limits and others to provide best quality and properties of obtained castings of ingots.

The abstract presents the results of experimental studies, devoted to investigation of the vibration treatment influence on the defects and structure formation in Fe-28Mn-12Al-0.9Si-1.4C steel as-cast ingots. It is known that high manganese steels, especially with high aluminum concentration, are very prone to shrinkage defects. Vibration treatment of melt during crystallization is an effective method of defects decreasing and structure refining. Corresponding dependencies are almost not investigated, so this work is dedicated to establishing dependencies of quality and structure forming of as-cast Fe-Mn-Al-C steel with a high content of manganese and aluminum under the influence of vibration. Such method hasn't been tested on steels with high Mn and Al content yet. The main variable treatment parameters were vibration frequency and the melt pouring temperature. For comparative analysis, ingots were obtained without treatment and under three vibration frequencies – 12, 24 and 48 Hz.

Vibration treatment of Fe-28Mn-12Al-0.9Si-1.4C steel with a frequency of 12 Hz has a low effect on defects but has a sufficient influence on refining the macro- and microstructure of castings. The highest defectivity and the best grain refinement is provided by 48 Hz vibration frequency treatment. 24 Hz vibration treatment was determined as the optimal mode, which ensured minimal as-cast sample defectiveness and caused noticeable grain refinement, approximately twice, comparing to 12 Hz treatment and four times, comparing to untreated sample.

During the experiments, it was established that the solidus temperature for Fe-28Mn-12Al-0.9Si-1.4C steel is close to 1300 °C. According to the obtained samples microstructure analysis, it was determined that the optimal temperature for casting and pouring steel with such chemical composition is 1450 °C. An increase in this temperature leads to a significant loss of the vibration treatment effect, which appears in grain growth and defects formation.

This research has been funded by National Research Foundation of Ukraine, competition "Science to Strengthen Defense Capabilities of Ukraine" (Project No. 2023.04/0021), "Production of armor elements for military equipment from ultralightweight steels using secondary raw materials". The authors wish to acknowledge the NRFU for their support.

UDC 669.02

USE OF ALUMINUM PRODUCTION WASTE IN THE OUT-OF-FURNACE PROCESSING OF STEEL

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This paper presents a critical analysis of the out-of-furnace processing of steel, with a particular focus on the potential use of aluminium waste as part of the slag mixtures employed in steel refining [1-3]. One of the most commonly employed methods of out-of-furnace steel treatment is the treatment of steel with liquid slags containing lime and alumina for the purpose of desulfurization and deoxidation. Mixing metal with specially prepared (synthetic) slag intensifies the transfer of harmful impurities (sulfur, phosphorus, oxygen) into the slag. Synthetic slags must be free from excessive oxidation, a condition conducive to the deoxidation of steel and desulfurization. Moreover, the CaO activity within these materials must be kept at its maximum level. Therefore, iron oxides should not be present at all, or their content should be limited.

The principal advantage of the method of steel processing with synthetic slag is its high level of productivity. The entire operation is carried out during the tapping of metal from BOF into the ladle, which occurs in a matter of minutes. The productivity of the units increases, as technological operations (desulfurization and deoxidation) are transferred to the ladle. The utilisation of aluminium waste for the manufacture of synthetic slags and the out-of-furnace processing of steel enables the conservation of nature and the environment, as well as the enhancement of the ecological situation due to the elimination of hazardous industrial waste [4]. Furthermore, this represents an economic benefit, given the sale or utilisation of secondary raw materials.

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UDC 669

OPERATION OF AN ELECTRIC ARC DEVICE DURING OUT-OF-FURNACE STEEL PROCESSING AT A LADLE-FURNACE INSTALLATION

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At the current stage of development of metallurgical production, a high level of quality of steel products is largely ensured by a combination of various technological operations of out-of-furnace refining of liquid metal, which inevitably leads to an increase in the duration of its stay in the ladle. Deep refining of steel in a ladle-furnace unit (LFU) is mostly accompanied by a significant decrease in its temperature. At the same time, even under conditions that ensure minimal heat consumption during CCM processing, the outlet temperature needs to be slightly increased to ensure the required steel casting parameters, which inevitably leads to additional electricity consumption. The degree of electricity absorption depends on the conditions of heat exchange between the arc and the metal, which in turn depend on the shape, size and nature of the arc. These parameters are determined by the parameters of the electric arc device (EAD) of the unit. During the operation of the EDM, an arc column is formed between the graphitized electrodes and the metal, consisting of a mixture of neutral gas particles, electrons, ions and atoms, a pair of electrode material and metal [1].

The manufacturer determines the melt heating rate by arc power, voltage level, and with a slag thickness of 150-200 mm, guarantees a heating rate of 4 °C/min at the 16th transformer voltage level, and about 3 °C/min at the 12th voltage level. Studies have shown that this heating rate is not always observed and is associated with changes in the intensity of heat transfer in the plasma-slag-metal system [2, 3].

In a stably existing electric arc, thermal equilibrium is maintained, which is characterized by the fact that the amount of heat released is equal to the amount of heat transferred to the environment. Therefore, when the arc cooling conditions or physical properties of the environment change, its parameters change.

The electric arc discharge, in the process of EDM operation, constantly changes its position along the entire plane of the electrode end and the surface of the liquid metal. The chemical composition of steel is adjusted at the EAF by adding bulk materials to the ladle, such as ferroalloys, pig iron, etc. The stability of arc combustion depends on the properties of the metal surface: when the arc moves to solid particles of the added materials, the temperature of the contact points changes, which affects the stability of combustion and heat exchange with steel, and therefore reduces the electrical efficiency and increases electricity consumption.

From this, it can be concluded that the operation mode of the electric arc device determines the efficiency of steel heating in a ladle furnace. At the same time, the main factors affecting the efficiency of the EDM are the stability and stability of electric arc burning and, as a result, the efficiency of heat transfer from them to the metal. That is, by solving the problem of increasing the efficiency of EDM, it is possible to reduce electricity consumption during out-of-furnace steel processing and reduce the duration of its processing.

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UDC 669.046.669.162.267.6:669.162.221.2

SIMULATION OF THE INTERACTION PROCESSES OF COMPONENTS OF THE TWO-PHASE FLOW INTRODUCED INTO CAST IRON DURING INJECTION DESULFURATION

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The use of off-furnace desulfurization of cast iron [1,4, 5-9] with various dispersed desulfurizers [2] is due to the desire to achieve the most complete removal of sulfur from the melt in the shortest possible time. The actual results of the industrial application of off-furnace desulfurization indicate [4] that the practical results of the technology in many cases are not sufficiently stable and far from the possible and expected. The studies were carried out on computational and "cold" physical models [3]. Magnesium, ground lime and calcium carbide were evaluated as desulfurizing reagents. Based on the actual results of physical modeling and subsequent calculations, an improved expression for the depth of jet immersion depending on the parameters of the injection through the underwater circuit was formulated [6]. The processes of interaction of gas and solid phases in the zone near the lance during desulfurization in the ladle were investigated. It is shown that during injection desulfurization of cast iron, the gas component of the flow stops its directional movement in the melt up to 80 mm (actually 50-60 mm), solid particles continue to move in the cavity and hit the surface of this cavity. To assess the further movement of the particle through the "gas cavity-melt" boundary, the depth of particle penetration into the cast iron melt was calculated. Models and nomograms were developed to determine the depth of immersion of reagent particles as a function of the injection velocity of the two-phase flow. Recommendations are given regarding the parameters of magnesium and ground lime injection, etc.

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UDC 669.02

FEATURES OF DESULFURIZATION OF STEELS WITH ULTRA-LOW SULFUR CONTENT

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The paper analyses the main sources of sulphur introduction into steel when using different charge materials and methods of their preparation, including various methods of out-of-furnace desulfurization of hot metal [1]. The question of the effectiveness of BOF melting with a reduced desulfurization level with subsequent out-of-furnace processing of steel to remove sulphur is considered [2, 3].

It has been determined that deep desulfurization of steel is possible through the use of technological complexes "UDCH - steelmaking unit" and "UDCH - steelmaking unit - LF". Their use provides an opportunity to optimize the costs of steel production, expands the assortment of scarce types of metal products and allows to eliminate a number of restrictive conditions that complicate the current production of steel. Kinetics of steel desulfurization depends on the type of desulfurizer reagent, its chemical composition, temperature conditions, conditions of mixing steel in the ladle, additional technological operations, ladle processing of metal [3, 4].

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UDC 669.046.669.162.267.6

STUDY OF GAS-DYNAMIC PATTERNS OF POWDER MIXTURE INJECTION ON "COLD" MODELS

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In today's environment, domestic steelmaking enterprises, and especially steelmaking within them, are experiencing a significant negative impact from the shortage of high-quality raw materials and the lack of stability of incoming charge materials. At the same time, in order to overcome these problems, the world's practice includes technical solutions for out-of-furnace treatment of charge materials, including liquid iron. Thus, an urgent issue of domestic metallurgical science is to determine the effectiveness of the most common methods of out-of-furnace treatment of cast iron in relation to the current realities of domestic steelmaking.

Based on the theory of two-phase flows (gas - solid particles), which is based on the mathematical description of the systems under study, a methodology for theoretical evaluation of the influence of the characteristics of two-phase flows (gas phase flow rate, solid phase feed rate) and the characteristics of the route has been developed, (channel diameter, length of horizontal, vertical, and inclined sections, and material of the route) on the change of parameters (pressure drop between the beginning and the end of the route, velocity of the gas and solid phases) of the two-phase flow [1-4].

Using the developed methodology [5, 6], preliminary calculations of the pressure drop, gas and solid phase velocities were performed for CaO particles with diameters of 60 and 100 μm; FeO – 70 and 450 μm; Na_2CO_3 – 100 μm) and Al – 500 μm at a gas flow rate of 100 nl/min and a solid phase feed rate of 1.67 kg/s and 2.5 kg/s, which are transported through a channel with a diameter of 4 mm with a horizontal section of 1 m and a vertical section of 0.6 m.

An installation for studying the hydro-gas-dynamic laws of powder mixture injection on "cold" models was mounted at the laboratory base of the IMM. Tests of the installation were made without reagents, using soda, using lime, and using a CaO-Na_2CO_3-FeO mixture.

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

UDC 669.046

AUTOMATIC CONTROL SYSTEM OF THE ENERGY MODE OF ARC STEEL MELTING STOVE OF JSC «NIKOPOL FERROALLOY PLANT»

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The productivity of arc steelmaking furnace (ASF) and the consumption of electricity per ton of steel largely depend on the choice of a rational electrical mode, which should ensure the most complete use of the installed capacity, input into the furnace as much energy as possible per unit of time and prevent overheating of the furnace masonry. To ensure high-performance ASF work, chipboards are equipped with automatic power regulators that maintain the specified power of the electric arc. The operation of this automatic regulator is based on changing the position of the electrodes to adjust the length of the arc [1]. Control of the arc melting process is carried out, as a rule, in the conditions of uncertainty of the properties of the control object and the absence of a decision support system.

For making relevant decisions in order to achieve the maximum productivity of the furnace with minimum energy consumption, a complex automated control system was developed that regulates the electrical parameters of the arc and the movement of the electrodes. To implement this task, the scheme of relay control of chipboard power using the asynchronous short-circuited motor is used. The automatic conrol system of the ASF power management consists of Simatic S7-300 modular programmable controller, an ET-200M distributed input-output system modular station, and an ET-200S distributed peripheral station. According to information about the current voltage of the electricity network, the temperature of the bottom and lining, the control system calculates the electrical and thermal regimes that meet the conditions of the minimum specific electricity consumption, the duration of melting and the cost of steel. The information support of the system, the algorithm of its operation and the appropriate computer program have been developed.

Computer simulations in the Matlab/Simulink environment proved the stability of the controller's operation with the aperiodic nature of the transient processes and increased speed of the controller compared to the traditional DC motor controller. The developed system allows for uniform arc burning by adjusting the position of the chipboard electrodes from the operator's computer. The amount of automatic control and management tools provided on ASF ensures support of specified technological modes of the electrofusion process, as well as the safety of operation of unit.

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UDC 669.184:004.942

INFORMATION-MODELING FORECASTING SYSTEM FOR THE DURABILITY OF THE TOP CONVERTER LANCE

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Effective control of modern metallurgical production requires continuous monitoring of all technological processes. Such control can be ensured through the presence of MES (Manufacturing Execution System) and SCADA (Supervisory Control and Data Acquisition) systems, which allow the control of production processes [1]. These systems represent specialized software designed to solve a variety of production tasks at the shop or enterprise level. In most cases, they operate in real time within the framework of Industrial Control Systems and Instrumentation and Control Systems; however, they can also function autonomously, providing data collection and processing, quality control, delivering necessary information, and forming recommendations for optimizing the technological process and equipment control. Therefore, the presence of an information-modeling forecasting system for the durability of top converter lances, as part of the aforementioned systems, will address the current issues of converter production.

Information-modeling control systems are in high demand in metallurgical production. This includes the need for thermal mode simulation systems for both standard top converter lances and special slag-splashing lances used for hot repair of the converter lining through the slag-splashing method. Top lances, regardless of design and purpose, often fail due to significant thermal loads, slagging, weld seam destruction, and burn-throughs. The use of specialized software allows for effective control of lance design and cooling system processes, forecasting, and timely signaling of overheating or critical equipment conditions, which ultimately contributes to increasing the durability of the device and preventing emergency situations in production.

In order to address the current task of determining the compliance of input technological parameters with the safety criteria for conducting the BOF process as a whole, a computer-based information-modeling system for forecasting the thermal mode of the barrel of top oxygen and slag-splashing lances has been developed. The mathematical models, as the core of the system, involves solving the heat conduction differential equation in cylindrical coordinates with given initial (temperature distribution in the calculation area) and boundary conditions of the second and third kinds (on the outer and inner surfaces of the lance barrel, respectively). The integral-interpolation method was applied for the numerical solution of the heat conduction equation. The temperature field calculation was performed using the sweep method (modified Gauss method) with an implicitly unconditionally stable scheme.

The software application was developed in the Microsoft Visual Studio environment. It does not require special computer infrastructure and operates locally (without the need for internet access), while also not requiring any special skills to operate due to its intuitive interface. The developed information-modeling system allows for the evaluation of design and technological parameters of top lance operation as criteria for safe operation. Its use in «consultant» mode ensures optimal design of top lances with an effective water or gas cooling system, aimed at maintaining the proper thermal mode throughout the entire operational period, as well as ensuring the reliable operation of the structure without emergencies.

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Metal Science and Heat Treatment of Steel

UDC 621.785:669.15"26"28"292-194.018.26:621.771.25:621.79

METHOD OF PREDICTIVE DETERMINATION OF LOW-CARBON Cr-Mo-V STEEL STRAIN HARDENING DURING THE MANUFACTURE OF WELDING WIRE

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Determining the level of steel hardening depending on the parameters of the technology of its cold plastic deformation, in particular drawing, and creating methods for calculating strength indicators on these principles are relevant areas of activity of modern metalworking plants. The strain hardening of steel during drawing is mainly influenced by the degree of deformation and the heating temperature of the processed workpiece, namely the related processes of strengthening and softening of the metal. Provided that the parameters of the drawing technology are constant, it becomes possible to calculate the predicted value of the metal's tensile strength, the required tensile forces of the drawing machines, and also to determine the compliance of the cold-deformed wire with the requirements of the standards [1]. Considering that low-carbon alloy steels wire rod for welding purposes are a processing workpiece that is subjected to cold deformation by drawing, one of the main indicators of its mechanical properties is the tensile strength.

The results of the practical application of the author's method for predicting the ultimate tensile strength of cold-deformed wire depending on the degree of total relative compression of wire rod are presented, which is based on the well-known Tulenkov-Zolotnikov equation [2], and which was modified by introducing an empirical coefficient (k). This coefficient takes into account the integral influence of the chemical composition and structural parameters of the steel, which significantly affect the strain hardening of the metal during drawing. The authors' accumulated many years of experience in analyzing changes in mechanical properties of a wide range of steel grades using direct drawing technology (without annealing) allowed us to determine the coefficient $k = 1.17\text{-}1.22$ for low-carbon steels (C $\leq$ 0.15% wt.) with a ferritic matrix, which are additionally alloyed with chromium (0.70-1.30% wt.), molybdenum (0.50-1.30% wt.), vanadium (0.10-0.30% wt.) and contain manganese and silicon in the ranges of 0.70-1.60% wt. and 0.20-0.80% wt., respectively.

Using the specified method, the dependence of the strain hardening of a wire made of low-carbon chromium-molybdenum-vanadium steel (grade CrMoV1Si) during drawing process on the mechanical properties of the wire rod in the delivery state was established. The range of the initial strength of steel wire rod diam. 5.5 mm (R_m = 450-550 MPa), which guarantees compliance of the ultimate tensile strength of cold-formed wire with a diameter of 1.2-3.0 mm with the requirements of existing standards.

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UDC 669.131.6:669.112:669.1.017

THE RELATIONSHIP BETWEEN CHEMICAL MICROSEGREGATION AND THE STRUCTURE OF FLAKE GRAPHITE IN GRAY CAST IRON

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Gray cast iron with lamellar graphite is widely used across various industries. It is an inexpensive, recyclable material with a relatively low environmental impact, including low CO_2 emissions.

The formation of the lamellar graphite structure in cast iron remains a subject of extensive research. Lamellar graphite in gray cast iron can take various forms – needle-like, flake, straight, twisted, and rosette-like – and can vary in size. The shape, size, and distribution of graphite in gray cast iron are highly sensitive to minor changes in chemical composition (particularly at the local level) as well as to the cooling rate. Within a single cast component, diverse graphite particles can form, making the controlled formation of various lamellar graphite structures within a single cast product an important task.

Currently, there is a lack of knowledge regarding the effect of segregation-induced microheterogeneity on the formation process of graphite particles with differing morphologies and sizes.

This study analyzed the morphology of graphite particles in gray cast iron and examined the sequence of formation of particles of different shapes and sizes, as well as their relationship with chemical microsegregation. The gray cast iron sample studied had a chemical composition close to eutectic (3.94% C; 2.59% Si) and crystallized under slow cooling conditions. Metallographic analysis and microhardness measurements of the structural components were conducted. Hot etching in an alkaline solution of sodium picrate was used to visualize chemical microsegregation.

The sample exhibited massive, rosette-like, star-shaped, and dendritic forms of graphite, which, depending on their location in macro- and microvolumes, varied in size. Chemical microsegregation, arising at all stages of crystallization, manifests as variations in silicon and carbon concentrations. Since silicon reduces carbon solubility, in silicon-rich areas, carbon concentration is lower, resulting in hardness variations across different areas of the sample. Microstructural studies indicate that the intensity and topology of chemical microsegregation affect the location, size, and shape of graphite inclusions.

The study revealed the staged formation of various graphite particles in gray cast iron. The topology of chemical microsegregation and the associated intensity of element distribution, the location, size, and shape of graphite, as well as the wave-like sequence of microhardness changes in the metal matrix, indicate the existence of dynamic processes within the cast iron melt. These processes affect the melt's structure and the distribution of chemical elements within it-i.e., its chemical microsegregation, which, in turn, influences graphite formation. Dynamic processes in melts are determined by their physical properties (density, viscosity, surface tension, etc.), temperature, and the rate at which it changes, i.e., crystallization kinetics.

UDC 621.785:669.15-194:669.1.017

FEATURES OF THE STRUCTURAL FORMATION OF THE SAE BRAND LOW-CARBON STEEL DURING COOLING FROM THE ROLLED HEATING

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Bar sections of the round diameter from the low-carbon steel SAE brands, require the constant increase of the improvements of the reliable quality assurance of the system. Processes that include, after rolling heating, the temperature and speed parameters of cooling, which ensure the formation of a homogeneous structure, are promising. Depending on the conditions of the hot deformation, different structural states can be observed in rolled steel, fixed by cooling after hot deformation, which determine the properties of the metal. If the metal was subjected to aging at the temperature of the end of the deformation, then processes of the collective recrystallization take place in it, which manifests itself in the formation of nuclei capable of further growth. In steels with a low carbon content, after hot deformation, grinding of the austenite grain leads to a decrease in the size of the pearlite areas. The formation due to collective recrystallization of a large austenite grain leads to a decrease in the amount of structurally free ferrite. Therefore, it is relevant to study the effect on the structure formation of SAE grade rolled steel when using temperature-speed parameters of cooling from rolling heating.

Graded rolled products made of SAE 1008 low-carbon steel with a round diameter of up to 18.0 mm were studied. The rolled product after the high-speed finishing unit with a hot rolling temperature (higher than A_3) was cooled with water before being laid out into coils to different temperatures higher than A_1, then cooled at an average rate of ~ 3.0°C/s to ambient temperatures.

The most important parameter of the microstructure is the grain size, which is one of the most effective ways of the controlling the structure, which leads to a change in mechanical properties. Metallographic studies made it possible to establish the influence of heat treatment parameters on the structure of the studied steel, which is ferrite with small areas of lamellar pearlite. With the help of computational and analytical studies, it was established that after high-speed hot deformation, it is the temperature at the end of cooling that affects the average conditional diameter of the grain. In the production of SAE-type low-carbon graded rolled products, a processing scheme with adjustable two-stage cooling at an average temperature of A_1 + 150°C on the coil former should be used, which forms a more uniform grain, which will ensure a minimum spread of mechanical properties. An increase in temperature during cooling from rolling heating leads to the formation of heterogeneity in the microstructure, which is undesirable.

UDC 621.785:535.211

WEAR RESISTANCE OF LASER-PROCESSED WHEEL STEEL

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The expediency of local strengthening of the rolling surface rounding zone of railway wheels by means of laser treatment has been proven. Based on the study of railway wheels worn during operation, which have different profiles of the tread, it is shown that the flow of intense plastic shear under conditions of sufficiently high contact stresses during operation leads to intensive wear in the rounding zone, which can result in undercutting of the crests [1, 2].

It has been established that laser treatment of wheel steel in pulsed radiation mode creates a laser-strengthened zone with a dispersed martensite structure, which is identical to the "white layer" that forms under operating conditions on the tread. Studies have shown that such a structure is unfavorable from the perspective of exploitation. It is demonstrated that during laser processing in continuous radiation mode, it is possible to obtain a microcomposite bainite structure of the laser-strengthened layer, which is favorable for operating conditions. At the same time, the parameters of the strengthened layer, the fine steel structure, as well as microhardness and hardness can be varied within certain limits depending on the initial state of the wheel steel, as well as the mode of continuous laser exposure. A comparative analysis shows that the modes of laser processing, as well as the degree of dispersion of the initial microstructure, determine the effect of laser strengthening of wheel steel.

A promising mode with a laser beam power of 600 W and a movement speed of 5-15 mm/s is proposed, which is recommended to be used, especially in combination with traditional heat treatment. It is also recommended to carry out local laser strengthening of the rounding zone during the production of railway wheels after quenching and before tempering to reduce thermal stresses.

The increase in the wear resistance of wheel steel after laser treatment indicates the effectiveness of applying strengthening laser technology through the purposeful use of internal reserves of the structural adaptability of the surface layers of steel in operational conditions. The prospects of local laser processing of the rounding zone with the attainment of a microcomposite bainite structure in continuous laser radiation mode are discussed, which will not only increase the wear resistance of the tread of railway wheels but also reduce the risk of undercutting of the crests during operation. This treatment can be applied both to new railway wheels after traditional heat treatment and in railway depots during the restoration of worn profiles of the tread by regrinding.

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UDC 621.774.35

THE PROBLEMS OF LOW TECHNOLOGICAL PLASTICITY OF 04Cr14Ti3B1V STEEL DURING PRODUCTION OF PIPES FOR NUCLEAR ENERGY

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For transportation and storage of spent nuclear fuel, containers made of 04Cr14Ti3B1V steel alloyed with boron are used [1]. High-chromium steel 04Cr14Ti3B1V alloyed with boron is used for their production. When boron is introduced into steel, a large quantity of borides is formed, which negatively affects its mechanical properties and technological ductility during the production of hot-rolled pipes [2-5]. The goal of the work was to study the influence of boride inclusions on the mechanical and technological properties of 04Cr14Ti3B1V steel.

In steel 04Kh14T3R1F two types of boride inclusions were revealed: $(Ti,Fe,Cr,V)_2B$ with a shell $(Ti,Cr,V)_2B$ and $(Fe,Cr)_2B$, which may have significant chemical heterogeneity. In the process of hot deformation, phase and structural transformations occur: a change in the composition of borides due to the redistribution of elements, dynamic diffusion crushing and separation of "satellite" particles, brittle destruction of borides, boride transformation $(Ti,Fe,Cr)_2B \rightarrow (Fe,Cr)_2B$, as well as melting of inclusions.

Boride inclusions in the process of hot deformation are not plastic and are the sources of the appearance of cracks, which contributes to a decrease in the technological plasticity of 04Cr14Ti3B1V steel. Transformations of boride inclusions contribute to changes in the structure and mechanical properties of 04Cr14Ti3B1V steel under different deformation conditions, which must be taken into account when developing pressure treatment modes to improve process plasticity.

A study of the behavior of boride inclusions during hot pressure treatment of steel and their influence on the formation of a deformed matrix, as well as the development of destruction near the inclusions, made it possible to determine the processing modes (temperatures and degrees of deformation) that contribute to obtaining an optimal structure that provides increased impact toughness of 04Cr14Ti3B1V steel.

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UDC 669.13.111.2.017:620.18:001.8

THE RELATIONSHIP OF FRACTAL DIMENSIONS WITH THE MORPHOLOGY AND DISTRIBUTION OF GRAPHITE INCLUSIONS IN GRAY CAST IRONS

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It is known that for the quantitative description of fractals, a sufficient condition is the definition of the fractal dimension or a parameter that describes the preservation of statistical characteristics when changing the scale. The analysis of traditional methods of studying the structure of metals and alloys (light and electron microscopy, quantitative metallography, X-ray structural analysis) shows that none of them can be universal and suitable for solving the full range of tasks related to the identification of quantitative characteristics of the structure of metallic materials [1].

The application of fractal theory for the analysis or modeling of various processes of structure formation and determination of their relationship with material properties is a widespread, accessible, and reliable direction in materials science. This approach has proven particularly useful in understanding the structure of gray cast iron. The search for the average fractal dimension of graphite inclusions in the structure of gray cast iron was carried out following GOST 3443-87 standards (appendix No. 3, scale No. 1) according to the methodology, the essence of which was to determine the closest convergence of fractal dimension values, which was calculated using cell and point methods [2].

According to the calculation results, the following average values of the fractal dimension (D_t) were obtained depending on the morphology and distribution of graphite inclusions: lamellar rectilinear form (1.180), lamellar swirl form (1.328), nest-like distribution (1.344), rosette distribution (1.539), distribution in interdendritic colonies (1.590), interdendritic point distribution (1.799). Additionally, the fractal dimensions of the metal matrix (D_f), as well as the length of the graphite/metal matrix interface (L_{tf}) in the structure of gray cast iron, which varied in the intervals D_f = 1.977-1.890 and L_{tf} = 5820-21071 pixels, were determined. in accordance.

The obtained values of fractal dimensions made it possible to distinguish graphite inclusions by morphology and distribution in the structure of gray cast iron, which makes it possible to create a universal method of quantitative assessment of the elements of its structure using fractal analysis.

The calculated data have specific numerical values, so in the future they can be used to create analytical models for the predictive determination of the properties of gray cast iron depending on the features of the formation of the final structure. The considered method for determining the fractal dimension can be useful when studying the features of structure formation processes and evaluating the morphology of graphite inclusions at different stages of gray cast iron processing, starting from the smelting stage and ending with the final heat treatment. In addition, fractal analysis can be used to determine and evaluate the influence of morphological parameters of graphite inclusions on the formation of quality indicators of gray cast iron, which causes certain difficulties when using traditional methods of quantitative analysis. Further research will be focused on establishing statistically significant correlations between the fractal dimension and the properties of gray cast irons, taking into account the final structure formation.

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UDC 621.785.3

ABOUT INTENSIFICATION OF PEARLITE SPHEROIDIZATION IN BORON-CONTAINING STEELS FOR COLD EXTRUSION

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The use of boron-containing steels significantly expands the production capabilities of high-strength fasteners obtained through cold deformation methods. In the technologies for producing cold-deformed products, the most effective method for preparing the structural state of steel prior to cold deformation is the softening heat treatment operation. Its purpose is to alter the structural state by transforming the carbide phase from a lamellar to a more favorable globular form. Steel with such a structure exhibits the lowest hardness and is more easily processed during subsequent reworking (upsetting, cutting, cold bulk stamping, etc.). Additionally, granular pearlite is the optimal initial structure for conducting further heat treatment, as it shows less tendency for austenitic grain growth during heating. Therefore, structural steels for cold upsetting should initially possess a structure of granular pearlite of a specific grade.

To achieve a structure of granular pearlite in hot-rolled steel billets, they are subjected to spheroidizing annealing prior to forging, a process known to be diffusion-based. Consequently, existing spheroidization methods require extended durations to complete and are energy-intensive. To accelerate the spheroidization process, various schemes of preliminary treatments involving both rolling and specialized heating of the billet are employed.

The pre-treatment modes utilized prior to spheroidization lead to an increase in the dispersion of carbide particles within pearlitic colonies and to an elevated degree of defectiveness in the crystalline lattices of the ferritic matrix, due to the reduction in the decomposition temperature of austenite during the eutectoid (pearlitic) transformation interval. These changes in structure following the pre-treatment regimes result in a slight reduction in the duration of the spheroidization process, although this reduction is not sufficiently effective.

Developing modes that significantly reduce the duration of spheroidizing annealing for low-carbon boron-containing steels is a pressing task, as it will not only reduce the energy consumption for heat treatment but also enable spheroidizing annealing within the continuous technological line of fastener production.

In the study, three main directions for the comprehensive intensification of spheroidizing annealing are examined. The first direction is associated with the preparation of the structural state of the steel blank prior to annealing, taking into account the characteristics of cementite spheroidization in low-carbon steels and the requirements for the structure after annealing with the distribution of cementite globules in the ferritic matrix. The necessary changes in the structure immediately before the spheroidization process are proposed to be achieved by the decomposition of supercooled austenite at lower temperatures. The second direction of intensification is related to the development and substantiation of temperature regimes for spheroidizing annealing, considering the changes in the values of thermodynamic and kinetic factors during the development of structural transformations. The third direction of intensification of spheroidizing annealing is associated with the use of internal heat transfer at all stages of the implemented regime. Heating with an internal heat carrier leads to a local increase in temperature in micro areas at the interphase ferrite-cementite boundaries of pearlitic colonies, where the diffusion rate of components is crucial for the structural transformation of lamellar pearlite into granular.

UDC 620.18:669.131.6:62-242.2:621.74

INFLUENCE OF TECHNOLOGICAL FACTORS OF PRODUCTION OF THE POURED PURVEYANCES OF PISTON-RINGS IS FROM GREY CAST IRON ON THEIR STRUCTURE AND HARDNESS

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The production of quality purveyances of piston rings of the individual founding from grey cast-iron becomes complicated that the necessary structure of graphite and metallic matrix is formed as cast without the use of heat treatment. It predetermines the necessity of clear control of chemical composition of cast iron and technology of casting. The controlled description of mechanical properties of the poured rings purveyances from grey cast iron is hardness that additively depends on the structure of graphite and structure of metallic matrix. Even at the observance of technology of production there can be cases of forming of unsatisfactory structure and hardness of the poured rings-purveyances from grey cast-iron. Reason of it consists in the inherited influence of materials of charge, the negative action of that can be removed by the change of the modes of casting or varying of chemical composition of cast iron.

The idea of researches consisted in the analysis of influence technologically of possible ranges of temperature of overheat, holding time and temperature of pouring on a structure and hardness of rings purveyances at the set chemical composition of cast iron in %wt: C = 3.72; Si = 2.82; Mn = 0.79; P = 0.4; S = 0.045; Ni = 0.23; Cr = 0.26; Cu = 0.48; Mo = 0.53; Ti = 0.05.

Conducted estimation of influence of technological factors of casting in sand-clay forms, namely temperatures of overheat, holding time and temperature of pouring of fusion on hardness and structure of the poured purveyances for the production of compression piston-rings of different size. On the requirements of technological instruction, a temperature of overheat must be 1530-1560ºC. It is shown that fluctuation in the temperature of overheat and pouring of fusion in a range 10-50ºC and its holding time during 1-11 minutes does not give appropriate influence on hardness and microstructure of founding of rings-purveyances from grey cast iron. Hardness after length of founding of rings-purveyances is different, and presents 94-112 HRB, that answers requirements GOST 621-87. The least hardness of founding of rings-purveyances is observed in areas that fit closely to the pouring system.

It is set that the structure of graphite and metallic matrix of founding of rings-purveyances from grey cast-iron, without regard to the observance of technological process of their production, often does not answer the requirements of the specified standard. The maximal size of the graphite inclusions 120-250 μm, that exceeds the necessary size of 80 μm concordantly GOST 621-87. Further heat treatment (middle tempering) without phase recrystallization was conducted with the aim of removal of casting tensions, which led to an increase in the size of graphite inclusions.

Bainite-martensitic structures, which are not permissible according to GOST 621-87, are formed in the metal matrix of castings of blank rings from gray cast iron, the tempering of which causes a decrease in the hardness of blank rings.

For providing of accordance of requirements for GOST 621-87 in relation to the structure of graphite and metallic matrix, and also prevention of decline of hardness after heat treatment of the poured rings-purveyances must be decreased maximal size of the graphite including of to 80 μm and to provide forming of dispersible pearlite from no more to the 5 pre-eutection ferrite. For the assured providing of the above mentioned requirements, on condition of constancy of technological process of casting, expediently it is advisable to adjust the chemical composition of fusion of cast iron taking into account content in him gases (O, N, H), that hereditarily depends on the origin of materials of charge, basic from that, is domain cast-iron and the turnover of its own production.

UDC 669.14.018.29:669.11

GRAY CAST IRON ALLOYED WITH A HIGH-ENTROPY ALLOY

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High-entropy alloys (HEAs) have attracted significant interest in modern materials science due to the wide range of possible element combinations and unique properties not found in traditional materials, such as resistance to high-temperature oxidation. However, creating HEAs with a structure of solely substitutional solid solutions is challenging, as it requires highly pure components without impurities that could form interstitial solutions. This makes structural and property research of HEAs expensive. Therefore, at initial research stages, the use of ferromaterials becomes practical, especially when studying the interaction of HEAs with iron-based melts, where the carbon and other impurities in ferromaterials can be disregarded.

In this study, gray cast iron (3.46% C, 2.30% Si, 1.1% Mn) was selected and alloyed through vacuum induction melting with an HEA of Fe-Ni-Cr-Cu-Mn (24.18% Fe, 20.85% Ni, 23.30% Cu, 15.8% Mn, 14.28% Cr, 1.46% Si, 0.68% C) as well as with a mix of pure components at 2% and 5% by mass for comparison. Chemical analysis showed that gray cast iron more effectively absorbed alloying elements such as Ni, Cu, and Mn when the HEA was used as a ligature. Additionally, after annealing the alloys at 920-930°C for 4 hours, the cast iron alloyed with the HEA demonstrated slightly higher hardness values, suggesting this approach could be promising for developing wear-resistant alloys.

UDC 669.184.244.66

NON-EQUILIBRIUM ANALYSIS OF THE GRAPHITIZATION PROCESS IN CAST IRONS

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A diffusion-vacancy mechanism has been developed that describes the process of graphitization of cast iron, and does not use the pressure of graphite on the matrix to explain the diffusion of iron. The values of thermodynamic forces and kinetic coefficients were calculated for the case of graphitization of a binary alloy of the Fe–C system with 2.5% C at 1100°C. It was established that under the conditions of a stationary flow of vacancies during the graphitization of cast iron in the solid phase, the concentration of vacancies at the γ-phase – graphite boundary is approximately 0.97723 times less than the concentration of vacancies in the γ-phase. An assessment was made of the influence of alloying elements, using the example of chromium and silicon, on the graphitization of cast iron with 2.5% C.

A thermodynamic parameter of T_G graphitization is proposed, which takes into account the influence of all alloying elements (except for carbon and iron) [1]:

$$T_G = \sum_{k=1}^{N} \beta_k N_k , \tag{1}$$

where N is the number of considered alloying elements in cast iron.

At a given graphitization temperature, for the formation of graphite in the cast iron structure, rather than cementite, the thermodynamic condition must be fulfilled:

$$T_G \geq \ln(a^G{}_C / a^K{}_C) \approx a^G{}_C - a^K{}_C. \tag{2}$$

At $T_G > 0$, the thermodynamic parameter of graphitization characterizes the degree of graphite stability and can be related to the morphology and size of graphite inclusions.

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UDC 662.338:621.89:123

DEVELOPMENT OF TECHNOLOGY FOR OBTAINING ACOUSTO-OPTICAL CRYSTALS BASED ON TELLURIUM DIOXIDE

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Improving the quality of acousto-optical (AO) crystals can significantly improve the accuracy and efficiency of military devices. This is extremely important in the context of war, where every technical advantage can be decisive. Military devices must operate under extreme conditions such as high temperature, vibration, mechanical shock and electromagnetic interference. Improvement of AO crystals to increase their endurance and reliability ensures stable operation of devices even in the most difficult conditions.

Tellurium and its compounds, in particular tellurium dioxide, have unique properties that make them indispensable for AO modulators, deflectors and tunable filters. The need to grow large, high-quality TeO_2 crystals arises from the growing demand for new technologies that require materials with high optical performance for use in critical devices. However, the growth of large TeO_2 crystals is associated with a number of technical challenges, such as the need to optimize temperature gradients, growth rates, and reduction of defects in the crystals.

For the successful growth of large TeO_2 crystals, it is necessary to study the process of crystallization and phase transitions in the material, which is critically important for obtaining significant advantages in the quality of single crystals.

This knowledge allows fine-tuning of the process parameters, which are key factors in obtaining high-quality crystals. It should also be noted that the growth of large TeO_2 crystals requires control of the purity of the starting materials and accurate analysis of impurities.

Thus, the application of new technological solutions for growing TeO_2 crystals will allow solving the problems of scaling the size of the grown crystals suitable for use in devices of responsible purpose.

UDC 662.328:620.75

ANALYSIS OF APPROACHES TO ENSURING HIGH RELIABILITY AND DURABILITY OF RAIL TRAFFIC

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Railway transport is a component of critical infrastructure. Innovations in the railway industry not only improve the efficiency of traffic, but also make a significant contribution to the safety of transportation and optimization of maintenance costs. Thanks to the introduction of the latest technologies and materials, modern railway systems are becoming more reliable and economical in operation.

The interaction between the wheel and the rail is the physical basis of train movement on railways. At the same time, the requirements for the indicators of the interaction of wheels and rails in different contact zones are contradictory. On the one hand, the coupling of the wheels with the rails should be such that there is little resistance to the movement of the train. On the other hand, in order to realize the necessary traction force, it is necessary to ensure a high and stable level of traction of the locomotive wheels with the same surface.

Contact fatigue and wear are competing mechanisms of damage and when certain conditions are combined, they occur alternately on railways, which leads to increased interchangeability of wheels and rails. The operational reliability and durability of the wheel-rail pair is ensured by a rational balance of wear and tear resistance. Thus, increasing the strength and hardness of the wheel rim is one of the most important tasks for ensuring the overall reliability of rolling stock.

Sufficient wear resistance contributes to the long-term preservation of the geometry of the profile and the correct distribution of loads in the contact patch. However, under the conditions when the metal along the contact surface is subjected to operational loads for a long time, the structure undergoes changes: local deformation occurs, dislocation saturation occurs, and fatigue cracks can originate and develop. Therefore, a certain amount of wear, which can reduce the length of fatigue cracks from the surface and remove destructured metal, is a useful process.

Modern trends in the production of structural steels for railway use show that the degassing of steel in a vacuum in order to reduce the hydrogen content, effective deoxidation and rational alloying of steel, which together provide the specified mechanical and operational characteristics, are promising [1-3]. However, the manufacturing method (cast, deformed) and structural condition (heat treatment, structural heterogeneity) of wheels and rails should also be taken into account. Depending on the chemical and structural heterogeneity, the response to operational loads may differ.

The results were obtained within the framework of the Ukrainian-German project "Influence of structural and chemical heterogeneity on wear resistance and propagation of fatigue cracks at the wheel-rail contact point" (state registration number 0124U003037) under contract M14-2024/KC.0227.24 dated 05/30/2024.

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UDC 662.312:624.534

INFLUENCE OF CHEMICAL COMPOSITION ON THE STRUCTURE AND HARDNESS OF RAILWAY AXLE STEEL

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Taking into account the considerable number of complex approaches with the use of information technologies to justify the choice of the content of chemical elements in steel and the limitations inherent in them, it is proposed to use the concept of directional chemical bonding, which ensures high predictive accuracy and obtaining its necessary properties at the level demanded by the consumer. An analysis of the requirements of the regulatory documentation regarding the chemical composition, namely the content of the main components such as carbon, manganese and silicon, in steel for railway axles of EA1N, F and OS brands was performed. Applied information technologies using the concept of directed interatomic interaction, when the criteria are complex and characterize the entire composition at the same time, as well as obtained linear patterns of influence of the integral indicator of the chemical composition on hardness.

The purpose of the study is to establish the regularities of the influence of the chemical composition on the formation and transformation of the phase structure and hardness after deformation and thermal aging of carbon steel for railway axles. The object of research was laboratory ingots of carbon steels, which are comparable in chemical composition to steels for railway axles according to state, European and American standards. The samples made from them were subjected to hot plastic deformation (HPD) followed by heat treatment (HPD + TO). The microstructural analysis of the studied steels was carried out.

The regularities of the influence of the chemical composition on the ratio of phases and the hardness of the investigated steels in different states were revealed: cast, after GPD and GPD + TO using the concept of directional chemical bonding. It was established that with an integral parameter of the state of charge (ZY) less than 1.20 e, that is, with a certain chemical composition in the studied range of values, the hardness of the steel in the state after GPA exceeds the hardness of such steel in the state after GPA + TO.

UDC 669-413:112.227.333

TECHNOLOGICAL ASPECTS OF OBTAINING CARBIDE-FREE BAINITE IN THICK ROLLED METAL SHEET

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In order to obtain the required level of mechanical, technological and operational properties, it is important to correctly choose the parameters of the technology of strengthening heat treatment of thick sheet metal from separate heating, taking into account the thickness of the sheet and the chemical composition of the steel.

A promising direction for obtaining high strength while ensuring sufficient plasticity and resistance to cracking of structural steels is the formation of a structure of finely dispersed bainite ferrite without the release of cementite-type carbides in combination with stable residual austenite [1]. The formation of such a structure is achieved due to the complex alloying of steel with chemical elements, which allow to almost completely suppress the processes of carbide formation in bainite ferrite (silicon, aluminum, cobalt, nickel) [2], and/or appropriate heat treatment.

The standard method of heat treatment for forming the structure of carbide-free bainite (CFB) is isothermal quenching, which can be carried out both from the austenitization temperature and from the intercritical temperature interval.

The analysis of literary sources showed that for steels of a certain chemical composition, obtaining CFB is possible as a result of continuous cooling from the austenization temperature both in air and with a furnace. According to the work [3], the following mode of heat treatment is promising: continuous cooling in air and with a furnace from the intercritical temperature interval Along with bainite, a certain amount of uniformly distributed ferrite component is preserved in the structure. It is noted in the works [4, 5] that the combination of CFB, ferrite and a sufficient amount of residual austenite can have a positive effect on the characteristics of crack resistance.

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Progressive Metal Processing Technologies

UDC 621.771.251

THE FORMATION OF ROLLING TEMPERATURE ALONG THE STRIP LENGTH

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It is known that a monotonous change in the rolling temperature along of the strips length (the so-called «temperature wedge») occurs on vast majority of hot rolling mills, regardless of mill type, the location of main equipment and assortment of products. The choice of way to eliminate the consequences of temperature wedge depends on many components, most of which are based on the compensation of already existing wedge or its consequences. For example, acceleration of the finishing group of cages, change of deviation between the rolls of the cage depending on change in metal temperature, various methods of heating the rear end of the roll, etc. Of course, eliminating this phenomenon is more effective than trying to compensate for its consequences.

In this study, an attempt was made to determine the control actions to stabilize the strips temperature in continuous state with typical location of rolling equipment. The process of rolling typical blanks with a length of 12 m and a section of 360×110 mm into ready-made strips of 360×3.4 mm according to the technological instructions and actual settings of the crimping values and speed modes of the cages was analyzed.

As a result of the study of changes in metal temperature, that is, the rolling temperature in first cage of continuous mill, taking into account the cooling conditions of various parts of the workpiece after it is removed from the furnace (at the same initial average mass temperature along the length), it was found that a temperature wedge is formed during rolling in the first cage (rolling time ~ 50 s) and, under known circumstances, it slightly decreases in all subsequent cages.

Analysis of the study results showed that the main reason for the formation of temperature wedge in conditions similar to the equipment location is the different cooling time of separate workpiece sections during its transportation from the delivery window from furnace to entrance of this section of the workpiece to rolls of first cage. It is shown that under the appropriate technological conditions of rolling, the process of forming the rolling temperature in first cage can be effective control action by changing the speed of pulling the workpiece out of furnace. The pulling takes place with the help of special rollers with electric drive. Therefore, controlling the pulling speed depending on actual difference in rolling temperatures of the front and rear ends of the roll can be effective way to stabilize the temperature. This fact was confirmed experimentally on the strip polling mill 300 [1]. In addition, it is shown that different trajectories of movement of the front and rear ends of workpiece have little effect on their temperature before rolling.

Therefore, in order to stabilize the rolling temperature along length of the strip, it is necessary to ensure the same cooling time for all workpiece parts during its transportation to first cage.

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UDC 629.76/.78

DETERMINATION OF CUMULATIVE JET PENETRATION DEPTH INTO AN OBSTACLE WITH VARIABLE THICKNESS

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Pyrotechnic devices based on linear shaped charges are widely used in rocket and space technology for stage separation and detachment of structural elements [1]. The design of these systems involves a number of complex engineering tasks, one of which is determining the penetration depth of the cumulative jet into obstacles of variable thickness. The accuracy of predicting the penetration depth is critical to ensuring the reliability and safety of rocket and space systems. The presence of local inhomogeneities in the separation section of the rocket significantly complicates the design process and requires a detailed analysis of cumulative jet behavior.

To address this issue, the primary focus is placed on establishing a functional relationship between the penetration depth of the cumulative jet and the focal distance of the linear shaped charges installation [2, 3]. A calculation for determining the cumulative jet penetration depth for arbitrary cross-sections of a structure with a variable thickness obstacle is presented.

These materials may be useful to engineering and technical personnel in the development and optimization of pyrotechnic systems in rocket and space technology.

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Modeling and optimization of technological processes

UDC 669.02/09.411:669.18.001.8

PREDICTIVE MODELS OF THE PROPERTIES OF METAL ADDITIVES AS THE KEY TO THEIR RATIONAL USE AT THE LADLE-FURNACE INSTALLATION

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The modern metallurgical industry is marked by a computer and information breakthrough, which is provided by scientific fundamentalism. This is evidenced by the significant number of created specialized computer systems, which in European countries and Japan have been brought to the level of a «digital duplicate of the process», which in turn ensures high controllability of metal smelting processes. The key to the adequate operation of the software of such systems is stable predictive models adapted to specific production and developed on reliable data. The «Metallurgy» data bank was created in the Iron and Steel Institute of Z. I. Nekrasov of National Academy of Sciences of Ukraine, which is the undisputed leader in terms of the volume of collected data, its information content (physico-chemical, thermophysical properties of interacting melts, technological features of production and other data), covering various classes of steels, alloys, cast irons, slags, slag-forming mixtures, ferroalloys, as important components of metallurgical production and its full cycle of obtaining high-quality steel. It is these data that we used as an information basis for modeling, and the physico-chemical basis is provided by the use of a unique concept of directional chemical bonding [1], which, unlike others, considers melts as chemically unified systems, and the introduction of interatomic parameters reveals the essence of inseparable chain of the «composition - technology - structure - properties». According to the starting points of the concept of directional chemical bonding, the chemical individuality of the system, reactivity and structural state of the melts are expressed using the method of coding the chemical composition of the experimental melt in the integral parameters of the interatomic interaction: Z^Y – parameter of the state of charge of the system, e; d – weighted average internuclear distance, 10^{-1} nm; $tg\alpha$ – constant for each element, which characterizes the gradient of the change in the radius of the ion when its charge changes; ρl – directed charge density, e/nm. On the basis of the identified important informative parameters of interatomic interaction and the results of correlation and regression analysis, predictive models were developed for calculating important physicochemical properties of ferromanganese, ferrosilicomanganese, ferrosilicon, ferroboron, aluminum wire, chromium-containing ferroalloys, in particular melting and crystallization temperature, density and thermophysical characteristics (thermal conductivity; heat capacity; specific electrical resistance) with sufficient accuracy of prediction ($R^2 \geq 0.9$), which makes it possible to recommend their use in automated systems of scientific research and automated systems for controlling the technological process of steelmaking. The above-mentioned ferroalloys, in particular, are used when bringing the required chemical composition to steel grades 40Cr and SAE. Carrying out calculations on representative samples t - Student's criterion, made it possible to establish the significance of the aluminum content on the change in the melting temperature of SAE steel, which is consistent with the technological map of the process, namely, the processing at the «bucket-furnace» installation and the additional introduction of aluminum. Thus, the organic combination of software products operating at manufacturers with the proposed blocks of developed predictive models will allow obtaining adequate numerical values of the degree of assimilation of additives, which realistically reflect the process of distribution and interaction of elements in the «metal-slag» system and increase the effectiveness of operational decisions.

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UDC 621.771.23:669.14.001.24

COMPLEX OF MATHEMATICAL MODELS FOR FORECASTING HOT ROLLING PARAMETERS AND QUALITY INDICATORS OF STRIP AND LONG ROLLED PRODUCTS

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Long-term experimental and theoretical studies of hot rolling technologies for strrip and long rolled products, conducted in the Department of Processes and Machines Metal Forming, allowed to develop a set of mathematical models for forecasting deformation parameters and product quality indicators. The developed models differ from the known ones by a higher forecasting accuracy, including due to factors that were not previously taken into account or were taken into account insufficiently correctly. In particular, the actual chemical composition of the rolled product is taken into account; incomplete softening of the metal during pauses between deformations; structural composition of the rolling mill (characteristics and location of rolling stands, the use of heat-saving screens, intermediate rewinding devices, forced cooling systems for rolled products between stands; parameters of devices for cooling rolled products after the deformation); roll cooling parameters.

The set of mathematical models allows to calculating the following parameters:

– temperature of the rolled product in the mill line, starting with the delivery of the blank from the heating device and ending with post-deformation cooling of the rolled product;

– energy-force parameters of deformation in all rolling stands of the condition - horizontal and vertical;

– temperature parameters of operation of working rolling rolls;

– wear of rolling rolls;

– longitudinal and transverse thickness variation of the rolls;

– deviation of sheet metal from flatness;

– parameters of the microstructure of strip and long rolled products;

– mechanical properties of the rolled product: yield strength, tensile strength, relative elongation, relative contraction (for long rolled products).

The developed complex of mathematical models was successfully applied at many rolling mills of metallurgical enterprises to solve important practical problems. Among them, it is advisable to highlight the following:

– development of effective options for the reconstruction of rolling mills;

– comparative assessment of various proposals for the construction or reconstruction of rolling mills;

– modernization of cooling systems for rolling rolls;

– determination of rational parameters of technological equipment for rolling conditions;

– development of new types of strip rolled products, reinforcing rolled products and wire rods;

– development of more effective modes of rolling the existing range.

The created complex of mathematical models will allow us to determine effective solutions for the revival of ferrous metallurgy facilities in Ukraine in the post-war period.

UDC 621.771.06:681.518.54:531.3

DEVELOPMENT OF DIAGNOSTIC METHODS OF TECHNICAL CONDITION OF ROLLING CAGES EQUIPMENT IN TRANSIENT WORK MODES

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A new approach to determining the technical condition of rolling mill equipment, which was established in the ICH in the last two decades, was considered [1, 2]. It is based on the use of parameters of transient processes in non-stationary modes of operation, first of all, during the gripping of metal by rolls and the data of mass experimental and industrial measurements on six continuous wide-band hot rolling mills. For the first time, it was proposed to determine the state of wear and clearances by the reaction delay time of sections of the drive line to the impact load in the rolling cage [3]: the larger the gap, the longer the reaction delay time. This indicator is used in other methods: setting the strip in the rolls with increasing speed (impact on the rolls) [4], using the speed of propagation of the shock torsional wave along the sections, in the method for multi-filament wire looms [5]. For the first time, the presence of correlation fields of the values of dynamic and static moments was established, which are approximated by a linear dependence, the angle of inclination of which changes with the deterioration of the technical condition of equipment and technology [2]. It is proposed to use the values of the coefficients of variation of the dynamic moment and the coefficient of dynamism, which are determined from arrays of measurements, along with the coefficient of variation of the moment in the steady rolling mode. By comparing the combinations of their three values, it is established which excitations prevail - the instability of the rolling parameters, for example, the dispersion of the metal temperature, its change along the roll, or the equipment and the action, above all, of the clearances. A diagnostic model of the drive line was developed, taking into account the dynamics of gear engagement of gear rolls, wheels and gears of the reducer and their axes in the supports in the presence of a number of gaps, it is shown that the loops of axis movements, shock forces on the bed have characteristics associated with specific gaps.

Research experience indicates the effectiveness of diagnosing rolling equipment in transient modes.

Ways of development of diagnostic methods according to the defined approach are considered. These include the search for new correlation fields, for example, the peak force in foundation bolts – a constant moment; use of features of rolling technology and equipment (cells 5, 6 of state 1680), creation of purposeful modes of rolling and operation of equipment aimed at increasing the informativeness of transient processes.

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UDC 669.184

INTERRELATIONSHIP OF FEATURES OF COLD MODELING AND INTERPRETATION OF OBTAINED RESULTS

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In modern conditions, along with the use of numerical modeling methods, methods of full-scale physical modeling have become widespread in metallurgical processes. This is due to the complexity of the simultaneous mathematical description of metal production processes from the point of view of physics, chemistry and heat engineering. Based on modern experience in modeling metallurgical facilities, high-temperature and low-temperature modeling are distinguished. Low-temperature modeling methods are based on the use of organic and inorganic substances with a melting point significantly lower than that of real metal and slag melts as model liquids. The best modeling option for transferring the results obtained to a real industrial facility is high-temperature modeling on volumetric models. However, a significant disadvantage of this research method is the high cost and technological and environmental complexity of organization at research center sites. Therefore, at the moment, low-temperature physical modeling methods are most widely used, which is associated with the low cost of the process and the possibility of multiple repetition of experiments.

It is known that in order to achieve similarity of processes to real metallurgical facilities (converter or ladle) in a physical model, it is necessary to observe the similarity of the values of the main factors that determine these processes - the so-called similarity criteria (for example, for modeling using water, the modified Froude criterion is used as the main one). Compliance with the similarity criteria does not provide an understanding of how much the interpretation of visual results corresponds to reality. For example, in the case when photo/video recording of processes is carried out through water from above, or through a transparent container and water from the side. It is known that light, passing from one medium to another, changes its speed and direction, which is reflected in the visual change in the linear dimensions of the object being studied and placed in the specified environments. Most often, transparent glass or plastic containers are used to create cold models, which have their own characteristics, first of all, the passage of light, which forms a visual picture of objects inside the model. To analyze the influence of the type of container through which observations and photo recording are carried out on the course of cold modeling, a series of photographs were taken under different conditions: the presence or absence of lighting, the presence of water around the object, and different shapes of containers in which the object is placed. As objects of study, multi-colored objects of regular and irregular shape were selected. Transparent cylindrical and square in cross-section plexiglass containers were used as containers for modeling. The ratio of linear dimensions of objects placed in the middle of the containers was chosen as a comparison parameter. It was established that when studying objects through the convex wall of a cylindrical container without adding water, we visually see no change in geometric indicators, however, the measured geometric parameters indicate distortion (the range is associated with the study of bodies of different shapes): due to plexiglass by 0.5-2.2%; due to the convex composition of the cylindrical shape of the container by 2.0-3.0%; due to water and flat plexiglass by 3.8-5.7%; due to water and convex plexiglass by 21.9-36.2%. It was found that the combination of simultaneously flat and convex plexiglass, separated by a small water layer (up to 1 cm thick), reduces the amount of distortion to 4.9-9.9%.

To improve the interpretation of the results when conducting physical low-temperature modeling for the purpose of visual observation through the wall, it is possible to recommend the use of a system of containers: the inner convex one, which models the geometric parameters of the unit, and the outer one with flat walls filled with a liquid with the same optical parameters, which reduces image distortion.

UDC 669.14.018.352.2:621.771.25:621.785

METHOD OF CALCULATING THERMAL STRENGTHENING PARAMETERS OF CARBON STEEL WIRE ROD ON THE BASIS OF SIMULATING THE PROCESS OF INTERRUPTED QUENCHING WITH SELF-TEMPERING

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Rolled steel, in particular carbon steel wire rod, is one of the mass types of metal products, which is usually used for processing into various metal products by the method of cold plastic deformation. The variety of manufactured products makes it necessary to obtain steel wire rod with different levels of mechanical properties, in particular, with increased strength indicators and sufficient plasticity. The situation is additionally complicated by the fact that the volumes of wire rod within individual commercial orders do not always correspond to the minimum industrial batches, and a well-founded determination of the parameters of the technological process directly in production conditions is economically inexpedient, since it significantly reduces productivity and affects the sorting of finished metal products. To solve the existing problem, which consists in guaranteed receipt of steel wire rod with regulated strength, a methodology for calculating the duration and intensity of water cooling of rolled steel on the wire line of the rolling mill has been created, the essence of which is based on the principle of additivity [1].

The calculation of the specified thermal hardening parameters was carried out according to the following algorithm:

1. Numerical solution of the differential equation of heat conductivity with given initial and boundary conditions. Initial data: thermophysical characteristics of the material, rod diameter, cooling duration, range of average values of the heat transfer coefficient in tabulated form. The duration of water cooling (stage No. 1) was determined based on the length of the water-cooling route and rolling speed. During the calculation of the self-tempering process (stage No. 2), the final state of the water-cooling process (stage No. 1) is taken as the initial condition of the self-tempering process.
2. Analysis of the obtained data to determine the depth of the hardened layer and the self-tempering temperature. The value of the depth of the hardened layer was determined from the available discrete set of calculated values by the method of linear interpolation. The self-tempering temperature is defined as the surface temperature of the rolled product at a given time and depends on the location of the pyrometer, rolling speed and the speed of movement of the wire rod turns on the roller conveyor of the Stelmor line.
3. Analysis of the obtained dependences of the depth of the hardened layer and the self-tempering temperature on the average heat transfer coefficient. Determination of the required depth of the hardened layer. Initial data: wire rod diameter, yield strength of the finished rolled product and rolled product with a model type of structures (ferritic-pearlitic, martensitic).
4. Calculation of the yield strength from the self-tempering temperature taking into account, for a given diameter of the wire rod, its integral strength depending on the depth of the hardened layer.

The proposed method for calculating the parameters of thermal hardening (duration and intensity of water cooling) was successfully tested in the conditions of a continuous fine-gauge wire mill during the manufacture of various profile sizes of carbon steel wire rod (0.21 % C; 0.56 % Mn; 0.06 % Si).

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UDC 004.9; 621.74

NUMERICAL SIMULATION OF LOW-DENSITY TWIP-STEEL CASTING AND SOLIDIFICATION

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High-strength Fe-Mn-Al-C TWIP steels are promising structural materials due to high manufacturability and a complex of mechanical properties that can be adjusted by deformation and heat treatments. This class of materials is based on the concept of high-entropy iron-based alloys having a multiphase structure. They have high strength and plasticity (400 MPa ≤ yield strength ≤ 1200 MPa, 600 MPa ≤ tensile strength ≤ 2000 MPa and 30% ≤ total elongation ≤ 100%). Fe-Mn-Al-C steel is about 18% lighter than conventional ones. This combination of mechanical characteristics contributes to the wide use of this type of alloys in the aerospace field to produce highly loaded frame parts.

Due to the high content of manganese (15-35 wt. %), these alloys mainly have an austenitic structure, which determines their ability for extremely effective strain hardening. The high content of aluminum in TWIP-steels (5-12 wt. %) ensures a significant decrease in their density and an increase in corrosion resistance.

Due to the peculiarities of the chemical composition of TWIP steels, cast large-sized semi-finished products have many defects of shrinkage origin - shrinkage shells, cracks, weights, leaks, etc. This causes the complexity of the production process of this material.

The abstract presents the results of numerical simulation of low-density TWIP steel casting in a casting system with four cases of feed channel configuration: alloy supply from below at an angle of 15° and 30°, side feed direct and feeding from the side through a six-stage loop feeder.

The results of numerical simulation showed that during the casting process of the low-density steel experience not only the influence of temperature stresses, but also additional effect from the circulating fluid flows. In this case, the greatest impact, expressed in maximum values of temperature, is observed in the corners of the mold and persists until the metal level reaches the surplus.

Temperature distribution in the mold showed that in case with side feed direct, the mold riser does not freeze. Therefore, in this case, feeding the mold with molten metal will occur until the solidus temperature is reached. Accordingly, taking into account the propensity of this class of steels to the formation of gas shrinkage defects, this case can be considered optimal.

UDC 62-551.454

OPTIMIZATION OF THE WORK MODE OF THE OUTPUT SIDE OF MINOR MILLS

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Rolled products are produced from carbon, structural and low-alloy grades of steel. After rolling on the output side of the mill, the rolled stock, cut into bars, is cooled on a rack cooler, then collected in bundles, transported to the cold cutting shears. With scissors, it is cut into measuring or standard bars. The cut bars are collected in the pockets of the scissor conveyor belt, weighed, tied into bundles and fed to the warehouse of finished products by an electric overhead crane.

One of the important indicators of the mill's operation is the rolling rate. Ensuring the maximum possible rolling speed, based on the operation of the technological equipment, reduces the cost of finished products due to, for example, a reduction in energy consumption when the speed is reduced or technological downtimes.

The work of transporting rolled strips collected in a package by a conveyor belt to cold cutting shears is considered. The weight of a package of stripes varies significantly depending on their length and number. The braking distance of the transported package also depends on this.

The cutting of the package with cold cutting scissors is carried out under a stop, so the package is brought to them at a crawling speed. The longer the path, the greater the time spent cutting, which reduces the overall rolling rate.

The developed system makes it possible to determine the acceleration and deceleration parameters of the roller drive during the transport of the package by the roller conveyor to the cold cutting shears for the first cleaning cut.

The package can have strips of different lengths from start to finish, depending on the cutting algorithm. Therefore, the path of acceleration and deceleration of the package for cutting on cold cutting shears can be different. However, package moments of inertia and static moments affect the acceleration and deceleration processes equally. Determining the acceleration time and path, you can also determine the deceleration path. The ratio of the acceleration path to the deceleration path obtained for the cleaning cut is used to determine the deceleration time for the next cut. Each time the roller conveyor is turned on, this ratio is refined.

The conducted simulation modeling of the system operation showed that in this way it is possible to accurately set the package in front of the stop of the scissors and reduce the path of movement of the bundle of rods at crawling speed to almost zero, and thereby increase the productivity of this section.

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UDK 669.184.001.57

SIMILARITY IN COLD MODELING OF TOP BLOWING IN OXYGEN CONVERTERS

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Blowing a liquid metal bath with supersonic oxygen jets is a crucial part of the oxygen converter process. The interaction between oxygen jets and melt not only facilitates the oxidation of impurities in melt but also leads to intricate hydrodynamic phenomena within the fluid bath. These phenomena significantly impact the melting process, ultimately influencing the key technical and economic parameters of the operation. Therefore, the determination of the key aspects of the interaction between gas flows and a liquid bath, as well as the analysis of related hydrodynamic processes, has always been a priority task for metallurgical science [1-3].

One of the scientific methods used in the study of metallurgical processes is "cold" modeling [1,4]. Such modeling is easy to implement, visual and relatively inexpensive, making it widely used for studying hydrodynamics in converter baths. "Cold" modeling is based on similarity theory and requires criteria for similarity to be equal between the original and the model.

Based on these recommendations [1,5,6], the criteria for defining top blow in "cold" modeling are Mach number and Newton criterion. The equality of Mach numbers ensures similarity of gas jet flow on the original and in the model [6]

$$\mathrm{Ma} \equiv \frac{\mathrm{w}}{\mathrm{c}} = \mathrm{idem}, \qquad (1)$$

where w is local flow velocity, m/s; c is speed of sound, m/s.

Compliance with Newton's identity criterion is necessary to ensure dynamic similarity between the model and the original. One possible form of this compliance is complexity

$$\mathrm{Ne}_3 \equiv \frac{\mathrm{i} \cdot \mathrm{n} \cdot \cos \alpha}{\mathrm{m} \cdot \mathrm{g}} = \mathrm{idem}, \qquad (2)$$

where i is momentum of single flow rate, H; n is number of nozzles; α is nozzles inclination angle, deg; g is acceleration of gravity, m/s²; m is mass, kg.

To ensure geometric similarity, it is often recommended to use simplex [7, 8]

$$\frac{\mathrm{H_f}}{\mathrm{d_{ex}}} = \mathrm{idem}, \qquad (3)$$

where H_f is bath lance distance, m; d_{ex} is nozzle exit diameter, m.

However, the use of simplex does not allow us to identify the interaction modes between gas jets and liquid baths, which can lead to distortion of the results. Therefore, in order to determine the conditions for "cold" modeling, which takes into account the effect of the gas jet introduction mode on the overall hydrodynamic picture in the bath, we can use the experimental dependencies proposed by [9]. These dependencies are represented by equations relating the main parameters of the blow mode and determining the limit values for which the mode of gas current interaction with the liquid changes

$$\mathrm{A} \equiv \frac{\mathrm{H_f}}{\left(\frac{\mathrm{i}}{\rho_\mathrm{l} \cdot \mathrm{g}}\right)^{\mathrm{a}}} = \mathrm{idem}, \qquad (4)$$

where ρ_l is density, kg/m^3; a is the empirical indicator of the degree is determined by the cavity mode (for splashing mode, the value is 0.456; for penetrating mode, it is 0.462; for "hard" blowing, it is 0.465).

Thus, the geometric similarity of the "cold" model of the top blowing can be determined based on the dependencies that define the boundary conditions for transition between cavity mode.

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