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Iron and Steel Metallurgy: Technology, Innovation, Quality

PROJECT OF NEW BOF SHOP CONSTRUCTION IN PJSC "ZAPORIZHSTAL"

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Data on new HRC production complex construction project in PJSC "Zaporizhstal" were announced including general layout, scope of objects and key technological assets such as hot metal desulfurization, combined blowing BOF steelmaking, LS treatment in LF and vacuum degasser and further casting and rolling in CSP module. Key performances of the gas cleaning and dedusting facilities were presented.

DEVELOPMENT OF CRITERIA FOR ASSESSING ALKALINE CAPACITY OF BLAST FURNACE SLAG IN THE CONDITIONS OF USE OF RECYCLED MATERIALS

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The need to dispose of secondary resources stored in the repositories containing significant amounts of alkaline compounds and other impurities in addition to iron and flux additives, and using them as blast furnace charge materials, has led to an increase in alkaline loading and, as a consequence, a deterioration of technical and economical work blast furnaces. In this connection, an urgent issue is the assessment of the alkaline capacity of blast furnace slag when changing its composition and properties, as the main factor for the removal of alkaline compounds from the furnace.

To perform an operative predictive assessment of the content of potassium and sodium oxides in the slag melt under the actual operating conditions of blast furnaces in the absence of their control or to replace expensive methods for monitoring the content of alkaline oxides in blast furnace slag, developed indicator for estimating the actual concentrations of alkaline oxides in the slag melt - alkaline capacity. The use of the obtained indicator in the systems of industrial control and in scientific research will allow to establish a rational slag regime of the blast furnace smelting process for maximum removal of alkaline compounds from the blast furnace, and will ensure the operational reliability of the unit when recycling secondary resources is not lower than the rate of their accumulation.

The publication contains the results of studies conducted by President's of Ukraine grant for competitive projects F-82 (Presidential Decree No. 242/2019-rp).

INCREASING THE BLOWING EFFICIENCY OF BOF BATH WITH PARTIAL POSTCOMBUSTION

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In modern production conditions, the production of high-quality crude steel is carried in basic oxygen converters (BOF). However, the existing oxygen lances of the most advanced design does

not provide: improvement of thermal balance of smelting, fast formation of slag and removal of phosphorus while high carbon content in the bath; decrease of probability of skull formation on the main and auxiliary technological equipment; effective application of wall accretion; implementation of the combined blowing of BOF bath during its whole life.

The results of the given researches aimed for the increase of energy efficiency of steel production allowed to determine the rational designs of oxygen lances while the combined blowing of BOF bath. It has been found that the most appropriate is the use of two-tier oxygen lance with two-row or double-loop heads, equipped with independent paths for process gases supplying. According to the results of high-temperature modeling, their predominant efficiency in comparison with the traditional designs of two-tier and classic oxygen lances has been determined.

According to the results of the carried out researches, it has been determined that the use of oxygen lance of the developed design in comparison with the traditional ones would allow increasing the yield of crude steel by 0.15 - 0.30%; reduce the consumption of slag-forming additives (lime + dolomite) by 2.5 - 3.5 kg / t and decrease the blowing duration by 1.0 - 1.5 min.

MULTI-LEVEL GAS-COOLED SKULL LANCE

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The innovative design of gas cooled multi-level skull lance with the possibility of changing the distance between the levels and the direction of the side nitrogen jets, affecting the direction of movement of the gas-slag stream reflected from the slag bath, is proposed. The lance is designed to intensify the “hot” repair of the converter lining during periods of identification of the zones of outdated wear. Lateral nozzles with a variable angle of inclination provide an opportunity to redirect the reverse gas-slag flow to the identified "problem" zones and restore the rational profile of the converter working space.

A feature of the patented design of gas-cooling lance is the ability to quickly change to a determined by calculations value the distance between the tip and the upper block of the side nozzles. The upper block and the lower layer of the lance are connected by means of a threaded connection with sealing by a temperature-resistant gasket.

The direction of the reverse gas-slag stream reflected from the slag bath during the blowing is controlled by nitrogen jets flowing from the Laval nozzles of the lance tip by changing the position of the side nozzles of the upper block relative to the Laval nozzles of the lance tip in the vertical plane.

It should be noted that, the results of the industrial test of the two-level skull lance showed no signs of erosion of the deposited skull slag layer in the sectors of intersection of gas flows from the side nozzles and converter walls.

INTERACTION OF PRIMARY CONVERTER SLAG WITH REFRACTORY

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The nature of the influence and regularities of the interaction of converter slag of the first blowing period of the converter bath with the surfaces of periclase-carbon refractory as unprotected as protected by a layer of skull slag coating, were theoretically investigated and confirmed during high-temperature studies.

The value of the contact angle was taken as the optimization parameter, and mass amount of the CaO and MgO in the slag and the size of the solid refractory particles, that were simulated additives not saturated by the slag during this period of converter smelting, were taken as the influence factors. According to the results of the experiments, the wetting angles and the adhesion work of the slag of various chemical compositions to the refractory were determined, that corresponded to the slag from the moment of the formation of the primary slag till the composition before intermediate deslagging from the converter. The nature and patterns of the influence of unsaturated particles of slag additives on the change in slag viscosity and adhesion were also established.

It was confirmed that the maximum adhesion to periclase-charcoal refractories with different carbon contents (from 4 to 20 wt.%) provided by acidic slags, with a slight degree of dependence on the carbon content in refractories. Clarification of the dependence of adhesion on the carbon content in periclase-charcoal refractories, with a gradual transition from acidic to mid-base (with a basicity of more than 2.0) slags, allowed to propose measures to prevent the destruction of the refractory in the first period of converter smelting.

It is shown that the following factors have the greatest influence on the change in the contact angle of the midbasic slag: particle sizes of solid non-soluble additives in the slag (more than 3.0 mm negatively affect the contact angle of the refractory); exceeding the content of magnesium oxide by more than 7.5-8.0%, that leads to an increase in the contact angle of the refractory; an increase in CaO with a rational content of magnesium oxides leads to a decrease in the contact angle.

To calculate the rational composition of primary and intermediate basic slags, taking into account the size and quantity of unsoluted particles of additives, the corresponding mathematical models are proposed. Numerous modeling studies shown that with an increase in MgO content in the slag of more than 14%, the wetting character (the effect of increased basicity and oxidation) changes to the opposite, that coincides with the known results of other researchers. At MgO content of up to 14%, slag oxidation level of 13% and CaO content of 30%, respectively, the wetting angle is 33.7 degrees, that determines the developed contact surface of the slag with refractory. With an increase in the content of MgO in the slag to 16-18%, in the first melting period, with a slag oxidation level of 13% and 30% CaO, the contact angle increases to 68.9-71.5 degrees, that provides a free contact of the slag with refractories and its effects on the destruction of the lining.

IMPROVEMENT OF METHODOLOGY FOR DETERMINATION OF METALLURGICAL VALUES OF AGGLOMERATED WASTE

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Due to the exacerbation of the problem of scarcity of quality scrap, metallurgical enterprises use not only iron ore materials with low iron content, metal additives in the form of dust, sludge and wastes of machine-building enterprises, but also consider the possibility of recycling radioactive scrap. Today, as a resource of raw material for the steelmaking, briquettes from the wastes of metallurgical and machine-building industry, including cast iron and steel chips, can be considered. Steel shavings differ from other types of light scrap with great heterogeneity of hardnessin in section, the presence of oxide films and impurities, that somewhat complicate the formation of a dense and strong piece during cold pressing of briquettes.

The disadvantages of using in the smelting process of briquettes of steel chips with a high content of harmless impurities are: the overspending of lime on the melting due to the need to compensate the low basicity of the non-metallic part (slag) of briquettes; increased wear of periclase carbon refractories due to interacting with the overoxidized acidic slag of the first blowing period; possibility of cooling of a metal bath at rapid spontaneous destruction of a briquette with iron crast

formation on it and increase of iron oxydation at oxygen injection; removal of small fraction, that strew from the briquette, with the exhaust gases at loading of scrap, etc. The percentage of liquid iron from the briquette depends also on the presence and amount of cutting fluid on the surface of the chips.

In order to improve the method of determining the metallurgical value of briquettes, the authors of the present work conducted a series of high-temperature experiments of samples of briquettes of steel chips smelting in the induction crucible furnace ICF-016 in argon protection surrounding. In the first stage of the experiments, the density of each briquette sample was determined using the hydrostatic weighing method and the briquette strength index. In the next stage of experiments, the briquettes were melted in an induction furnace.

The obtained results were analized using the provisions of the theory of metallurgical processes and methods of material-heat balance calculation. The calculated values were compared with the results of chemical analysis of slag to determine the degree of completion of the processes. In the next stage, taking into account the chemical composition of the slag formed during the smelting of steel scrap, we specified the mass of non-metallic inclusions that came to the slag from the composition of the briquettes of steel chips. In accordance with the density and strength of the investigated briquettes according to the requirements of DSTU 2141-2002 a wide range of contamination with harmless impurities (from 2.47 to 7.33%) was established.

The macrostructure of the slag obtained during the smelting of briquettes into steel was also investigated and the possible influence on the dynamics of slag formation in the initial period of converter melting was evaluated.

According to the results of experiments and calculations, an advanced estimation technique with the introduction of an integral index of contamination of briquettes is proposed, that is intended to take into account the total number of non-metallic inclusions, harmless and harmful impurities, losses due to the removal of cutting fluid, etc.

HIGH TEMPERATURE STUDY OF FEATURES OF TOP BLOWING A METAL BATH IN OXYGEN CONVERTER THROUGH THE ANNULAR COAXIAL NOZZLE

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The process of interaction of a high-speed gas stream of an oxidizing agent flowing from the top blowing lance during oxygen conversion with melt is a determining and decisive factor in the development and occurrence of thermal and exchange processes. It is known that the improvement of blowing modes is one of the highly efficient energy-saving directions, that allows to improve the technical and economic indicators of the production of converter steel quite quickly and without significant financial expenses. However, to date, the issue of the efficiency of the absorption of oxygen by a metal melt to the main oxidation reactions from its total amount supplied to the smelting, do not receive due attention.

Physical modeling of blowing through an annular coaxial nozzle (that contributes to the reduction of flow dissipation) revealed that the gas jet from annular coaxial nozzle along the axis has a larger dynamic head than from the one standard nozzle and resulting in deeper penetration in liquid. The paper presents the results of a high-temperature study of the nature and characteristics of blowing a metal melt through the top lance with an annular coaxial nozzle based on a 60-kg laboratory converter in comparison with the work of four nozzle tips. On the basis of continuous video recording by a high-speed camera with a frequency of 300 frames per second and recording of technological indicators, the nature of the interaction of an oxygen jet with a liquid bath was studied and the conclusions obtained at the “cold” modeling about higher dynamic pressure and deep penetration into the melt of the jet using an experienced tip were confirmed. Earlier ignition of the melting and a significant increase in the temperature of the sub-lance area recorded by the

pyrometer were revealed, probably due to the creation of a zone of intense postcombustion of CO to CO_2 in the sub-lance region. However, the deep penetration of the jet led to a more stringent blowing with the formation of a smaller amount of slag, probably due to a smaller intake of iron oxides in the slag than in comparative heat. According to the magnitude of the decrease in the level of carbon in the melt compared to comparative melts at a same level of the amount of oxygen supplied, an increase in the proportion of oxygen spent on carbon oxidation using an experimental tip was found, with a corresponding increase in the rate of carbon oxidation during the blowing.

THE MODERN CONDITION OF ONE-DECK TYERE USAGE IN THE OXYGEN CONVERTED PRODUCTION IN UKRAINE

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The group of processes in the oxygen converts manufacturing which refers to the top and combined blowing has been using since 1980`s. Nowadays we can observe the tendency of one-deck tuyere usage in the metal converting process [1,3]. These tuyers have limited control actions on metal blowing and also require strict conditions on charged material conditions [1,3].

It is important to mention that there is a range of complications on the modern stage of black metallurgy in Ukrainian oxygen converted tankhouses such as [1,3]:

– the lack of charged material quality, sulfur and phosphorus concentration;

– the grab iron cost overrunning over the cast iron cost;

– the mixture making converter operation changing because of cast iron structure and temperature fluctuation;

– the absence of multilevel grab iron sorting;

– the poor quality of lime, the lack calcium fluoride and magnesia slugging materials;

– the absence of iron and manganese commodity masteralloy during blowing;

– the usage of limestone masteralloy and bath lancing with the help of technological nitrogen for hot heat cooling;

– the limited usage of lodleman desulfuration before jetting metal into tuyere cast iron and further combined blowing liquid-alloy in the converter aggregation.

In conclusion we would like to point out that one deck construction of overhead tuyere for blowing metal lead to the unstable work of Ukrainian oxygen converted tankhouses and metal product quality.

REDUCTION OF CHROMIUM OXIDE WITH CH_4 - CO_2 AND CH_4 - H_2O MIXTURES

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In recent years, the use of hydrocarbon gases in various technological schemes in metallurgy has been intensively developing. To a large extent this is applied to methane. The introduction of "raw" methane into a high-temperature metallurgical unit initiates various transformations, which are often difficult to analyze comprehensively. The development of a physicochemical model of the methane use in the processes of solid-phase reduction of chromium-containing raw materials will allow us to develop the technological basis for the production of multi-component sponge ligatures.

It is known that CH_4 on the catalytic surface is converted by water vapor (or CO_2, O_2), which is the main method for the production of hydrogen and synthesis gas (a mixture of CO and H_2 in various ratios). Thus obtained gas can be used in gas or complex reduction of oxides. At the same

time, methane successfully disproportionates on solid surfaces already in the low-temperature region: $CH_4 = C + 2H_2$. The development of this reaction may be accompanied by cluttering the surface with carbon black, which blocks the reaction surface and slows down the process as a whole. The use of CH_4 - H_2O mixture promotes gasification of soot carbon and, as a result, accelerates the process. Methane conversion is also carried out by oxide of oxygen (partial oxidation of methane - POM), which formally can be considered as direct reduction of oxide by methane. Apparently, the mechanism of this process involves the deep oxidation of methane to CO_2 and H_2O with catalyst oxygen (lattice or adsorbed) at the first stage $CH_4 + 4O_{cat.} = CO_2 + 2H_2O$ and the participation of products in the subsequent steam and carbon dioxide conversion of methane. However, the thermodynamic probability of such a process is difficult to evaluate.

We performed thermodynamic modeling of the process of chromium oxide reduction with a steam-methane mixture depending on the temperature and composition of the system. The results indicate that the process may proceed according to various schemes depending on temperature: below the Cr_2O_3 reduction start or above it. In this case, extremes of some components of the equilibrium gas phase take place, which requires a detailed analysis. It can be assumed that the reduction of chromium oxide with the CH_4 - H_2O mixture is realized through the sequential POM mechanism, and the peak value of water vapor can be explained by the ratio of the equilibrium constants of individual transformations, in particular, methane vapor conversion and carbon gasification with water vapor, etc.

When CH_4 is partially replaced by carbon, the process retains these features, but in the region of higher temperatures. The reduction of other oxides is also accompanied by the appearance of extremes. The movement of the concentration peak of water vapor to a higher temperature region may be due to differences in the “activity” of carbon introduced with the charge and formed during the decomposition of methane, as well as POM with oxygen of oxide. Such an assumption is based on the almost identical results of two variants of process modeling. Certain differences occur when the proportion of carbon and chromium oxide has been changed.

THE EFFECT OF INCREASING THE PROPORTION OF MOLTEN IRON ON THE FEATURES AND HEAT BALANCE OF THE OXYGEN-CONVERTER PROCESS

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The current conditions of "existence" of the oxygen-converter process are characterized by uncontrolled growth of prices for raw materials, energy resources and scrap metal. The quality of the latter is constantly declining. This in conditions of steel smelting in units of high tonnage (> 300t) makes it difficult to organize stable melting, especially when obtaining quality grades of steel. Ensuring the production of high-quality scrap steel in the required amount is difficult, even when using a selective scrap method. A promising area of research for improving the oxygen-converter process under real conditions is the physico-chemical justification of a rational method with an increased fraction of pig iron, which at first glance seems regressive.

It is shown that with the increase in the converter smelting fraction of liquid iron, the disadvantages of using coolers (scrap, rolling scale, lime, etc.) used in the classical scheme of the oxygen-converter process are its advantages.

In the scheme of simplified calculation of the thermal side of the experimental melts, the change in the physical heat of the liquid iron, the heat of the exothermic oxidation reactions of the iron impurities consumed for heating, melting and bringing the temperature of the coolers to 1600 ° C were taken into account. Calculations of the thermal balance of the investigated melts were performed for ratios of metal scrap / cast iron, in% as 75/25; 80/20; 90/10.

The algorithm of rational process management with the high pig iron fraction, which includes double cooling of liquid metal at corresponding carbon contents and metal temperature, is

presented. The choice of melting coolers based on the materials of the natural resource base of the Ukrainian FM, containing CaO, $CaCO_3$, MgO, SiO_2, Al_2O_3 and Fe_xO_y, as well as slag-forming materials of purpose for a number of man-made wastes of metallurgical and other industries is substantiated. The advantage of using iron ore or its concentrate is the possibility of their addition on the tract of bulk materials at any time purging to accelerate the process of formation of the basic slag and to cool the melting.

When conducting experimental melts on the model of the converter with the upper oxygen purge on the surface of the bath after raising the temperature of the bath above 1530-1550°C sequentially experimental slag-forming mixtures for their functional purpose. The physicochemical features of the steel smelting process with the high fraction of liquid iron have been specified.

It is experimentally set that at part of liquid cast-iron in metaloshikhti of the converter melting which is more than 90% it is necessary to increase as an amount of coolers so amount of additives. It allows to get the set temperature of metal on the extract of metal in a scoop.

It should be noted that most effectively technology with megascopic part of cast-iron can be realized in a converter with the combined blowing with a leadthrough on the finishing stage of melting of produvki of converter bath by an argon for achievement of content of carbon in a metal at level ~0,03-0,06%.

The problem of deficit of crow-bar is decided, diminished specific expense of oxygen; the decline of content is attained in steel of harmful admixtures, increase, degrees of desul'furacii and output suitable on iron.

Expediently at the increase of part of liquid cast-iron to promote the temperatures of metal on the issue of melting. It will allow at out-of-furnace treatment of steel, keeping a proper reserve of physical warmth of metal, substantially shorten time of his electroheating on UKP, to decrease negative poured in thermal streams from a high temperature arc on firmness of refractoriess of slag belt and specific expense of electrode mass of the graphitized electrodes.

SIMULATION OF HYDRODYNAMIC PROCESSES IN THE BLAST OF THE LADLE THROUGH THE BOTTOM BLASTING DEVICES

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One of the most effective ways of increasing the quality and properties of mass-produced metal products and resource conservation in metallurgy is the ladle processing of metal. Observance of the established modes of blasting, which in turn significantly influence the formation of the bubbling zone, in the ladle treatment of steel at the installation of the "ladle-furnace", is an effective means of reducing the material and energy intensity of steel.

In order to choose the location of bottom blowing devices and the intensity of blasting, the "cold" model of 250 tons of ladle, research of the influence of the blasting parameters on the bubbling formation zone, baring the mirror metal.

The results of the research are given in table. 1.

Table. The influence of gas flow and slag thickness on the relative area of the metal mirror baring

Thickness of slag, mm	The relative area of baring of the metal mirror at the gas flow rate (l/min)		
	100	400	800
200	1%	22%	80%
220	1%	21%	77%
240	1%	20%	73%

It was found that the slag thickness does not significantly affect the relative area of metal baring compared to gas consumption. When refining the blast (100 l/min), the change in slag thickness does not affect the baring of the metal mirror, whereas at the blast of 400 and 800 l/min. the surface of the metal mirror is baring by approximately 20-22% and 73-80%, respectively, depending on the slag thickness. It is noted that when using the blast blocks located on the periphery, the slag is concentrated in the opposite side of the ladle from their location. The peculiarity of blasting through two blast blocks is the formation of stagnant zone. The method of statistical analysis provides equations that allow to determine the basic principles of formation of the bubbling zone and its effect on the layer of slag when blowing through the blowing blocks. The general form of the equation that allows you to calculate the relative area of baring of a metal mirror is given below:

$$S = 1{,}12 \cdot 10^{-4} \times q^{1,9} \times h_{шл}^{\ -0,49}\ , \%,$$

where q - the gas flow rate, l/min;

h - slag thickness, mm;

S - the relative area of baring of the metal mirror, %.

According to the results of the calculation of the process of removal of non-metallic inclusions, it is established that the percentage of removed non-metallic inclusions increases from 9 to 26% with increasing consumption of neutral gas from 100 to 800 l/min.

HIGH-TEMPERATURE MODELING OF DEOXIDATION OF IRON-CARBON MELT BY RESIDUAL CARBON

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The results of high-temperature studies of the deoxidation of an iron-carbon melt by residual carbon during discharge from a steelmaking unit are presented. The characteristics of the equipment and the methodology for laboratory research are presented in [1].

The study was carried out in 2 stages. At the first stage, argon was injected into the high-carbon melt to determine rational purge regimes with a minimum angle of gas-metal flow opening (GMF) (*α)*. It has been established that the degree of its organization has the greatest influence on the processes that occur in the GMF. Melt treatment with argon in a single-chamber channel equipped with a 4-nozzle block ($Q_{g.1}$ = 0,05 m^3/min per nozzle) did not give positive results due to an increase in α to 10-15°.

Carbon burn, due to a decrease in the protective effect of argon, was ΔC = 0.99%.

When using a two-chamber channel equipped with a 2-nozzle purge unit with $Q_{g.1}$ = 0.1 m^3/min. and the flow opening angle α = 5-7°, the decrease in the carbon concentration in the melt was 0.53%. The most rational melt processing mode was obtained at $Q_{g.1}$ = 0.05 m^3/min. (with an opening angle α = 1-3°) in a two-chamber channel (ΔC = 0.04%). When the melt was released without argon treatment, the carbon burn was ΔC = 0.14%, which confirms the relevance of protecting the metal stream from the influence of atmospheric oxygen by increasing the degree of organization and formation of a protective gas shell.

At the second stage of the studies, by argon was treated an unoxidized low-carbon melt with a Mn content <0.05% and traces of Si. A two-chamber steel outlet channel equipped with a 4-nozzle purge unit was used.

After processing the melt with argon ($Q_{g.1}$ = 0.05 m^3/min.), the decrease in carbon concentration amounted to 0.014-0.023%. The aluminum content after deoxidation (in samples melt with by argon processing in all experiments) was increased on average by 0.02%, which indicates a decrease in aluminum fumes and the implementation of carbon deoxidation.

It was confirmed that with an increase in the initial carbon content in the melt, the fraction of oxygen removed increases. So, when processing a melt with an initial carbon content [C] = 0.033-0.050%, the fraction of oxygen removed was 12-19% (rel.), and the decrease in aluminum fumes was 14-20%, respectively.

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RESEARCH ON FEATURES OF DIRECT RECOVERY OF IRON FROM TITANOMAGNETITE CONCENTRATES

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The report informs on the laboratory tests of the possibility of using the technology of direct reduction of ITmk3 iron for the recovery and heat treatment of iron-titanium concentrates and magnetite ore concentrates of various deposits.

The ITmk3 technology, developed by the Japanese company Kobe Steel, Ltd, is based on the process of solid-phase reduction of iron oxides in ore-flux-coal pellets, carburization, melting and fusion of reduced iron particles at temperatures up to 1450 ° C, and metal separation from slag with the formation of metal granules when cooled. The process is carried out in a rotary hearth ring furnace; the slag is finally separated from the cast iron after the final stage of cooling outside the furnace. After separation of gangue from iron, metal granules - “nuggets” are formed at the exit; their degree of metallization is 100%; carbon content is reached up to 2.5-4.0%; the content of other elements (including silicon) is below 0.4%.

A characteristic feature of the ITmk3 process is that the entire process takes place in a separate pellet. The composition of this pellet is selected so that the process is fully completed within the set reaction time (8-12 minutes) and the desired chemical composition of the product is achieved. The internal atmosphere of the furnace provides the required heating and maintains a reducing environment around the pellet.

The reports sets out characteristics of the raw materials, which were used for tests carried out in the chamber furnace of the Nisshin laboratory (Japan). Ore-flux-coal pellets were produced out of the mixture of titanium concentrates and iron ore concentrates, with different proportions of iron and carbon composition (Fe / C) in pellets, which were then reduced in the chamber furnace in different temperature and time environments.

Tests using only iron-titanium concentrate showed that while maintaining a constant basicity of slag (B = 0.8), the ratio of iron and carbon in Fe/C pellets changed as follows: Fe/C = 3.4; 3.6; 3.8 (the proportion of carbon in the pellets ranging from 16.35% to 14.90%). During these tests, a small amount of nuggets was formed, and melting of the slag and separation of the reduced iron and slag were not observed at all due to the high melting point of the slag, which is mainly due to the high TiO_2 content in the slag.

Mixing iron-titanium concentrate with magnetite concentrates allows to increase the total iron content in the mixture and lower the melting point of the slag. Good quality nuggets were produced as a result of all tests with a mixture of iron-titanium concentrate and iron ore concentrate (65% Fe) with a share of iron-titanium concentrate of 20%, 30% and 50%. However, at a 50% ratio of concentrates in the mixture, slag formation was 428 kg / ton of nuggets. With so much slag, the technological process can be difficult. Therefore, along with the use of high-quality iron ore

concentrate, the proportion of iron-titanium concentrate in the mixture is recommended to be no more than 40%.

DEVELOPMENT OF THE “SLAC” DATABASE FOR THE DEVELOPMENT AND SELECTION OF RATIONAL STRUCTURES OF THE SLAG MIXTURES OF STEEL-MELTING PRODUCTION

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Created at the Iron and Steel Institute of Z. I. Nekrasov of the National Academy of Sciences of Ukraine (ISI NASU) the base of experimental physical and chemical data on the properties of slag melts “Slag” [1, 2] is focused on satisfying the information needs of theoretical and applied metallurgy [2] and has been at the stage for more than 20 years in continuous operation, improvement and active replenishment with new experimental data.

The database uses IRS developed in the C # programming language. To create databases, a program is used that processes the input information on the basis of a data passport, that consists of three blocks characterizing the experimental conditions. After entering information into the database, the program allows you to index text fields for further use of the search for relevant documents.

Directly, the IRS allows you to view the contents of the database, find relevant documents according to hierarchical queries, and upload the found information to Excel files. Programs for the final processing of information obtained from the database allow you to visualize factual data, perform various types of analysis.

In general, the “Slag” database contains information on the properties of various metallurgical slags and oxide systems. The database saves the researcher from the need to carry out lengthy, laborious and expensive experiments, speeds up the search for the necessary information, and also allows the selection of compositions of oxide materials with the required level of properties in the required temperature range by means of a computational experiment.

In order to develop the scientific foundations about the structure of slag melts and use the new knowledge gained to develop and select the rational composition of the slag of the steelmaking production (slag ESR and SFM), forecast models for their quick assessment based on the accumulated data in “Slag” database was improved, and also developed algorithmic and software tools for generating triple diagrams of the technological properties of oxide systems (Fig. 1).

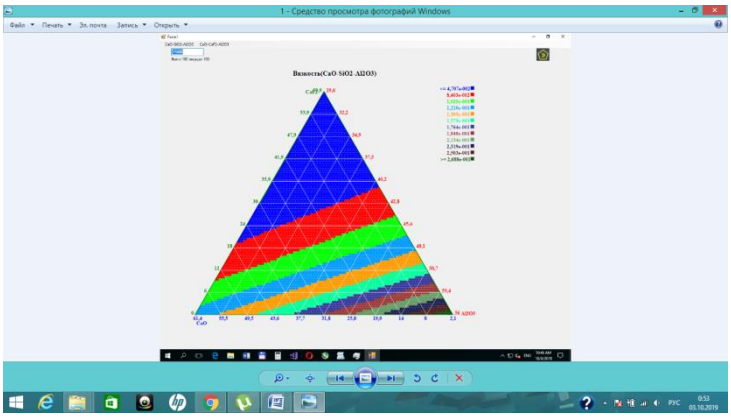

Figure 1 – Triple system viscosity chart CaO-Al_2O_3-SiO_2 at 1500ºC

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MODERN TECHNOLOGICAL ROUTE OF PRODUCTION OF QUALITY IRON CARBON INTERMEDIATE PRODUCTS IN THE RAW MATERIALS AND ENERGY CONDITIONS OF UKRAINE

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The modern technological route of production of high-quality iron-carbon intermediates involves the smelting of cast iron in blast furnaces with the focus on maximum productivity without restrictions on the chemical composition of the final product. Further extra-desulfurization of cast iron, which can be implemented in accordance with one of the three applicable worldwide schemes of cast iron desulphurisation: KR process; mono-injection of magnesium metal; co-injection of magnesium and lime based mixtures. The process of obtaining high-quality iron-carbon intermediate can be carried out with two fundamentally possible technologies: duplex processing process - sequential refining of cast iron in two converters and smelting process in one converter.

The analysis of energy consumption at different stages of metallurgical production shows that the largest amount of energy is consumed by sintering production. The main task in the technological chain of production has become "blast furnace - oxygen converter" is to create favorable conditions for resource and energy saving.

The involvement of metallurgical waste in sintering, as well as the partial replacement of natural gas with coal dust and the reduction of the requirements for the chemical composition of pig iron give rise to a significant reduction in the cost of pig iron production.

Analysis of the use in the smelting process of pig iron with partial replacement of coke with coal dust and partial replacement of raw materials by metallurgical waste in combination with the increase of blast furnace productivity showed that there may be an increase in the content of pig iron in the iron and subsequent conversion temperature of cast iron.

When choosing the option of iron desulfurization technology, it is necessary to take into account the conditions of implementation of the technology and the cost of its implementation. Comparative analysis of the cost of pig iron desulfurization by various reagents and methods shows that the technology of iron desulphurization developed by the ISI NASU, magnesium dispersed injected into the melt through the immersed lance of, is accompanied by a high degree of utilization of magnesium, the least heat loss the minimum consumption of the reagent for processing.

To solve the problem of removing phosphorus from metal in oxygen converters was developed double-circuit lance of a fundamentally new design, which is provided with a system of independent supply of basic and additional oxygen, which is regulated with the possibility of replacing it with nitrogen in the desired melting periods.

The lance of this design allows the formation of a highly basic ferrous slag on the bath surface. The presence of such slag in combination with a relatively low metal temperature (about 1400 ^{0}C) allows even at high carbon content in the metal (up to 2%) to carry out the process of dephosphorylation of the metal melt.

Creating end-to-end technology for the production of high-quality competitive metal products in modern conditions poses the task of optimizing the multi-chain chain of metal production. In solving this problem a significant role belongs to the development of information-modeling system of analysis and decision-making to choose the optimal scheme of technology,

which will, depending on the conditions of metal smelting and quality requirements are ready to recommend the most economical version of production technology.

Information bases that provide the solution to this problem are databases of fundamental, technological and regulatory background. The unified methodology for creating modular model modifications allows them to be extended in the process of algorithm development and to generate models of metallurgical processes into a single end-to-end model in order to organize an optimal scheme of metal production of a given quality with minimal energy and raw material costs.

Electrometallurgy

DETERMINATION OF CONTROLLED TRANSMISSION PARAMETERS BY SIMULATION OF TEMPERATURE DISTRIBUTION AT THE END OF THE TAPE ELECTRODE

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The calculation determines the dependence of the temperature distribution in the radius of the tape electrode. The problem of forming a welding bath when welding under a flux by tape electrode depends on the distribution of thermal energy across the width of the seam, that affects the quality of the welded products.

To determine the optimum melting parameters of the electrode metal, it is necessary to determine its dependence on the time of formation of the electrode metal droplet. Given the complexity of the experimental determination of droplet formation parameters, it is more appropriate to obtain these conditions on the basis of analytical dependencies.

The metal drop at the end of the electrode during the combustion of the arc is under the action of forces, the main are surface tension, electrodynamic force created by welding current, gravity, reactive force caused by the pressure of gas flows and vapors of metal, the pressure of the flow of charged particles.

The dependence was obtained, that allows to describe in detail the temperature distribution at the electrode radius:

$$T(x,t) = T_{пл} \exp\left(-\frac{\eta_э UI}{\lambda S T_{пл}}\right) x \cdot \exp\left(\frac{\eta_э UI}{\lambda S T_{пл}}\left(\frac{\eta_э UI}{\lambda S T_{пл}} a - V\right) t\right)$$

$T(x,t)$ – temperature of electrode in point x at the moment t, °C;
λ – coefficient of thermal conductivity of the electrode material, J/m·sec;
a - coefficient of thermal conductivity, m^2/sec;
$T_{пл}$ – melting temperature, °C;
η = 0,2;
S – cross cection, m^2;
V - electrode feed rate, m/sec.

Liquid metal accumulates at the end of the fusible electrode. The radius of curvature of the surface of the liquid metal is constantly changing. It is known that the excess pressure in a fluid created by surface tension is maximum with a minimum radius of curvature. That is, the maximum pressure due to surface tension forces occurs at the moment when the liquid part of the metal ends in a hemisphere. Electrodynamic force overcomes the force of surface tension, the neck forms, the molten metal squeezes out and separates from the end of the electrode. However, the residence time of the molten metal at the end of the electrode to a certain point leads to significant overheating of the metal, that in some cases is undesirable.

In the process of melting the tape electrode, the drop moves with the arc and accumulates thermal energy, transferring it to the welding bath at the moment of short circuit.

The results of the calculation showed that it makes no sense to consider the nature of the temperature field distribution after 0.1 s, because the electrode temperature at point x at time 0.12 sec reaches more than 2000 ° C for Св08А and more than 4000 ° C for tape electrode Х18Н10Т.

Thus, when melting the tape electrode the volume of liquid metal required to form a drop is formed depending on the thermophysical properties of the tape material and the parameters of the

surfacing mode in the time interval of 0.01 - 0.1 s. It means that in order to determine the optimal mode of forced transfer of an electrode metal when surfacing under flux with a tape electrode, it is necessary to study the frequency range of oscillations of the end of the tape electrode 10 - 100 Hz.

NEW CARBON MATERIALS FOR THE PRODUCTION OF ELECTRODE MASS AND SMELTING OF MANGANESE FERROALLOYS IN ELECTRIC FURNACES

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Self-baking electrodes are the most important structural element of high-power ore-reducing electric furnaces; technical and economic indicators of smelting ferroalloys depend on their reliable operation. The reliability of the electrodes, in turn, depends both on the operating conditions and on the physico-mechanical characteristics of the electrode mass, in particular, on thermal stability.

The report informs on the study and improvement of the technological scheme for the production of electrode mass in the conditions of the electrode mass workshop of the Nikopol Ferroalloy Plant. Despite the decrease in the quality of the feedstock used for the manufacture of electrode masses, the technology allows for reliable trouble-free operation of self-firing electrodes of large cross sections (2800 × 650 and a diameter of 2000 mm). It is shown that the use of artificial graphite and graphite-containing materials in a charge significantly improves its quality and allows one to increase thermal conductivity and reduce electrical resistivity.

Developed, manufactured pilot (5-10 tons) and industrial (70-350 tons) batches of electrode masses with a specific electrical resistance of less than 80 μOhm and a mechanical tensile strength of more than 2.2 MPa. The test results of these masses in industrial furnaces of ferroalloy plants for 2-4 months are positive.

The proposed scheme for the use of ferrogas for calcining anthracite will increase the degree of utilization of secondary energy resources and reduce energy consumption.

The report presents the results of studies of the metallurgical properties of special highly reactive carbon reducing agents produced by the Yasinovsky Coke and Chemical Plant and used for smelting ferrosilicon manganese at the Nikopol Ferroalloy Plant. It is shown that the strength of pieces of experimental and conventional reducing agents in the initial size ranges from 233 to 320 kg / sample, while the strength of the samples of experimental coke is 3.4% higher than the base samples.

The values of electrical resistivity (resistivity), measured for all coke samples in the particle size class of 6-3 mm, ranged from 1.05 to 2.10 Ohm · m. The resistivity of experimental coke is on average 1.34 Ohm · m compared to an average resistivity of 1.10 Ohm · m for ordinary coke from the coals of the Donetsk basin. Those, the average value of the electrical resistivity of the samples of the experimental special reducing agent is 11.6% higher compared to the base samples. An experienced reducing agent also has the best reactivity (flammability) indicators.

Thus, the performed set of studies showed higher properties of the experimental special reducing agent for the production of the Yasinovsky Coke and Chemical Plant compared with the standard nut coke. In the Nikopol Ferroalloy Plant, the technology of smelting ferrosilicon manganese using new types of highly reactive reducing agents has been developed, which is characterized by a higher degree of manganese extraction into the alloy with a reduction in energy consumption compared to the use of ordinary coke nut.

NUMERICAL SIMULATION OF THE FILLING PROCESS IN A CONTINUOUS CASTING-PLASMA METHOD OF OBTAINING A BIMETALLIC STRIP

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In the current volume of global production of equipment that works in conditions of wear, materials with high resistance to thermomechanical fatigue and an extended service life are required. The problem is especially acute in the mining industry, where the equipment operates in conditions of intense abrasive and impact-abrasive wear. One solution is to use bimetallic products, a set of properties which combines as structural and wear-resistant properties (according to materials used). The continuous casting-plasma method for the manufacture of bimetallic structures allows to obtain bimetallic strips, which are used to increase the wear resistance of buckets and truck bodies for mining and earthmoving equipment.

The principle of the method consists in preheating the workpiece to the temperatures necessary for diffusion connection, followed by pouring liquid melt on the treated surface and cooling the strip in the mold. The melt is poured onto the substrate in two stages:

1. Start: initial free filling of the internal cavity with liquid metal without movement of the workpiece;

2. Operating mode: filling of the free volume which is formed as the movement of a bimetallic strip in the process (characterized by a constant flow of liquid metal depending on the linear speed of the workpiece and the dimensions of the deposited layer).

Earlier research was conducted on the first stage of casting (start), where it was found that when carrying out the process without preheating the workpiece, it is impossible to obtain a diffusion joint at the steel-cast iron interface. To ensure the connection of the substrate with the molten melt, preliminary heating to temperatures T> 800 ° C is required. The optimal design of the casting device with the presence of a zone that reduces the distance from the processing section of the workpiece by the plasma source to the area of primary contact with the liquid melt is selected. [1]

By means of numerical simulations based on the data obtained was the study of the casting process at the second stage. The operating mode is a stationary process in which the heat loss of the investigated system is constant.

The zones of the greatest heat loss, which are the cause of premature crystallization of the metal in the casting device, are determined, which in turn leads to an emergency and a shutdown of the casting process. The reasons are analyzed and methods for reducing heat losses as applied to the existing design are implemented. The optimal size of the hole for feeding the melt into the casting device, the pouring temperature of the molten metal, the thickness of the heat-insulating layer between the crystallizer and the casting device and the feed rate of the billet, which ensure a stable process, are determined.

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Technologies for the treatment of cast iron and steel

CRITERIA AND MODELS FOR THE ASSESSMENT OF THE EFFICIENCY OF IMPLEMENTATION OF ALLOYS AND REFINING ADDITIVES FOR SIDE STEEL PROCESSING

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In global practice, the pressing issue today is the generation and development of innovative technological solutions to improve the quality of metal products, expand the operational capabilities of steels and special-purpose alloys, accompanied by the rational use of energy and raw materials and satisfy the ever-growing needs of consumers. Production of high-quality and high-grade grades of steels by the content of harmful impurities (sulfur and phosphorus), proving the chemical composition by the methods of introduction of special refining, modifying, alloying additives, slag-forming mixtures is most effectively achieved at the stage of its treatment). Technological control of the complex of physicochemical properties of steel by methods of mathematical modeling and development of quality criteria is an important link in the steelmaking and foundry production, since the kinetics of reactions and the degree of heterogeneity of the physicochemical system are limited by temperature, melting rate, density of interacting components. For successful reactions of metal-to-slag reactions and directional formation of the required properties of them in the production of high-alloy and special steels and alloys, operational forecast models, which in real time describe the metal-slag-additive system and are integrated into the ACTS, are important. Previously, we have developed models for prediction of melting and crystallization temperatures, densities of one-component melts, iron-carbon, chromium-nickel steels, high-alloy nickel alloys, aluminum and magnesium alloys with high prediction accuracy and taking into account their individual features, based on experimental parameters, based on experimental parameters interatomic interactions that characterize the chemical and structural state of the systems under study. The models were tested by comparison with the well-known foreign specialized computer complex JMatPro with the assistance of scientists of Paderborn University (Germany), which confirmed their adequacy for making decisions on the management of the melting temperature. It should be noted that for the sampling of the melting point and crystallization data of the heat-resistant nickel alloys, there is a significant inconsistency of the calculations using the JMatPro program, unlike the proposed models based on the original directional chemical bonding concept.

A macro scheme of a throughput algorithm for predicting the composition of the final products of melting during their bucket finishing has been developed. On the example of 09G2S steel for the DMC conditions based on the agreed data by material balance methods, the analysis of the distribution of Si and Mn elements during bucket treatment was performed. The similarity of the parameters of influence on the distribution of both silicon and manganese is revealed, which is related to their proximity in the structure of clusters of one-component melts - microhomogeneity. As a result of the analysis, adequate models were obtained for the basic thermodynamic distribution functions of Si and Mn depending on the integral parameters of the chemical composition of steel, slag and additives, which characterize their chemical activity in the form: LSi, LMn = f (input parameters of metal, slag, additives and technology). As a criterion for the choice of rational alloying and refining additives, we propose ρl, which allows one to structure one-component metal melts and to choose the most successful chemical composition of additives based on revealed patterns. The results of the research are recommended for industrial use in order to make a scientifically sound choice of alloying additives and directional molding of the final product, which will reduce energy costs through the integration of the developed models in ACMT steel production.

RESEARCH OF EFFICIENCY OF MASS-TRANSFER PROCESSES WHILE BLOWING IN TEEMING LADLE

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Blowing of metal with inert gases is a necessary stage of steel production at modern metallurgical enterprises. It is used as a component of the technological cycle of production of high quality steel in BOF with combined blowing, while ladle treatment in LF and while vacuum treatment, and as a single operation for melts refining. Blowing of the metal with inert gases significantly affects the physical and chemical processes occurring in the liquid metal melt, improves the removal of non-metallic inclusions, gases and increases the homogeneity of the melt in chemical composition and temperature.

In order to determine the influence of the design of the bottom blowing block on the efficiency of mass transfer processes in the bath of teeming ladle, a low-temperature modelling of metal melt homogenization during neutral gas blowing has been carried out. Homogenization time was taken as the objective function that determines the effectiveness of the process.

According to the simulation results, it has been approved the self-similarity of the dimensionless homogenization time during blowing through the bottom block for the characteristic size of the flow area more than 1 mm. It has been determined that the most effective design of the bubbler of the bottom device for melts blowing is the use of non-oriented porosity materials. Their use allows obtaining a stable column of small bubbles, thereby reducing the homogenization time by 14%.

IMPROVEMENT OF MELTS ALLOYING PROCESS IN MODERN METALLURGICAL INDUSTRY

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Metal alloying is a necessary stage of steel production in modern metallurgical enterprises. It is used as a stage of the technological cycle of high quality metal production in BOF, while metal processing in LF and VD.

The steel production process is based on the oxidation of excess impurity content. It is achieved by the oxidizers adding into the melt (gaseous oxygen or solid oxidizers such as iron ore or manganese ore). At the end of the smelting, the total oxygen content of the steel consists of dissolved oxygen in the melt and associated oxide inclusions that have not been released from the melt.

In modern conditions, alloying process is carried out in several stages. About 30-50% of the alloying elements are added into the steel at the stage of smelting in the form of oxide compounds. About 30-40% of alloys are added into the steel while tapping after deoxidation. The final correction of the chemical composition of the liquid steel is carried out by wire processing in LF.

In order to increase the resource and energy efficiency of the steel alloying process, it is proposed steel alloying in mould by adding alloying elements in the pre-crystallization period.

TO THE METHOD OF CALCULATION THE POWER OF BATH MIXING IN OUT OF FURNACE MELT TREATMENT

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Despite the considerable amount of works subjected on the bath mixing, today there is insufficient data regarding the question of what proportion of energy supplied to the bath goes to the mixing, and dissipates. Numerous empirical expressions was proposed by the authors of numerical studies to evaluate the melt mixing power and magnitude of energy dissipation. The variety is due to the specific conditions of supply of gas, gas and powder streams, formation of bubbles of different shapes and sizes, their flooding to the surface of the bath, etc., that are inherent in a particular system (or unit). At the same time, the use of the proposed expressions for the conditions of mixing the melt in the ladle, taking into account the integrated effect of gas jets and bubbles that float to the surface of the bath, requires a balanced approach. The authors take into account gas consumption, temperature and mass of the melt, the depth of gas penetration into the bath, but the results in one case refer to the mixing power and in the other to dissipated energy, that complicates the comparison of the calculation results. Almost all expressions do not take into account the size of the bubbles that are formed during the destruction of gas jets, or formed as a result of reactions. This is due to the assumption that the bubbles formed are about the same size. The conditions of their grinding, isothermal expansion of the bubbles of the non-assimilated bath gas carrier, change of the total reaction surface of the bubbles under different conditions of their formation and forms don't take into account.

According to the results of experiments on the study of hydrodynamics of the bath in the ladle, using the injection of gases and reagents through the nozzle of a rotating submersible lance, it was established that the best dispersion in the volume of gas bubbles is provided at a rotational speed not exceeding 2.17 $sec.^{-1}$, at specific gas consumption up to 0.018 m^3/min. With further increase in lance rotation speed and specific gas consumption, the intensity of formation of large bubbles prevails over the crushing forces and large mushroom bubbles emerge to the surface of the bath, that in real conditions of treatment can lead to a decrease in the rate of absorption of the reagent. At the same time, the volume of powder free zones (so-called "dead" zones), when using a rotating lance with two nozzles, did not exceed 10-15% of the total volume of the bath. For conditions of use of a stationary lance with one and two nozzles, it was 40-55%. But the distribution of the powder reagent by volume of the bath depends largely on the intensity of mixing.

The authors established that as the speed of the submersible lance increases, the gas saturation of the bath decreases (with the transition to "channel" mode and the size of the bubbling zone is limited). This affects both the mixing power and all the processes that accompany a gas blowing. Grinding of gas bubbles in the bath occurs in both laminar and turbulent flow due to the interaction between the solid and dispersed phases. The movement of gas or gas-jet jets immersed in the bath when using a rotating lance contributes to the change in the relationship between inertial and surface tension forces. To account the rotation of the submersible lance, it is necessary to determine the amount of dissipated energy of the gas jet, that depends on the length of the jet and the speed of rotation of the lance. It was established, that using a two-nozzle submersible lance with nozzles located at an angle of 90^o to the lance axis, the length of the jets decreases, respectively, by increasing the lance rotation speed from 0.22 m (at 0.5 rpm) to 0.12 m (at 1.5 rpm). The current study proposes a method for determining the power of melt mixing in the ladle, taking into account the change in size, number, bubble velocity as a function of the speed of rotation of the submersible lance.

It was determined that the amount of dissipated energy of the jet is proportional to the size of the bubbling zone and increases with the speed of rotation of the lance. To increase the mixing capacity of the liquid bath, a prerequisite is to increase the size of the bubbles, that can adversely

affect the degree of absorption of reagents to remove impurities during the ladle refining of cast iron. Combination of the use of mechanical agitation with the additional dispersion of gas volumes during the rotation of the lance may be combined with increasing the intensity of mixing. Under these conditions, the intensity of mass transfer processes in the bucket bath should be expected.

RESEARCH OF THE REGULARITIES OF MASS-EXCHANGE BETWEEN SLAG AND LADLE BATH IN THE CONDITIONS OF BLOWING INTENSIFICATION

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The content of iron drops in the slag, that download from the surface of the bath after the refining of the melts, largely determines the specific costs of implementing the technology. The presents of iron in the form of drops of various shapes and fractions in the volume of slag, the mass during the course of desulphurisation by co-injection technology (for example, installation of desulfurization of the converter shop of PJSC "DMK"), doubles, leads to direct losses of processing.

Methods of investigation of slag-metal volumes (hereinafter referred to as slag), formed during the injection of a mixture of lime and magnesium (with a ratio of CaO to Mg for various ladles from 2.3:1 to 5.2:1), consisted of the following steps. The selected slag samples were crushed to separate the slag from the metal part. The metal part (iron drops), using a set of laboratory sieves, was separated into fractions <0.5; 0.5… 1.0; 1.0… 2.5; 2.5… 5.0; 5.0… 10.0 and> 10 mm.

It is determined that the ratio of characteristic groups by the diameters of the drops is: 0.5… 2.5 mm - 10…16%; 6…8 mm - 10… 20%; > 10mm - 30… 45%. After the distribution of the metal drops by fractions with determination of their weight, the chemical composition of each fraction (carbon, phosphorus and sulfur content) was determined.

It was confirmed, as in previous and other studies by other authors, that slag formed during the desulphurization of pig iron by injection of a mixture of magnesium and lime, in most cases, consists of unused lime, graphite, iron scraps and residual mixer slag. The losses of cast iron with additionally formed slag during the studied period amounted to 1.89… 2.64 kg / t of cast iron.

It is established that the sulfur content in iron drops when using a mixture of CaO with magnesium, in general, increased compared to the use of technology of magnesium injection without additives.

An expression is proposed to determine the effect of the diameter of the drops on the final sulfur content for the conditions of co-injection technology of injection of the mixture at the installation of a cast iron finishing of the PJSC “DMC” converter shop.

The inheritance of the desulfurization mechanism, the mechanisms of the iron droplets falling into the slag and the flow of mass transfer processes between the slag and the ladle bath, the regularities of removing the surfactant sulfur from the metal drops during its present and movement in the liquid slag bath, confirmed by the trend of decreasing sulfur content in the metal drops with increasing of its diameter.

PECULIARITIES OF WAVING IN A LADLE WITH A SUBMERSIBLE ROTATING LANCE

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The determination of the patterns and features of the formation of waves on the surface of the covering slag during the injection of gas through the nozzles of submersible stationary and rotating lance was performed using the method of full factor experiment on a cold model of large scale ladle. Water (20^oC) was used to model the metal melt, compressor air was used for carrier gas (X1), and a layer of synthetic engine oil (6…30 thick, (X_2)) was used to simulate a layer of coating slag formed in the course of the injection of a mixture of reagents (lime and magnesium). One- and two-nozzle tips of submersible lance with cylinder nozzles with a diameter of 0.0013 and 0.001 mm, respectively, were used. The rotation speed of the tip of the submersible lance around the vertical axis (X3) was varied from 0 to 240 rpm.

The results of the coinjection technology of ladle desulphurisation of the converter shop of PJSC “DMK” were used as the initial data for modeling. The influence of specific costs and fluctuations of carrier gas pressure, level of filling of ladle with melt, level of slag, design of tip of the submersible lance, speed of its rotation and depth of immersion in the bath on the amplitude of oscillations and height of “swirl” on the surface of the bath are investigated.

After conversion to natural values, mathematical models were obtained to determine the influence of the investigated factors.

Mathematical models were obtained to determine the dependence of the “swirl” height (H) on the surface of the bath from the influence factors. So, for example, for a single-nozzle submersible lance in the range of its speed from 120 to 240 rpm:

$$H_1 = 1.3888 - 0.00044 \cdot X_1 - 0.1178 \cdot X_2 - 0.0628 \cdot X_3 + 0.00001 \cdot X_1 \cdot X_2 + \\ +0.00158 \cdot X_1 \cdot X_3 + 0.2425 \cdot X_2 \cdot X_3 - 0.00148 \cdot X_1 \cdot X_2 \cdot X_3$$

For 2-nozzles lance respectively:

$$H_2 = 0.858 + 0.0041 \cdot X_1 - 0.0413 \cdot X_2 + 0.167 \cdot X_3 - 0.001 \cdot X_1 \cdot X_2 - \\ -0.00072 \cdot X_1 \cdot X_3 + 0.000625 \cdot X_1 \cdot X_2 \cdot X_3$$

According to the results of processing the obtained experimental data, the conditions for the organization of a rational blowing mode for the injection of a mixture of reagents into the depth of the bath, deviation from that promotes the ejection of slag-metal mass outside the ladle, forming a "breakthrough" mode of blowing the bath, leads to an increase in the amplitude of its fluctuations and “swirl” height on the surface.

To ensure the rational modes of ladle desulphurization of cast iron, reducing the specific consumption of magnesium and increasing the degree of its use in the conditions of co-injection of reagents, it is advisable to consider:

1. Maximizing the dispersion of reagent injection zones into the bath, increasing the volume of bubbling zones, including by rotating the tip of the submersible lance around the vertical axis.
2. Provision of the maximum possible, in these conditions, the flow of carrier gas and the mixture of reagents, the level of the slag and its fluidity.

USE OF CENTRIFUGAL FORCES FOR REMOVAL OF NONMETALLIC INCLUSIONS IN TUNDISH OF CONTINUOUS CASTING MACHINE

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It is known that nonmetallic inclusions (NI) in solid steel significantly decrease mechanical properties and occasionally even corrosion stability. There are such methods of nonmetallic inclusions removal as an inert gas blowing, modifying for improving their coagulation and coalescence, electromagnetic stirring, etc. The Japanese scientists have developed a technology of NI removal in inlet chamber of tundish by means of centrifugal forces which are created by the electromagnetic stirrer. This method, however, significantly increases cost of casting process due to the use of the additional equipment and change of a tundish design.

At the same time it is possible to create the centrifugal forces in inlet chamber of tundish by cheaper methods. It is suggested to use the kinetic energy of liquid steel flowing out of teeming ladle. For its most effective use, liquid metal should be directed in tundish tangentially under metal level, and a protective pipe should be installed not along an axis of the inlet chamber, but near the tundish wall. In this case the metal would flow along the chamber walls, initiating rotary motion of liquid in the inlet chamber. NI would move in the direction of a chamber axis.

The plan of researches has been developed for confirmation of efficiency of the suggested method. At the first stage it is necessary to determine by method of physical modeling the velocity of rotary motion of liquid necessary for removal of NI of certain sizes. At the second stage it is necessary to determine by the same method conditions leading of a stream for achievement of the velocity determined at the first stage. At the last stage of researches it is necessary to simulate precisely casting process on transparent model of tundish for determination of resident time of metal stay in chamber and to confirm an efficiency of NI removal by the suggested method.

RESEARCH DYNAMICS OF SURFACE WAVES IN INJECTION MELTING MELT REFINING IN LADLE

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The intensification of the processes of ladle refining of pig iron by injection methods is limited by the turbulence of the process of wave formation on the surface of the bath, the extreme degree of that leads to the melt overflow from the ladle. Therefore, the results of theoretical and experimental studies of wave dynamics on the open surface of the melt in the ladle are presented in this work when processing it by injection method through an immersed lance. The process of refining of cast iron with granular magnesium was taken as the basis. The purpose of the paper was to evaluate the influence on the dynamics of the process of wave formation of key factors, its significance and the relationship with each other.

The main possible sources of excitation of the upper layer of the liquid bath can be the following processes: the slamming of bubbles on the surface, vibration of the lance, separation of bubbles in the adjacent zone, bubble bursting, hydrodynamic flows in the volume of liquid baths, etc., which have different amplitude characteristics.

For the purpose of theoretical studies, a mathematical model was developed, where the fundamental assumption was to represent the volume of a liquid melt in the form of an oscillating layer, such as a pendulum, that is in the same system with the oscillator. Such a statement does not fully reveal the process of interaction, but at the overall physical level it shows important details of the development of the motion of the oscillatory system under consideration.

In addition, experimental studies were performed on a cold oscillation model of a freely suspended steel rod immersed in a fluid in a rocking vessel. The length of the pendulum was chosen so that the frequency of its oscillation in the quiescent fluid was consciously smaller, or was in the middle of the range of oscillation frequencies of the preset vessel.

On the basis of calculation-analytical and experimental studies of pendulum oscillations a system consisting of a layer of liquid and lance is considered. It is established that in addition to the natural frequencies of these elements, the system has two other eigenvalues. Given that the mass of the melt is much greater than the mass of lance or other pathogen, the frequency close to the resonant frequency of the bath, almost determines the behavior of the system when stir. That is, the system responds only to excitations in which the frequency is close to the natural frequency of the liquid bath. This important result suggests that in practice, it is necessary to know the resonant frequencies of a liquid bath, a lance device and all other sources of oscillation, accordingly, to try to damp the amplitude with this dangerous frequency. This can be done both constructively and technologically by changing the blowing modes. However, it should be noted that the frequency spectrum of the oscillation zone is quite wide and, of course, contains dangerous low frequencies.

INCREASING THE EFFICIENCY OF APPLICATION OF THE PROCESS HOT METAL DESULPHURIZATION IN LADLES

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At metallurgical plants in Ukraine (as in foreign practice), 2 types of cast iron ladle desulfurization technologies are used - co-injection with ground lime mixed with magnesium and mono-injection of granular magnesium (without diluting additives). The applied technologies for co-injection of mixtures of lime with magnesium are characterized by significant costs of very high-quality lime and magnesium, which in the end is accompanied by very significant costs - more than 5-6 dollars / ton of cast iron. In connection with the above, the Institute of Ferrous Metallurgy (HMI, Dnipro) carries out a series of research and development aimed at improving the technical and economic indicators of iron desulfurization processes both by mono-injection of magnesium and using lime.

HMI studies (based on industrial conditions) showed that with magnesium mono-injection, the main parameters for ensuring fast and economical desulfurization of cast iron are:

1. Fractional-dispersed composition of granular magnesium.
2. The concentration of magnesium in the injecting gas in the zone of the two-phase flow from the lance channel to the molten iron.
3. The flow rate of the injecting gas and its speed at the exit of the lance.
4. The state and level of dispersion of the two-phase flow flowing out from the lance in the zone of its flow into the melt.

The Ukrainian process of desulfurization of cast iron by granular magnesium (without diluting additives) stably remains the least costly and most effective in comparison with other technologies. Recent developments have shown that the main parameters for increasing the efficiency of the process by mono-injection of granular magnesium are the maximum concentration of magnesium and its partial pressure in the zone of flow outflow from the lance and mass transfer with the melt. In the current process of mono-injection of magnesium, the concentration of magnesium in the gas is brought up to 23–28 kg / m3. This allows you to ensure the actual magnesium content in cast iron is more than equilibrium. This eliminates the process of returning sulfur to cast iron after desulfurization. This provides the possibility of further saturation of cast iron with magnesium due to the fact that [Mg] sat. □□ [Mg] fact. Desulfurized pig iron after mono-injection of magnesium and downloading of slag is poured into a converter and part into casting

machines to obtain a wide range of metal products. Subject to all the operations for preparing cast iron for conversion, the sulfur content in the finished steel is almost the same as with other desulfurization technologies. In some cases, with magnesium desulfurization, the physicochemical properties of ladle slag are adjusted by adding 1–1.5 kg / cast iron, waste materials, or other non-deficient additives to the ladle.

When blowing powdered reagents, including ground lime and mixtures based on it, the situation in the lance zone differs from the process of blowing granular magnesium, since very small particles of lime (based on less than 0.1 mm) are not able to penetrate the melt and, as it were, periodic accumulation of powder occurs, which is uncontrollable come off and float in the melt.

In such adverse conditions, it is necessary to organize the crushing of large accumulations of reagents in the lance zone and to ensure the coordination of the processes for supplying the desulfurizing reagent and "fresh" portions of cast iron to the mass transfer zone.

The solution to the first problem was solved in 2 options:

1 - blowing lime with natural gas.

2 - introduction of 5–10% soda ash (Na2CO3) into the mixture.

In both cases, additional gas and vaporization contributes to the rupture and crushing of the accumulations of powder in the lance zone. Checking the above proposals on industrial ladles of various sizes showed that the addition of soda to the blown lime (5–10% in the mixture) increases the degree of desulfurization of cast iron by 10–17% absolute. The use of natural gas instead of dried air or nitrogen for blowing lime also increases the efficiency of desulfurization, increasing the degree by 10–25%.

The next improvement in the technology of pig iron desulfurization with CaO based reagents was realized due to fundamental changes in thermodynamics due to the transfer from the old CaO interaction scheme with the participation of Si cast iron to CaO interaction with Al introduced from outside. The implementation of the new scheme is accompanied by an increase in the Gibbs energy change (under the temperature conditions of ladle refining of cast iron) by almost 3 times. This predetermines more favorable conditions for the removal of sulfur from cast iron. Purging of cast iron with lime in blast furnaces with preliminary introduction of aluminum (0.5–0.6 kg / t of cast iron) confirmed the effectiveness of using Al both for blowing with dried air and for blowing with natural gas. According to the results of industrial purges of cast iron in 110-ton buckets, it was shown that the introduction of aluminum into cast iron doubles the degree of desulfurization, and the introduction of Al and the use of natural gas St.D increases from 20 to 70%.

The combined use of all the proposed improvements (preliminary introduction of Al, injection of lime with the addition of soda and the use of natural gas as a carrier) significantly increases the desulfurization ability of the technology with very low sulfur content (up to □ 0.002–0.005%) and reduce the consumption of reagent. Given the actual results obtained, it can be predicted that the specific consumption of reagents will be on average 50-60% less than those obtained at the Alchevsk Iron and Steel Works.

The above improvements of pig iron desulfurization processes with various reagents can significantly improve the economics of processes and their competitiveness.

Modeling and optimization of technological processes

MATHEMATICAL MODELING AT CREATION OF AUTOMATIC PROCESS CONTROL SYSTEM OF GAS EXHAUST DUCTS OF STEEL MELTING CONVERTERS

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Over the past 12 years SE "UkrRTC "Energostal" (hereinafter referred to as the Center) developed, manufactured, supplied and commissioned at 6 metallurgical plants in Ukraine and CIS countries 19 gas exhaust ducts of converters (GED C) with a capacity from 160 to 320 tons with a "wet" gas cleaning, having the same or better operational parameters than similar products of leading foreign companies.

To debug the software and algorithmic support of the automatic process control system of the GED C at the stands of the developer in regular situations and taking into account possible malfunctions, the Center has developed and uses a mathematical model of the processes in the GED C, which allows to improve the quality of the software of the automatic process control system of the GED C and to reduce the time to adapt the software to specific conditions during Start-up works at the Customer.

On the basis of the mathematical model of GED C processes for training and periodic training of operators of GED C boiler, a prototype of the "boiler operator simulator" was developed and implemented on two PCs, using thestock software for automatic process control system of GED C.

DEVELOPMENT OF A SOFTWARE PRODUCT FOR SOLVING THE ONE-DIMENSIONAL QUASILINEAR HEAT CONDUCTION EQUATION

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An infinite continuous steel cylinder of radius R is considered. The temperature field *T(x, y, z, t)* is assumed in the cylinder region, which is assumed to be symmetric about the Oz axis. At the initial time, the lateral surface of the cylinder is instantly cooled to a certain temperature, it is necessary to determine the temperature distribution *T(r, t)* inside the cylinder at any time *t> 0.*

Typical in thermophysical studies is a situation where the thermophysical properties depend not only on *x, y, z, t* but also on the temperature *T*, in this case, we obtain a quasi-linear heat conduction equation:

$$c(T)\rho(\mathrm{T})\frac{\partial T}{\partial t}=\frac{1}{r}\frac{\partial}{\partial r}\left(rk(T)\frac{\partial T}{\partial r}\right)+f(r,t,T),\ (t>0;\ 0<r<R) \qquad (1)$$

Here *T* is the temperature that depends on the spatial coordinate *x* and time *t*, *k* is the heat conductivity of the body, *c* is the specific heat, *ρ* is the density of the medium, *f(x, y, T)* is a known function that describes the density of thermal sources in the cylinder.

The solution of the differential equation (1) must satisfy the following additional conditions.

The initial condition:

$$T(x,0)=f_1(x),\ 0\le x\le 1, \qquad (2)$$

where $f_1(x)$ is known function in the interval $0\le x\le 1$ while $t=0$.

Two boundary conditions:

$$T(1,t) = f_2(t), \quad 0 \le t \le t_{\max}. \tag{3}$$

$$\left.\frac{\partial T(x,t)}{\partial x}\right|_{x=0} = f_3(t). \tag{4}$$

Here $f_2(t)$, $f_3(t)$ are known functions in the interval $0 \le t \le t_{\max}$.

There is a problem with rounding errors when you approach the task on a computer. To reduce the effect of rounding errors on the accuracy of the approximate solution, the transformation to dimensionless variables was made. The transition to dimensionless variables begins with the choice of values to be scaled. Scale factors were selected and the transformation to dimensionless variables for temperature, spatial coordinate, time coordinate, and thermophysical coefficients was made.

Thermal-physical coefficients of steel depend on temperature, but this dependence is established only experimentally. To obtain the values of the physical properties of the steel at any temperature, the method of least squares was used to obtain the density, heat conductivity, and specific heat dependences on the temperature in analytical form, these dependencies were used to find dimensionless coefficients of the physical properties of the steel.

The math problem (1) – (4) is solved by the net-point method using the explicit template. The computer program is developed in C# language for the numerical implementation of net-point method algorithms in the software development environment MS Visual Studio 2017. The program is verified in a test case, the results are expected.

TOWARDS THE DEVELOPMENT OF "METALLURGY" DATA BANK

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Created at the Iron and Steel Institute (ISI NASU) databases of slag melts have been functioning and developing for a long time (since 1987). Database management is based on the ideological basis of the ASPID family [1].

Database software " Metallurgy" has passed the path of functioning from the EU computer to the latest generation of personal computers. Thus for each of them it was necessary to develop the software complex. Each generation of computers forced to modify applications to adapt to the new environment and to deepen and extend the capabilities of the customer service.

Personal computers have dramatically changed the capabilities of both the system software and the shortening of application development times. The development of new programming languages (C #) and new debugging tools, that significantly allowed small-scale development.

To create a database "Metallurgy", the concept of storing information close to the original was proposed, that allowed to create retrospective databases and not change the type of stored documents.

For factual data of the document, the question of formalization of the description is somewhat complicated, that is connected both with the retrospective of its creation and with the coding of some characteristics. Some units were described differently (for example, Ci - Pa. C, CGC-poise). In this regard, there is a need to programmatically implement such features and display search results in one unit. To do this, you need to create a meta information, stored in the database.

Since users often store their information in different file types, to create a base, the "Create Base" program uses a formalized structure in Word files. Therefore, in order to dock with the database creation tools, it is necessary in each case to develop software for formalization and conversion from a user file to Word files.

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CONTINUOUS RENT INFORMATION SUPPORT IN THE SIX-YEAR GROUP

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For the first time, a computer model of the dynamics of filling, rolling and releasing a strip of a six-unit group was developed. The equations in the stand, drive line and strip are recorded in absolute terms. An algorithm for the transport delay of the transfer of strip thickness between stands is implemented. Using the model, we established the laws of the formation of interstand tension and strip thickness in the indicated modes and depending on the deviation of the thickness $\pm\Delta H_o$ and the temperature $\pm\Delta T°C$ of the strip at the entrance to the group, the rolling speed $\pm\Delta v$. Quantitative ratios are obtained.

The computer program is also intended for information support of continuous rolling. For example, due to the delay in supplying the peal, its temperature decreased by $\Delta T°C$ while the group was set to the nominal temperature $T_н°C$. At $\delta T = \pm\Delta T°C$ / $T_н°C = -1$ %, the interstand stresses increase by 1,2 – 2,3 times (depending on the gap) relative to the nominal tension. At the same time, the relative thickness difference $\delta h = \Delta h/h$ of the finished strip with a thickness h decreases by 3 times. Using the program, a new deformation-speed regime is calculated, based on which appropriate corrections are made. An increase in strip temperature causes a decrease in tension and an increase in relative thickness difference, which can also be adjusted. Similar dependences were obtained for deviations of the thickness $\pm\Delta H_o$.

A different effect is obtained by the combination of two perturbations $\pm\Delta T°C$ and $\pm\Delta H_o$. So, with the combination of $-\Delta T$ °C and $-\Delta H_o$ or $-\Delta T$ °C and $+\Delta H_o$, the strip thickness difference increases, while the tensions become noticeably smaller compared to the variants $+\Delta T$ °C and $+\Delta H_o$ or $+\Delta T$ °C and $-\Delta H_o$, when the tensions increase significantly and the thickness difference decreases. In the general case, such a combination of numerical values $-\Delta T$ °C and $+\Delta H_o$ is possible, for which there is no thickness difference, i.e. the action of one disturbance is countered by the action of another.

Thus, if the quantitative perturbations ΔT °C and ΔNo are known at the entrance to the continuous group, then using the developed computer model it is possible to adjust the rolling mode and achieve a decrease in interstand tension in order to avoid strip breakage or to increase the rolling accuracy.

DEVELOPMENT OF RESEARCH OF DYNAMIC PROCESSES IN WIDE BAND MILLS

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In the past two decades, active pilot measurements and theoretical studies of vibrodynamic processes in the equipment of stands of broadband hot-rolling mills have been carried out at the HMI. This made it possible to establish a number of new patterns, develop other computer models, and expand research.

1. For the first time, a new direction has been substantiated and developed - the use of transient parameters in order to diagnose the technical condition of equipment and the stability of the rolling process. The following were proposed and tested: - a new diagnostic feature - the delay time of the reaction of sections of the main drive line to the application of the load to the rolls; - Three coefficient of variation (dynamics, statics and their relationship) for the diagnosis of equipment and the rolling process.

2. An empirical correlation dependence of the maximum dynamic load on the static moment has been established and justified. On this basis, a method for monitoring the maximum dynamic loads in the drive lines of stands and a program for their statistical modeling was developed.

3. A mathematical model of the dynamic interaction of a six-unit continuous group is developed when filling, rolling and releasing it with a strip. The difference of the model is that the equations of elastic vibrations in the stand, the drive line and the strip are recorded in absolute values. An algorithm for the transport delay of the transfer of strip thickness between stands is also implemented. The features of the formation of interstand tension and deviations of the strip thickness are established.

4. The mathematical and computer models of rolling the welded joint on a cold strip mill allowed us to study the influence of the weld parameters, technology and equipment on dynamic loads and to search for rational rolling modes.

5. Using a new mathematical model, the dynamics of transients in the axes and gears of the gearbox is disclosed. The model is also intended for diagnostic studies.

6. Experimental rolling was carried out, which showed high efficiency in reducing shock loads when the rolls capture slabs with a curly leading edge.

FORMATION OF METAL IN BLACK CLOSED BEAM CALIBRES

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Theoretical studies of metal shape change in rough beam calibers are presented, which are carried out by finite element method using SIMULIA / ABAQUS software.

Mathematical models of calculation of height (vertical) deformation of open and closed flanges are developed on the basis of three series of theoretical experimental tests on models of rolling H-beam work pieces of steel CT3 at a temperature of 1100 °C.

The height deformation of the flanges was estimated by dimensionless parameters: the coefficients of height deformation of the shelf $\eta_H = H/H'$, open flanges $\eta_{ho} = h_o / h'_o$ and closed flanges $\eta_{hз} = h_з / h'_з$. Absolute values of deformations of the height of the shelves, open and closed flanges: $\Delta H = H - H'$, $\Delta h_o = h'_o - h_o$, $\Delta h_з = h'_з - h_з$. Here H and H' - the height of the shelf, and h_o і h'_o - the height of the open flange, and $h_з$ і $h'_з$ - the height of the closed flange (dimensions with a stroke for the workpiece after rolling). The deformation of the thickness of the profile elements was characterized by the following dimensionless parameters: $\eta_d = d / d'$ - the coefficient of compression of the wall in thickness, and $\eta_{to} = t_O / t'_O$ і $\eta_{tз} = t_з / t'_з$ - the coefficients of lateral compression of the open and closed flanges, respectively, $\eta_t = 0{,}5\left(\eta_{to} + \eta_{tз}\right)$ - the average throughout the caliber of the coefficient of lateral compression of the open and closed flanges. Here

d and d' are the wall thickness, t_o and t'_o are the average thickness of the open flange, $t_з$ and $t'_з$ are the average thickness of the closed flange.

The limits of variation of dimensionless rolling parameters that actively influence the height deformation of shelves and flanges were as follows: $1{,}373 \le \eta_d \le 2{,}371$, $1{,}000 \le \eta_t \le 1{,}305$, $1{,}37 \le B/d \le 6{,}73$ and $0{,}69 \le B/H \le 2{,}34$.

Theoretical analysis of the metal shape change allowed us to evaluate the influence of the main technological factors of rolling - the distribution of the crimps by the profile elements and the shape of the profile on the change in the height of the flanges of the two H-beam work pieces. As a result of the analysis of the distribution of displacements in the cross sections of the profile, graphical dependences of the height deformation of the shelves and flanges on the wall η_d compression ratio, the lateral compression ratio of the flanges η_t and the B profile wall width were constructed.

The mathematical model of metal shape change in the form of the following regression equations is obtained:

$$\eta_H = 0{,}3437 + 0{,}2671 \cdot \eta_d + 0{,}2117 \cdot \eta_t - 0{,}2365 \cdot (B/d) + 0{,}7231 \cdot (B/H),$$

$$\eta_{ho} = 0{,}7300 - 0{,}1151 \cdot \eta_d + 0{,}0572 \cdot \eta_t - 0{,}1341 \cdot (B/d) + 0{,}4290 \cdot (B/H),$$

$$\eta_{hз} = 0{,}1229 + 0{,}0403 \cdot \eta_d + 0{,}5085 \cdot \eta_t - 0{,}2139 \cdot (B/d) + 0{,}6476 \cdot (B/H).$$

It is recommended to use the obtained regression equations in practice in the development of working roll calibrations.

USE OF KNOWN TECHNOLOGICAL SOLUTIONS UNDER CONDITIONS OF MODERN FUNCTIONING OF ENTERPRISES OF BLACK METALLURGY OF UKRAINE

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An uncontrolled increase in the cost of energy and raw materials, a decrease in their quality and environmental problems of the main metallurgical processes characterize the current state of Ukraine's ferrous metallurgy. Obviously, these factors and a number of others determine the direction of the search, physicochemical substantiation and the development of rational technical solutions that will ensure under the current conditions the creation of the most efficient energy resources in terms of specific costs, rational in the balanced use of natural raw materials and effective in terms of solving environmental problems modern technology.

An analysis of the main reasons for the decline in production of pig iron and steel smelting indicates that, due to a number of objective and subjective factors, this trend intensifies, even if there are still sufficiently significant raw material bases and is becoming more and more stable. In our opinion, this led to a significant decrease in steel demand in the domestic market with an increase in the flow of metal products from abroad, increased competition for the sale of metal products in foreign markets and the inability to predict prices for both raw materials and energy carriers. Therefore, under these conditions, the further development and stable functioning of steelmaking, and the industry as a whole, can also be facilitated by the use of "regressive" at first glance technical solutions, which in the recent past during evolutionary development determined the main directions of development and improvement of metallurgical processes .

The results of scientific research are given in which the tasks set by a number of metallurgical plants are solved using "regressive" technological solutions. So, for the conditions of constant increase in prices for iron ore sinter by suppliers, a rational technique is to increase the share of iron ore in their own quarries in a blast furnace charge. In the absence of a sinter factory manufacturer in the structure of the plant, the production at the factories of the sinter supplier based

on iron ores own quarries. To solve the problem of steel scrap deficiency, the rationale and development of a rational scheme for oxygen-converter smelting with an increased proportion of molten iron using a number of smelting coolers is substantiated and developed.

Given the complex nature of the problem facing the metallurgists of Ukraine, an important task that is relevant in modern conditions, the solution of which depends on the efficiency of the metallurgical production as a whole, is the substantiated involvement in the main technological processes of the production of pig iron, steel and ferroalloys of industrial wastes of its own and a number of other industries. The most rational is the use of slag-forming mixtures of various functional purposes based on industrial wastes of metallurgical and other origin, which can be obtained in conditions of their joint heat treatment.

Thus, in the context of increasing the influence of economic factors on the results of the work of metallurgical enterprises, metallurgists must solve problems aimed at finding ways to reduce the cost of production and, accordingly, increase their level of production in order to strengthen their position in foreign markets for metal products. A certain positive contribution of "regressive" at first glance technological solutions developed at earlier stages of the development of metallurgical production is obvious and economically justified in the current conditions of the development of metallurgical technologies.

STUDY OF PECULIARITIES OF DEVELOPMENT OF SHIPPING DEFECTS OF STEEL IN SCCM

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One of the main problems of semi-continuous casting of steel is the yield of a suitable one, the value of which is smaller in comparison with the technology of continuous casting and depends on the shrinkage processes in the main part of the workpiece, which receive a significant development at the final stage of crystallization. In turn, the magnitude and depth of propagation of the shrinkage shell largely depends on the conditions of heat dissipation in the mold.

Investigation of the influence of the cooling intensity of the workpiece in the mold, as well as feeding the main part of it with fresh portions of the melt on the process of formation of the shrinkage sink was made on the physical model of SCCM with the use of paraffin as a model substance. It is established that the shallower sink has the lowest depth at 2.25 l/min during the flow of water to cool the mold and increases linearly to 4.5 l/min. Further increase in the depth of the shrinkage sink at water consumption up to 14 l /min has a complicated curvilinear character, which, apparently, is associated with the formation of a gas gap between the crust of the model substance and the wall of the shell of the mold of the laboratory unit. Moreover, at a flow rate of cooling water of 4.5-9 l/min, the depth of the shrinking shell increases by only 1-1.5 mm (up to 1.5%) and this range can be considered optimal in terms of crystallization time and the formation of the head of the workpiece. The melt topping in all cases has a positive effect on the quality of the semi-continuous cast ingot.

MODELING OF ELECTROMAGNETIC, THERMAL AND HYDRODYNAMIC TRANSFER PROCESSES IN THE METAL WELDING

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It is known from the literature that there are a sufficient number of developed mathematical models of the impact of concentrated energy sources on the metal, including welding. However, they do not cover all existing problems in welding production. Therefore, some features of technologies require improvement and further development of modeling.

Currently, it has become promising to use standard application programs that allow the numerical implementation of certain models. However, their application involves adaptation to a specific process. An actual method of simulation computer research is multiphysical modeling, which makes it possible to conduct a broad and comprehensive study of the phenomena and processes of the studied objects.

With the help of modern software package COMSOL Multiphysics modeling of physical processes of contact spot welding of steel plates S-235JR, which is implemented by numerical finite element methods. This three-dimensional problem was solved using the properties of axial symmetry arising from these technological conditions.

The formulated mathematical model assumes the solution of the given conjugate problem with involvement of three modules of the COMSOL package. The first step is to obtain an estimate of the current density distribution and determine the distribution of the electric and magnetic fields intensity in the volume of the weld pool. The problem is solved with respect to the distribution of the electromagnetic field potential (with initial and boundary conditions).

At the second stage, the thermal state of the welded plates, which are affected by the plasma flow, is determined. The model takes into account phase transitions during melting and evaporation.

Further, the velocity of the metal in the weld pool is calculated on the basis of the hydrodynamic equations. Calculations are carried out taking into account the influence of the Marangoni effect.

The obtained data reflect the investigated differential electrodynamic characteristics of the welding process, namely: vector electric and magnetic potentials, magnetic induction, electric and magnetic field intensity, as well as Lorentz forces.

Calculations of the thermal field in the plates allow us to estimate the nature of the influence of the energy characteristics of the electrodynamic process on the melting of the metal and the formation of the melt bath (size and depth of penetration).

On the basis of hydrodynamic calculations, the velocity field of the liquid metal in the weld pool and the influence of the melt movement on its formation are obtained.

The simulation results allow predicting and making changes in the electrodynamic, thermal, hydrodynamic processes in the area of contact spot welding and manage them.

Automation and modern methods of control of metallurgical processes and quality of metallurgical products

AUTOMATION OF COORDINATED CUTTING MANAGEMENT PROCESSES OF ROLLING ON CONTINUOUS SECTION ROLLING MILLS

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Improving the efficiency of rolling production by improving methods and system of coordinated cutting management in conditions of production of rolled metal, allows to reduce the loss of rolled metal and energy resources on its production.

The results of the analysis of the process of automated cutting management in the conditions of production of a measured rod are presented. As a result of the analysis of the production of billets and core metal, it was found that one of the most important factors that ensure the saving of rolled ferrous metals by minimizing excess waste of production, is its effective cutting. With each cutting operation, losses occur since on the one hand to ensure the productivity, and on the other to ensure the maximum output of measured products. It is shown that metal losses occur both due to cutting errors on the workpiece (± 150mm) and when cutting packages of rods, that is caused by repeated lengths of bars at a given length of the rod and mutual longitudinal displacement of the rods in the package, due to the instability of its deceleration during laying. Fluctuations in the length of the rods are determined by two components, the first is related to fluctuations in the length of the billet and the coefficient of drawing, and the second - with fluctuations in the current rolling speed.

The general regularities for optimal cutting of long rolled steel at different stages of rod production are established. It has been determined that in order to minimize the excess losses of fitt metal at cutting, in conditions of mass production of rolled metal, and increase of production of rolled metal, it is necessary to implement the interconnected management of the complex of operations of its production, that should take into account the peculiarities of technological process and equipment of rolling mill.

It is shown that the choice of the criterion for the coordinated management of the cutting of the rolling on continuous high-quality rolling mills is determined by the technical and economic indicators of the production of rolled metal. The main criteria are: minimum expected losses for one rolling bar of continuous billet for rolling of a certain profile size of fine grade rolled metal, that provides the maximum output of measuring rods with the maximum length of the bar of such rolling.

The proposed method of adjusting the speed of the rolling mode, where the change in the speed of the rolls of the draft group by the signal from the loop controller is effective for reducing the spread of the cross section of the roll at the outlet of the last stand of the draft group and the rolling speed at the exit of the last clearing stand continuous.

A method of cutting a rolled metal on a fine-cut mill has been developed, that provides the supply of bars on the refrigerator with lengths multiple of the measuring rod, regardless of the geometrical parameters of the original workpiece [1]. The loss of fitt metal in the cut with such cutting in the worst case is at most one measured length of the finished rolled billet, and the output of measured products is the highest.

A method of control of the process of inhibition of bars is developed, that in combination with an automated cutting system of rolled metal on a continuous fine mill condition to reduce the number of cuts and increase the output of measured products. A significant advantage of the system, in addition to minimizing the spread of the front ends of the bars, is a simplified functional scheme, compared with existing analogues [2].

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DEVELOPMENT OF A COMPLEX-TRAINER TO RESEARCH THE WORK OF AUTOMATED CONTROL SYSTEMS BASED ON MATLAB / SIMULINK AND SCADA-PACKAGE

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Modern automated process control system (APCS) is a software and hardware complex, which contains a large number of components of field devices and sensors, controllers, stations of operators, information servers, etc. Development of ACS modern technological processes - a complex and responsible task the solution of which is carried out in several stages: from the drawing up of a mathematical model to the design of the human-machine interface.

The purpose of the work is to create a complex simulator for the study of the work of automated process control systems. The software-training complex-simulator solves the following tasks: demonstration of SCADA-systems capabilities; transfer of data from Simulink mathematical modeling software package to SCADA system and vice versa; prompt computational processing of received data, presentation of information in a convenient for further processing form, work in real time.

As a SCADA package, TRACE MODE was selected, which has full support for OPC data exchange technology. Matlab / Simullink is chosen as the visual simulation package. The OPC CoDeSys server is selected as the OPC server. The PLC emulator SP PLCWinNT was selected for the software implementation of control algorithms in the programming languages of industrial controllers.

If necessary, each of the elements of the system can be replaced with a physical prototype. Which in turn extends the limits of using a simulator.

Because the system can work with a model, not just a real object, the system can be used to simulate freelance situations and evaluate the operator's actions in these situations accordingly. Because all activities take place in a controlled environment without risk to life and health, and without financial costs, such a simulator can assist the operational staff in the process of setting up the ACS, as well as for training purposes.

In addition, the system under development will certainly be very useful in the educational process of educational programs that involve the study of disciplines related to the design of automatic control systems, as it allows you to master the basic principles of building SCADA-systems, to learn to create management projects independently technological processes in the SCADA package.

DEVELOPMENT OF THEORY AND IMPROVEMENT OF TECHNOLOGY OF INSPECTION OF POWDER MATERIALS IN METALLURGY OF MELT AND AGGREGATE

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To choose the right research strategy, it is necessary to use the fundamental laws of science and apply them in high technology metallurgical production. Priazov State Technical University (Mariupol) and Odessa National University have developed software packages (more than 25) that can be used to simulate the most complex processes in blast furnaces, oxygen converters, plants for the out-of-furnace treatment of cast iron and steel, electric steelmaking, and cleaning plants gas and others. In each software package from 40 to 60 equations of motion, energy, combustion kinetics, and a number of closing ratios are jointly solved that provide intensification of energy and resource saving and improvement of metal quality when technological powders are fed into metallurgical aggregates and melts. The complexes took into account about 40 factors and physical impacts on the processes in transport pipelines, nozzles, supersonic and supersonic gas-powder jets, as well as on the combustion processes of various grades of coal in the tuyeres of the blast furnace and torch spraying of the lining of oxygen converters. You can calculate the flow flows, where the powder concentration will be at a level of from 2 to 300 kg / m3. With such a depth of study, no one has yet performed numerical calculations of gas-dispersed flows in metallurgy.

The widespread use of complexes will allow literally for years to reduce the time of introduction of high technologies in metallurgy.

IMPROVEMENT OF THE THEORY AND TECHNOLOGY OF GAS-POWDER SLAUGHTER SLAUGHTER IN OXYGEN CONVERTER

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The cost of steel substantially depends on the durability of the lining of oxygen converters. At refineries in some countries of the world, the lining resistance of converters is several times higher than at Ukrainian metallurgical plants. Using a system of multi-parameter equations, methods have been developed for calculating slag blowing in converters. The software package includes a joint solution of about 40 equations, and the calculations are performed taking into account the shock wave structure of supersonic gas-powder off-design jets, the concentration of powder in front of the tuyere nozzle block, the gas temperature in the converter cavity, and the addition of slag to the supersonic jet. Taking into account real factors allows one to more accurately calculate the mass-average velocity, density, temperature, momentum and power in any arbitrary section of the jet, as well as the depth of penetration of the gas-powder jet into the melt and the diameter of the hole. Methods have been developed that allow increasing the momentum of outflowing jets by almost 1,5 times and increasing the power of these jets by 2.5-3 times.

Increasing the durability of the converter lining allows solving another, no less important problem - by reducing harmful emissions, reducing the environmental burden on the environment,

which is especially important for the Azovstal Iron and Steel Works, where slag dumps are located on the shores of the Sea of Azov.

Metal science and heat treatment of steel

THE INFLUENCE OF THE AUSTENITE DECAY KINETICS IN HIGH CARBON STEELS ON THE FEATURES OF STRUCTURAL TRANSFORMATIONS PROCESSES AT CONTINUOUS COOLING

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Structural diagrams of austenite transformations at continuous cooling of high-carbon steels C80D, C86D and C92D (EN ISO 16120-2:2011) have been constructed and the obtained data are summarized in order to establish the permissible rates of continuous air cooling and the temperature of cooling onset (t_{co}, ˚C), at which a uniform distribution of structural components in the cross section of hot-rolled wire rod is provided. The decay kinetics of C86D steel austenite, unlike the C80D and C92D steels, in the continuous cooling rate range of 228…19 ˚C s is characterized by the presence of a bainitic transformation region, which is caused by a higher austenitization temperature (by 60…70 ˚C) and a higher manganese content (by 0.14 %). The increase of the upper critical cooling rate for C86D steel by 67 % compared to C80D steel is related to the flow in the intercritical cooling interval of bainite transformation. The influence of the continuous cooling rate on the absolute change of the onset temperature and the end of diffusion decay of austenite in C80D, C86D and C92D steels has been investigated. It is established that for the investigated steels in the interval of continuous cooling rates (0.10…14 ˚C/s) the austenite decay termination temperature exceeds the temperature of the decay beginning. In order to obtain a uniformly distributed structure of sorbitol perlite (GOST 8233-56), the continuous air cooling rate must be at least 14 ˚C/s along the cross section of high-carbon steels.

It is shown that the influence of increased austenite stability on the onset temperature pearlite transformation (t_{pt}, ˚C) is observed for C86D steel in the interval of continuous cooling rates of 0.1… 20 ˚C/s. The total interval of continuous cooling rates for the investigated steels can be roughly divided into the following components: 1) 0.1…20 ˚C/s – the predominant influence of austenite stability on the onset temperature of pearlite transformation; 2) 20…35 ˚C/s – the predominant influence of the hypothermia degree, in which the stability of austenite does not significantly affect the onset temperature of pearlite transformation.

The influence of the high carbon steel chemical composition and the austenite stability on the fundamental change in the kinetics of austenite transformations under continuous cooling has been established. So, if for C80D and C92D steels cooling at 35 ˚C/s to temperatures not lower than 200 ˚C is quite acceptable, then when cooling C86D steel at speeds ≥ 19 ˚C/s, bainite will be formed in the structure of the wire rod, which is unacceptable structural component in accordance with the requirements of the relevant standards. Unlike C80D and C92D steels, C86D steels must be cooled with stepwise cooling in the temperature range from t_{co} to (t_{pt} – 20…25 ˚C) at a rate of not less than 14 ˚C/s, followed by quasi-isothermal holding and subsequent cooling to temperatures up to 200…180 ˚C.

INVESTIGATION OF THE STRESS-CORROSION CRACKING OF PIPE STEEL 09G2SF OF A CONTROLLABLE ROLLING UNDER CATHODIC POLARISATION

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The investigations results of stress corrosion cracking (SCC) of pipe steel 09G2SF of controllable rolling in the NS4 solution (pH of 8.2) in the range of protective polarization potential normalized DSTU 4219, namely from -0,85 V up to -1,15 V against copper-sulfate electrode (c.s.e.), which corresponds to the range from -0.75 V to -1,05 V against chloride silver electrode (c.s.e.) were presented. A complex methodology, developed in E.O. Paton electric welding institute, which includes a method of polarization curves with various scanning rates of the potential, slow-strain test method, the analysis of the morphology of samples fractures and determination of the degradation properties (tensile strength, relative elongation and relative narrowing of the samples after destruction) coefficients was used.

From the analysis of the obtained results, we can distinguish three areas of the potentials in which the steel under investigation is in a non-equilibrium electrochemical state and the mechanism of the SCC of the steel varies depending on the applied protective potential. It should be noted that the coefficient of degradation of the strength limit in the completely potential range varies in a very slight degree, from 16% to 24%/ The changing in ductile properties is more significant.

In the region of potentials more positive than -0.85 V (c.s.e.), the process of stress corrosion cracking carries exclusively by the local anodic dissolution mechanism, which is confirmed by the nature of the breaking and the morphology of samples fractures. For the specimens a ductile fracture is peculiar which characterized by a significant tightening around the break line. The degradation ratio of the elongation is about 5%.

At potentials, more negative than -1.0 V (c.s.e.), the mechanism of stress corrosion cracking is determines by hydrogen embrittlement. The destruction line of the specimens is polygonal, in the region which adjacent to the breaking line, there were small cracks. In fracture morphology, the fragile component prevails, the degradation coefficient of elongation, which characterizes the degree of change in the ductile properties, increases from 4% to 14%.

In the potential range from -0.85 to -1.0 V, stress-corrosion cracking carries on a mixed mechanism. Both fracture and fragile components are present in the fracture pattern of the specimens, their ratio varies depending on the change of potential. For these conditions no monotonic changing in the coefficient of degradation of the elongation is observed, from 4% to 14%.

Thus, depending on the mechanism of stress corrosion cracking, the rate of development of this process may differs.

It is advisable to apply the results of the research in the complex of works on diagnostics of the main pipelines for preliminary determination of potentials areas in which the development rate of the SCC process may be different. This will allow us to develop approaches to optimize of electrochemical protection.

CORROSION RESISTANCE OF WELDED JOINTS OF LOW-ALLOWED PIPE STEEL PERFORMED BY HIGH-FREQUENCY WELDING

Nyrkova L.I., cand. of chem. scienses, Prokopchuk S.M., Mel`nychuk S.L.

The results of investigations of corrosion resistance under conditions of combined action of corrosion-active environment and constant deformation of low-alloy pipe steel 17G1SU and its welded joint performed by high-frequency welding (HFW) are presented. Welding was performed in accordance with existing technology for the production of HFW-pipes (TC-1303-006.3-593377520-2003). The electrochemical properties of these joints were also investigated.

It is known that welded pipes of low-alloy steel are characterized by low cost, stability of sizes, possibility of making pipes of different size in comparison with seamlessly ones. However, the structural, mechanical and electrochemical heterogeneity of such welded joints results in decreasing of the resistance to corrosion-mechanical failure, which effects on the life of the pipeline

in general. The corrosion is the main reason of its breaking in 90% of the cases, and it is the most commonly taking place in the weld area.

Preliminary evaluation of the properties of base metal and weld area in 3% NaCl solution, performed by potentiometry and polarization curves technique, showed a slightly higher activity of the weld. Thus, the corrosion potential in the weld area was about 15 mV more negative than on the base metal, but it has a tendency to stabilize over time. The limit diffusion current in the weld region is almost 4 times greater than that on the base metal (0.05 mA/m^2 and 0.19 mA/m^2, respectively). Whereas under free oxygen access in aqueous solutions, the corrosion flying with diffusion control, such a difference in currents can accelerate the corrosion process in this area, which needs an increased attention.

The results of long-term corrosion-mechanical tests of steel in 3% NaCl showed that during 1000 hours contact with the solution no local damages like pittings and corrosion ulcers was detected on the surface. Corrosion was identified as an entire non-uniform, the type of corrosion damages – corrosion spots. The rate of uniform corrosion of the welded joint of 17G1SU steel in the unstressed state during the whole exposure time in the environment is about 30-36% higher than that of the base metal. When the specimens were loaded to the level of 0.95 of the yield strength of the base metal, the rate of continuous corrosion of such specimens increases in 4-5 times: from 0.07 mm/year (in the unstressed state) to 0.2 mm/year (in the stress state) – for the base metal, from 0.11 mm/year to 0.20 mm/year – for the welded joint, respectively.

Based on the analysis of the obtained results, it was suggested that the weld area is more sensitive to corrosion and corrosion-mechanical fracture in the conditions of contact with the environment. For more complete information on the corrosion resistance of a welded joint under exploitation conditions, it is advisable to investigate its susceptibility to stress corrosion cracking under cathodic protection.

Thus, obtaining data concerning corrosion properties of HFW-pipes will be profitable for improving their quality and increasing the efficiency and reliability of welded joints of these tubes.

EUROPEAN EXPERIENCE OF DEFINITION OF AXLES FOR RAILWAY TRANSPORT

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Fatigue life of the railway axles is till today very actual topic. Design, calculations and testing of the axles has been developed before long time and basic procedures are anchored in the European standards EN. Due to the service of high speed trains and due to the higher demands on safety are these procedures continually precised and thereby is safety in service improved. Particular attention should be paid to improving the fatigue properties of the rail axles.[1,6]

At present time the procedures for design and calculation of the axles are defined by European standards EN 13103 and EN13104 [2,3]. Bending strain of the axle is calculate from loading forces – vertical (weight of the wagon and load), horizontal (from curves and crossings and braking forces) [4, 5]. From bending moments are than calculate bending stresses in all cross sections of the axle. Calculated stresses must be smaller than permissible stress, that is determined as fatigue limit of the axle divided by safety factor.

Full-scale real-axis testing is a very expensive method, it is cheaper and more convenient to perform laboratory testing on samples, but there is always some small uncertainty about the results obtained. There are also slight differences between test laboratories.[6]. Research is essential to ensure the reliability of the axis of high-speed trains.

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FEATURES OF HEAT TREATMENT OF STEELS WITH MIXED STRUCTURE

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Heat treatment is used to give the required quality indicators of metal products: strength, ductility, hardness, etc. Rolled steel for processing into metal products of the required dimensions should have low hardness parameters and high ductility. For this purpose, metallurgical and machine-building enterprises use heat-treating (softening, spheroidized annealing) at subcritical temperatures ~ A1 - 20 ... 30 °C with long isothermal aging. Structural transformations in heat treatment are known to begin with phases that have less thermodynamic stability: martensite and bainite. Therefore, it is much more difficult to obtain a spheroidized structure in pearlite class steels, which takes a long time. Studies have shown that in steels with ferrite-perlite-bainite structure in the process of annealing at reduced temperature (A1 - 70… 150 °C) structural transformations mostly occur in bainite, which confirms the decrease of its microhardness. At that time, the microhardness of perlite had initial or close values. Therefore, it is recommended to provide more bainite to reduce the heat treatment of steels with ferrite-perlite-bainite structure. It is established that, after heating to elevated temperatures, large austenitic grain contributes to the increase of stability of supercooled austenite, and at further continuous cooling and isothermal holding in the bainite region impedes the formation of pearlite structure. Upon further heating to temperature (A1 - 70 ... 100 °C), decay of bainite occurs with the formation of sorbitol of the release, which ultimately provides the achievement of the required values of properties: low hardness and high ductility.

For medium carbon steels alloyed with chromium, molybdenum and vanadium after hot rolling, an increase in cooling rate (in air) of 1.5 times allows to obtain a structure consisting of at least ~ 75% bainite, ~ 20% ferrite, the rest - perlite (chromolybdenum steel) or martensite (chromomolybdenovandium steel). For low carbon silica steels, increasing the cooling rate leads to a structure consisting of at least ~ 35% bainite, ~ 60% ferrite, the rest is perlite. In the resulting structure, upon further curing (softening annealing), due to the greater number of metastable phase components, structural transformations occur at lower temperatures and require a shorter holding time. Therefore, obtaining after rolling unfavorable deformation treatment of the structure allows to accelerate the intermediate heat treatment, thereby reducing energy costs, and provides high ductility of steel before deformation.

On the basis of the conducted researches, reduced modes of heat-limiting heat treatment for low- and medium-carbon alloy steels of various purposes are proposed.

NEW APPROACHES TO DESIGNING STRENGTHENING TREATMENTS WITH THE ACCOUNTING FOR EVOLUTION OF ALLOYS AT OPERATION

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The work is devoted to the generalization of studies on the implementation of a new approach to the design of innovative strengthening treatments of alloys of various functional applications based on the accounting and control of the evolution of the phase-structural state during operation.

The proposed approach is based on the principle of controlled phase-structural evolution at the stages of testing and operation, providing self-improvement of the microstructure and, as a result, the properties directly under the influence of the operating environment itself. This evolution is realized due to the "programmed" initially or controlled (optimal) development of deformational, in some cases thermo-deformational induced phase transformations during testing or operation (DIPTT, TDIPTT): martensitic $\gamma \rightarrow \alpha'$; $\gamma \rightarrow \varepsilon'$; $\gamma \rightarrow \alpha' \rightarrow \varepsilon'$ transformations (DIMTT); dynamic strain aging (DSA); transformation of the compositions and structure of dispersion hardening phases, etc. These transformations are accompanied by the effects of self-strengthening, self-relaxation of microstresses due to the formation of martensite deformation and precipitation of dispersed particles of solid phases, self-adaptation to operating conditions, absorption of part of the energy due to the self-organization of the phase-structural state.

Obtaining metastable states of austenite is possible in any phase-structural modifications: the main γ-phase; second phase; primary; eutectic; residual (A_{res}); secondary or reversed; satiated; powder in steels, cast irons, deposited metal, powder alloys. For this, it is necessary to use all possible mechanisms of stabilization and destabilization of austenite in order to rationally manage DIPTT (TDIPTT, DIMTT, DSA, etc.) while developing new and improving traditional methods and strengthening technologies.

Pure structural transformations are possible (TWIP - Twinning Induced Plasticity), the evolution of which during operation should initially be controlled not only by alloying, but also by processing. The implementation of the DIMTT or TWIP effects with the optimal evolution of the alloy during testing of the properties ensures the achievement of an abnormally high strength complex (ultimate tensile strength = 1600-2000 MPa), ductility (elongation = 15-25%), impact strength (KCU = 1.0-1, 6 MJ/m_2) structural steels, increased (1.5-4 times) wear resistance of steels and cast irons.

A new direction in the design of hardening treatments is the use of the principle of austenite heterogenization for the implementation of subsequent martensitic transformations during cooling and DIMTT, on the basis of which new methods and technologies for hardening steels and cast irons are created. Thermo-chemical methods have been created (carburizing, nitrocarburizing, high-speed thermocyclic cyanidation with induction heating, etc.) in combination with the original methods of heat treatment (quenching from differentiated temperatures, high temperature thermo-cyclic treatment, low temperature thermo-cyclic treatment, plasma treatment, etc.), providing the formation of gradient structures with differentiation of the number of A_{res} and the degree of its metastability along the depth of the layer, taking into account the subsequent evolution of the phase-structural state during operation.

COMPARISON OF THE SIMULATION RESULTS AND DEFORMABILITY EVALUATION OF STRUCTURE OF STEEL GRADE 09Г2С IN THE PROCESS OF LENGTHWISE ROLLING OF THE TUBE BILLET Ø 250 MM

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To carry out a comprehensive, in-depth analysis of the stress-strain state and to establish the direct effect of hot deformation on the microstructure of steel, its structural component which does not undergo any phase or structural transformations at the microlevel and is able to fully reflect the process of deformation and flow of the metal has been determined. Such a part of structure of steel is chemical heterogeneity that is inherited from dendritic segregation of silicon and manganese. This inherited chemical heterogeneity remains almost constant in quantitative terms with further temperature and deformation effects, despite the significant duration of the heating process and the soaking at high temperatures, but at the same time changing its shape and size. Based on these results, the method of metal deformed state evaluation by the former dendritic structure parameters change has been developed by the Iron and Steel Institute named after Z. I. Nekrasov of the National Academy of Sciences of Ukraine.

To evolve this method, the analysis of the stress-strain state formed into the last, round, roller pass of stand 900 of the tube preforming mill 900 / 750 – 3 during the rolling and comparing the results of simulation with the deformability structure evaluation of the tube billet with the diameter of 250 mm have been carried out.

The results of simulation and metallographic analysis have showed good convergence. On these results basis, the zones of active and passive deformation and their location in the direction of one-half vertical axis within the investigated billet cross section have been determined. The stick zone depth is 12.5 mm, the zone of intensive plastic deformation is concentrated at a distance of 50 – 112.5 mm from the billet center, and the central layers of the billet are the zone of passive deformation.

For the first time, it has been shown that the change in the shear stress τ_{zx} fully reflects the nature of change in the coefficient of structure deformability K of the large-size rolled metal. In the study of the strain effect on the microstructure of steel, the use its structural component – chemical heterogeneity inherited from dendritic segregation of silicon and manganese – allows to execute not only a quantitative evaluation of the intensity and localization of deformation, but also a qualitative evaluation of the change in shear stress within the billet section.

Further researches in this direction will expand the theoretical concepts of the formation of metal stress-strain state in high deformation areas during the rolling and become the basis for development of practical recommendations to improve the production technology of large-section rolled products.

THE INFLUENCE OF TEMPERING MODES ON THE PARAMETERS OF THE THIN STRUCTURE, THE STRESSES AND THE HARDNESS OF 25Cr2MoV STEEL

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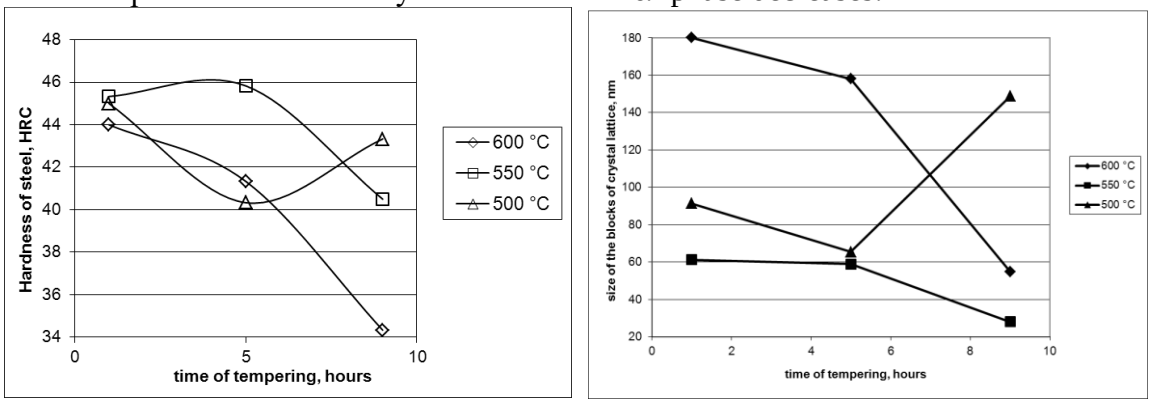
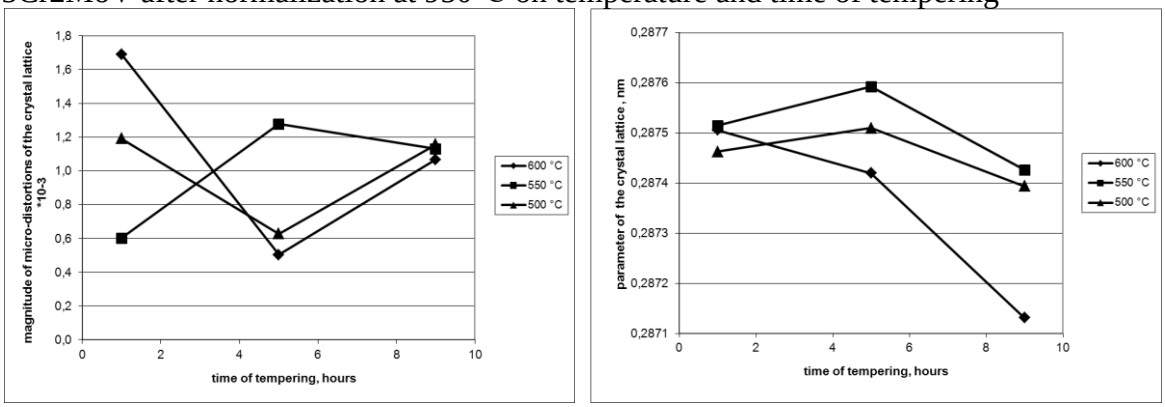
The results of studies on the effect of tempering regimes on the parameters of thin structure, stresses and hardness of 25Cr2MoV steel are presented. It is shown that the secondary hardness of steel 25Cr2MoV, tempered at a temperature of 550 °C, maximum after 5 hours tempering and is caused by the smallest size of the crystal lattice blocks (Fig. 1). It is established that at the initial stages of decay of a supersaturated solid α -solution of hardened 25Cr2MoV steel at 550 °C, the crystal lattice parameters increase (Fig. 2). During the next tempering time (9 hours), the bonding of the crystal lattices of these phases is broken, due to the separation of the carbide particles from the α -phase and the parameter a of the crystal lattice of the α -phase decreases.



a b

Fig. 1. Dependence of hardness (a) and size of blocks of crystal lattice (b) of steel 25Cr2MoV after normalization at 950°C on temperature and time of tempering



a b

Fig. 2. Changing the magnitude of micro-distortions (a) and parameter of the crystal lattice (b) when tempering 25Cr2MoV steel

Thus, it is established that the brittleness and hardness of 25Cr2MoV steel when released are not affected by quenching, but secondary stresses are coherent (determined by the size of the crystal

lattice blocks) and dispersive (determined by the magnitude of the micro-distortions of the crystal lattice).

Progressive Metal Processing Technologies

TECHNOLOGICAL FEATURES OF THE CHOICE OF A RATIONAL SCHEME FOR LINKING CONTINUOUS CASTING MACHINES TO SMALL-GRADE AND WIRE MILLS

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The technological features of the development of metallurgical enterprises focused on the production of small-section and wire metal products for continuous casting are considered. In particular, considered: the bar shape, the choice of CCM location, the scheme of transfer of continuously cast billets to small-section and wire mills.

Research on the production of long products from square billets of 130 and 150 mm has established that direct combination of a CCM with a rolling mill is almost impossible due to the difference in the speed of continuous casting and the rough group of the mill. In the case of cutting billets, there will be a low mill productivity due to a large cycle. The calculations confirm the unsuitability of this option for industrial implementation.

Combination with an intermediate furnace for continuously cast square billets of 130 and 150 mm has found wide application abroad. The performed calculations show that this scheme is technologically feasible, however, leads to significant energy losses, since it is necessary to almost completely cool the billet and its further heating. Even the use of an intermediate thermostat with a counter-flow of cooling and heated billets brings the use of energy to no more than 25 %.

The most effective option for joining the CCM with a rolling mill when using a continuously cast square billet is 130 and 150 mm of carbon and low-alloyed steel grades, which use a set of equipment based on a thermostat furnace for a billet 120 m long. This method of joining allows to reduce the energy consumption for billet heating by no less than 53%.

The considered technology of joining the CCM with a rolling mill will provide metal savings by reducing the thickness of the scale to 0.4-0.73 mm (an average of 1.1% of the billet weight), improve its quality by reducing the depth of the decarburized layer from 1.1 mm to 0.3 mm.

High-temperature oxidation of steel is accompanied by decarburization of the surface layer. This leads to a significant deterioration of mechanical properties: decrease in hardness, fatigue limit, hardenability, increases the tendency to quenching cracks, delamination, and distortion during pressure treatment. The depth of the decarburized layer depends on the oxidation conditions (temperature, duration of heating, etc.).

Obviously, it is beneficial to use a continuously cast billet heated to temperature (combined with an intermediate furnace or an intermediate thermostat). Due to the decrease of the heating time, the formation of scaling sharply decreases and, which is no less important, the size of the decarburized layer decreases.

The main result of the joining of the CCM to the rolling mill is to save thermal energy, since the heat of the cast billet is used for the further process. In addition, there are other advantages: saving metal by reducing the loss of furnace in furnaces, reducing the storage of steelmaking and rolling mills, reducing harmful emissions into the environment, reducing capital costs for the construction of heating furnaces.

The proposed technology provides for the transportation of liquid steel in the ladle from the steelmaking shop, casting on CCM located in the rolling mill, detecting defects in the hot stream and supplying hot billets with a temperature of 850 °C to high-temperature heating furnaces and the rolling shop.

The efficiency of the new technology is calculated as compared with the traditional one: placing the CCM in the steelmaking shop, cooling the cast billets after casting, delivering them to the rolling shop in a cold state, cold planting in a heating furnace and heating to the required rolling temperature.

When heated, hot heat significantly reduces the heat consumption for heating the metal, while heat loss (idle power) and heat utilization, which largely depend on the factors associated with the design of the furnace vary little.

Scale formation when heated is a source of loss of a suitable metal. The formation of scale is influenced by the heating temperature, the residence time of the metal at high temperatures, and the heating rate. According to the basic technology (cold charge), the scale layer is 0.6 mm or 1.9 % of the billet weight.

The considered technology of hot billet charge reduces the thickness of the scale to 0.3-0.4 mm, or an average of 1.1 % of the billet weight.

Along with a decrease in the oxidation of the metal, a decrease in the residence time of the metal in the furnace will provide a reduction in the depth of the decarbonized layer, which according to the basic technology is 1.1 mm, and a new 0.3 mm.

An increase of the billet size may require the installation of additional stands on the lines of roughing and intermediate stands, which will not affect the initial rolling speed and the hourly productivity of the mill. For small section and wire mills, the cross section of the original billet can be increased to approximately 150×150 mm. The choice of the optimal cross section requires an analysis of the size and brand assortment of the metal products of the plant, taking into account the necessary drawing ratios (at least 6-10).

Environmental problems of ferrous metallurgy

A SYSTEM APPROACH TO SYNTHESIS OF ROLLER PRESS RATIONAL CONSTRUCTION

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Reducing the resource base of enterprises in the energy, chemical and metallurgical industries requires the introduction of resource-saving technologies and equipment for their implementation. One of the areas of small fractional raw materials rational use, including those of technological origin, requiring agglomeration for the use of technological processing is the briquetting method. Roller presses are widely used as the main unit of technological lines for briquetting. Currently, there is a problem that machines and units design modern methods and programming tools do not allow to take into account all the features of roller presses design process, so this type of equipment rational design creation carried out by successive approximations developer's practical experience-based.

The analysis and generalization of the main tasks of structural-parametric synthesis and analysis carried out intending to form an approach solving the problem of finding the rational layout and design solutions for roller briquetting presses. The structure and the generalized scheme of the modeling system for solving the problem of synthesizing a rational design of a roller press formed. With concrete examples, possible applying options of structural-parametric synthesis methods to designing of the press as a whole, as well as its components and parts shown. Directions for further research on the creation of an effective tool for finding rational design solutions for roller presses and optimizing their operational, technological and technical characteristics formulated. Practical implementation of the system approach proposed in the work will help streamline and simplify the search for rational design solutions for presses and reduce the time and resources spent on design.