Iron and steel institute of Z.I. Nekrasov
of National academy of science of Ukraine

All-Ukrainian scientific and technical conference «НАУКА І МЕТАЛУРГІЯ»

22-24 november

Conference organizers:
Iron and steel institute of Z.I. Nekrasov of National Academy of Sciences of Ukraine

Ukrainian State University of Science and Technology of the MES of Ukraine

Conference Proceedings

DOI: 10.52150/2522-9117-2022-conferens

Dnipro
2022

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UDC 622.335

DETERMINATION OF DUST CONTENT AND FRACTIONAL COMPOSITION BEFORE AND AFTER HEAT TREATMENT OF DONETSK ANTHRACITE

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Development of technical means of heat treatment of bulk carbon materials, in particular anthracite, that aimed at using the regeneration of the physical heat of the treated material by means of blowing with heat carrier gas in a closed circuit with constant gas purification, is an urgent task. The peculiarity of fossil anthracite is the presence of dust in its composition, which is formed both at all stages of mining and transportation, and during the heat treatment process. In turn, this causes the need to remove anthracite dust from the gas stream. Thus, there is a need to study the content and fractional composition of dust, which is formed both before and during heat treatment of anthracite.

The anthracite from the Donetsk coal basin of fraction 25-6 mm was used for the study. The results of the technical analysis are shown in Table 1.

Table 1 – Technical analysis of the studied anthracite

Parameter	Designation	Unit	Value	GOST
Moisture content of the analytical sample	W^a	%	3.8	11014-2001
Ash content in the dry state	A^d	%	5.3	11022-95
Output of volatiles to the combustible state	V^{daf}	%	6.9	6382-2001

After the anthracite was selected, it was placed in a sealed bag and transported to the laboratory, where the anthracite pieces were removed after shaking. The dust from the bag was poured into a separate container and dispersed by fractions of sequentially fixed mechanical sieves with cell sizes of 40, 63, 100, 200, 315, 500 and 1000 micrometers. To determine the surface dust, anthracite was loaded in portions of 1 kg into the upper part of the sieves and shaken in a closed form for 5 minutes. The dust obtained on each sieve was weighed using electronic scales TVE-0.21-0.001. 8 kilograms of anthracite was selected and subjected to heat treatment in a muffle furnace at a temperature of 1200 °C for 2 hours. After cooling and removal from the furnace, the content and fractional composition of thermal anthracite dust was determined according to the specified method. The results of the measurements are shown in Figure 1.

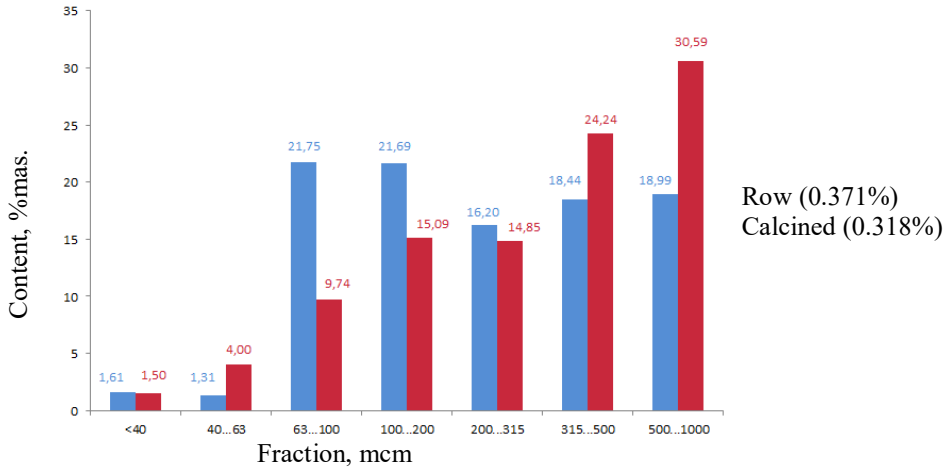

Figure 1 – Content and fractional composition of dust before and after heat treatment of anthracite

UDC 621.746.047:669.016.2

FEATURES OF THE PRODUCTION OF A QUALITY BILLET BY THE METHOD OF CONTINUOUS CASTING WITH INCREASED SERIES BY THE "MEL ON MEL" METHOD

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During serial casting, increased requirements must be placed on the stability of dosing devices of steel casting and intermediate ladles and the stability of their lining. In order to increase the stability and reliability of the lining of the skimmer, a special shotcrete coating based on MgO is applied to the working layer of the lining. To strengthen the area where the immersion cups are located, which is subject to maximum erosion (the slag belt zone), it is equipped with an insert made of stabilized zirconium dioxide, which allows pouring up to 8-10 melts through one immersion cup. To reduce the wear of stoppers, they are made with the maximum diameter in the area of the slag belt and the area above the stopper attachment. To achieve long-term pouring, it is advisable to make the upper part of the dispenser glass from a stronger material and cover it with a ceramic coating, which reduces the rate of overgrowth of the internal cavity of the dispenser glass. To protect the pouring pipe, stronger refractories of increased thickness are used in the zone of receiving the metal jet. To ensure the reliable operation of the lining of the intermediate ladle during the pouring of 10-20 melts, it is necessary to increase the stability of the bottom and walls in the place of the jet falling from the steel pouring ladle by installing high-alumina or magnesium bricks, which have high fire resistance and resistance to the erosive influence of the steel jet.

The temperature-speed regime of the technology of continuous casting of steel has a decisive influence on the stability of the liner during serial pouring of steel at the MBLZ. The optimal temperature of the metal in the ladle should exceed the liquidus temperature by 25-30°C. For this, during the pouring process, the metal is brought to the set temperature and further maintained at the specified level. It was noted that the heat loss of steel during its stay in the steel casting ladle through the walls, bottom and metal mirror is 0.45 - 0.6 ^{o}C per minute and depends on the condition of the lining of the steel casting ladle. Regarding the speed of casting in modern converter workshops with CCM, where casting by the "melt-on-melt" method is widely used, the casting speed of each section of the ingot is determined by the rhythm of issuing melts from the converters. The technologically possible casting speeds depend on the cross-section of the cast iron, the grade of steel and the purpose of the finished product. Thus, the factors limiting the rate of steel casting at the CCM can be summarized by their influence on the quality of the workpiece:

1) the formation of transverse cracks on the surface of the ingot caused by frictional forces between the shell of the ingot and the walls of the crystallizer (determining parameters are the length of the crystallizer and the coefficient of friction of the wall material and the lubricating material of the walls);
2) the formation of longitudinal cracks in the shell of the ingot before exiting the crystallizer, which are caused by difficult shrinkage (determining parameters - the absolute size of the faces, the ratio of the sizes of the faces, the coefficient of friction, the smooth or wavy profile of the working walls of the crystallizer);
3) the formation of longitudinal cracks after leaving the crystallizer, which are caused by the deflection of faces under the action of ferrostatic pressure (determining parameters are the length of the crystallizer, the absolute size and ratio of the faces, the design of supporting devices);
4) systematic breaks in the shell of the ingot during upward movement of the crystallizer (determining parameters – law, frequency and amplitude of reciprocating movement of the crystallizer, coefficient of friction, quality of the ingot surface).

UDC 669.184

RESEARCH AND DEVELOPMENT OF THE CONSTRUCTION OF A COHERENT-TYPE NOZZLE WITH THE PURPOSE TO IMPROVE THE TECHNOLOGICAL AND ENVIRONMENTAL INDICATORS OF THE CONVERTER SMELTING

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According to the statistical report of the World Steel Organization in 2021, the total production volume of converter steel was 73.2% of the total volume. And according to experts' forecasts, the oxygen-converter process will retain its position in the future. At the same time, the task of reducing carbon dioxide emissions per ton of finished products remains the most urgent. According to the works of a number of authors, the way to solve this problem is to increase the proportion of scrap in the converter charge. The specified effect is achieved due to the use of special lances to increase the degree of postcombustion of carbon monoxide - two-level and two-row lances, which ensure an increase in the heat content of the bath. At the same time the research and development of progressive designs of tips for lances, which will contribute to increasing the efficiency of postcombustion and, accordingly, their thermal performance, is relevant.

In the practice of electrometallurgical production, there are positive results of using coherent nozzles, consisting of a central nozzle and an outer annular shell, that creates a protective layer to increase the aerodynamic efficiency of the central jet. The literature presents the results of studies according to which it is possible to admit the expediency of using nozzles of the coherent type for the conditions of top oxygen-converter blowing.

Samples of laboratory nozzles of a coherent design were made, which differ in the ratio of the central and peripheral part while maintaining the equality of the general conditions of jet output (percentage of the ares of annular slot in relation to the total area of the nozzle, %: 75, 65, 50, 45, 35, 25). They were investigated by weighing the jet, estimating their impact forse with the help of a modified liquid manometer and shadow photography when the gas flow velocity at the exit of the nozzle was reached at the level of 2 M. The obtained results were compared with the parameters of cylindrical nozzles of the corresponding diameter.

According to the results of the conducted research, it was established:

- coherent jets are characterized by a fairly stable structure;
- the width of the initial opening of the jet is approximately two times greater and is maintained at a sufficient distance;
- the structure of a coherent jet with a share of the annular slot greater than 50% consists of a three-dimensional complex nodular structure of areas of increased pressure with short gaps between them, and with smaller parameters it is flagellated, as in a jet flowing from a cylindrical nozzle, with larger gaps between the seals;
- when blowing through nozzles of the coherent type with an annular gap of 45-50%, the structure of the jet is heterogeneous without existing seals.

Based on the results of weighing the jets flowing out of the coherent type nozzles and studying their impact forse, it was established:

- a significant (by 40-45%) increase in the weight and impact forse of the jet when using nozzles with an annular slot of 55-65%;
- the use of nozzles with an annular slot of 45-50% does not lead to an increase in impact forse;
- with an annular slot of 25-35%, the weight of the jet is less by an order of 5%.

Thus, the design of a coherent nozzle with an annular slot of 75% can be recommended for use on the second circuit or the second level of the top blowing lances of the oxygen converter. When they are used, more effective postcombustion of exhaust gases will be achieved due to the increase in the contact surface of the jet with flue gases.

UDC 669.094.22:549.26

FORMATION OF THE CARBIDE PHASE DURING THE COMPLEX REDUCTION OF CHROMIUM IN COMPLEX SYSTEMS

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The development of physico-chemical regularities of solid-phase reduction of oxides in order to obtain multi-component spongy ligatures is a very relevant direction in metallurgy. However, until now there is no single idea, both about the mechanism of the process and the regularities of the formation of the resulting recovery products. The existing views on phase and structural transformations during the recovery of chromium ore do not fully take into account and rely on the regularities of crystal-chemical transformations.

Solid phase recovery of chromium in simple and complex systems is practically impossible without the participation of carbon. Chromium has a high affinity for carbon, that leads to the formation of carbides.

Formally, at a given temperature, this can be represented by the scheme:

$Cr \rightarrow Cr_{satur..C} \rightarrow Cr_{23}C_6 \rightarrow$ solid solution (Cr_7C_3 in $Cr_{23}C_6$) $\rightarrow Cr_7C_3 \rightarrow$ solid solution (Cr_3C_2 in Cr_7C_3) $\rightarrow Cr_3C_2$.

This scheme is built according to the principle of the sequence of transformations.

Solid-phase reduction of chromium without the participation of carbon (for example, with hot-dried hydrogen) is realized sequentially $Cr_2O_3 \rightarrow CrO \rightarrow Cr$. The addition of carbon into the system triggers the formation of carbides, and as oxygen is lost, it can be assumed that the formation of oxycarbides of variable composition $Cr_2(O_{3-n}C_n)$ is possible against the background of increasing instability of crystallographic lattices of the oxide. The "life" of such compounds will be very small due to the high affinity of chromium to carbon, as well as the latter to oxygen. Further transformations are possible within the oxycarbide structure:

$Cr + 6/23C = 1/23Cr_{23}C_6$ and $C + 1/2O_2 = CO$.

In this form, the interaction of carbon with oxygen is energetically better, but it is difficult to estimate how the priority of these interactions will change within the oxycarbide crystal lattice.

Thus, at the first stage of recovery, two phases are formed: CrO and $Cr_{23}C_6$ through the intermediate phase of oxycarbide $Cr_2(O_{3-n}C_n)$, which provides a more stable state of the system and, therefore, lower energy costs of transition from one phase to another.

Recovery in the second stage of chromium monoxide ($CrO \rightarrow Cr$) can be accompanied in parallel, at T>697°C, by its disproportionation. Two reactions can occur simultaneously:

$CrO + C = Cr + CO$ or $CrO + C = Cr(O_{1-m}C_m) + CO$

And $3CrO = Cr + Cr_2O_3$.

Carbide $Cr_{23}C_6$ has formed in the first stage can further transform into trigonal carbide Cr_7C_3 (and further Cr_3C_2). Thermodynamically, the interaction of chromium with Cr_7C_3 carbide is also possible by the reaction:

$2Cr_7C_3 + 9Cr = Cr_{23}C_6$.

At the same time, the formation of $Cr_{23}C_6$ carbide is thermodynamically more preferable in relation to the reaction

$Cr + 6/23C = 1/23Cr_{23}C_6$. The carbon located in the sublattice of the introduction of oxycarbide, as oxygen is removed, interacts with chromium, forming $Cr_{23}C_6$ carbide.

Recovery of CrO in the second stage can also go through the stage of formation of oxycarbid $Cr(O_{1-m}C_m)$, which is further transformed into Cr or carbide $Cr_{23}C_6$. The thermal decomposition of CrO is accompanied by the formation of chromium oxide, which will then repeat the recovery algorithm given above: $Cr_2O_3 \rightarrow CrO \rightarrow Cr$.

UDC669.112.2:669.26

THE INFLUENCE OF THE ADDITION OF Femet ON THE CARBOHYDROTHERMAL REDUCTION OF CHROMIUM OXIDE

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Possible ways of developing the carbon-thermal reduction of Cr_2O_3 were subjected to experimental verification. The starting materials were chromium(III) oxide of the ChDA qualification and spectral graphite.

Studies conducted in a non-isothermal mode with a sample heating rate of ~10K/min showed that the carbon-thermal reduction of Cr_2O_3 began slightly above 1100ºC. At 1200ºC, the process had high speed and ω reached ~30%. The reduction of chromium oxide led to the formation of stable Cr_3C_2. However, it should be noted that X-ray structural studies revealed the appearance of small amounts of thermodynamically unstable Cr_7C_3. Experimental studies confirmed the conclusions of the thermodynamic analysis about the possibility of the appearance of unstable solid products during the carbon-thermal reduction of Cr_2O_3 and the participation of the formed Cr_3C_2 in the removal of oxygen from the oxide phase.

Since this work is aimed at developing the physicochemical foundations of solid-phase production of ferrochromic alloying materials, it is necessary to determine the effect of Fe_{met} on the kinetics of the process and establish a possible mechanism of such an effect. It was established that the introduction of iron inhibits the reduction of Cr_2O_3 by carbon at 1200-1300ºC. This is consistent with literature data. The negative effect occurred and changed little when the weight of the additive varied in the range from 10 to 100% in relation to the initial chromium content in the sample. The effect of inhibition of the process by Fe_{met} additives cannot be related to the deterioration of the contact of the oxide phase with C_{solid}. This conclusion is contradicted by the invariance of the Cr_2O_3 recovery rate when even large amounts of the inert Al_2O_3 solvent are introduced into the charge. The explanation of the established fact should be sought taking into account the ambiguous influence of iron on the kinetics of the process. On the one hand, Fe_{met} can accelerate recovery due to the catalytic effect on the reaction and the dissolution of chromium and its carbide in it. On the other hand, it is possible to slow down the process due to the consumption of part of CO for the carburization of iron and the formation of its carbide.

UDC 669.162

EVALUATION OF THE DYNAMIC CHARACTERISTICS OF A PARTICLE WHEN IT PENETRATES LIQUID CAST IRON

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Technologies for injection desulfurization of cast iron are based on the introduction of reagent particles (magnesium lime and calcium carbide) into liquid metal using high-speed gas jets. The regularities of the behavior of two-phase jets with liquids are complex, because the individual dynamic characteristics of an individual particle are lost. However, there remains an important question about the ratio of the number of particles that have sunk deep into the metal (in the case of using magnesium)

and the particles that have ended up in a floating bubble (in the case of using lime and calcium carbide). As a result, the question of the immersion of a single particle in a metal is interesting. From a hydrodynamic point of view, the problem of penetration of bodies into a liquid belongs to the classic type of hydrodynamic problems that are relevant nowadays. On the basis of the basic Navier -Stokes equations, methods have been developed for finding the dynamic characteristics of a body entering a liquid, taking into account the cavern formed behind it. To evaluate the dynamics of the particle, we will assume that the spherical body is motionless, and a layer of liquid impinges on it, the movement is quasi -stationary , and the pressure along the surface of the sphere entering the liquid obeys the Lagrange-Cauchy law.

It follows from the calculations that the depth of immersion of a magnesium particle with a radius 0.5 мм in the presence of a cavity behind the particle is several gauges. For an initial velocity of 20 m/s, this is about 6 gauges, and for a velocity of 140 m/s, about 10 gauges. Then the particle begins to be pushed out by the force of Archimedes. Thus, the particle practically does not go far from the main surface of the bubble formed by the gas jet. Further stages of the process are related both to small-scale turbulence, which is formed as a result of fluctuations of the tip of the gas jet, and to the behavior of the bubble itself, from its separation from the nozzle, floating and crushing.

The most important part of the process of refining cast iron with magnesium is its melting, evaporation, and then, thanks to the high partial pressure of the vapor, further dissolution in the mass of the metal. This ensures a fairly fast volume consumption of magnesium during desulfurization , which is the main advantage of the technology of its use. For lime or calcium carbide, for which desulfurization occurs on the surface of the particles, the main issue is the dispersion of the particles and their distance from the main bubble, which should lead to an increase in the reaction surface. The results of calculations for particles of lime (calcium carbide) for two cases: small diameters (0.1 мм) and large (2 мм), show that the specific degree of desulfurization largely depends on the diameter of the particles of lime (calcium carbide) that will blow into liquid cast iron. For large particles, the depth of immersion can be sufficient so that due to local oscillations and random impulses, a particle that is at a distance of about 10 - 15 ммfrom the surface of the bubble will not return to it. Small particles practically do not penetrate the surface, so they will clump in its vicinity and float in the form of clots. Such clots, depending on their size, can be broken up by impulse flows and, falling into large hydrodynamic eddy currents, spread over the entire volume and after the end of the main stage of the process, float up for a long time.

It should be noted that, based on calculations from the mathematical model, particle velocities drop rapidly, which leads to a change in the flow structure, i.e. in the case of the existence of a cavity behind the body, capillary forces will play a significant role. They are taken into account in the model, but as an additional factor.

UDK 669.184

INFLUENCE QUALITY IRON-CONTAINING BRIQUETTES ON ENERGY EFFICIENCY CONVERTER MELTER

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The use of iron-containing waste in an oxygen-converter smelter with an increased proportion of scrap metal in the metal charge requires additional research into the impact of their quality on energy-economic indicators.

An increase in the share of scrap metal in the metal charge by 1% is accompanied by a decrease in the physical heat input of recycled cast iron by 0.11 GJ/t. At the same time, the supply of heat is ensured due to the peroxidation of iron and the reduction of the energy intensity of the molten steel.

Adjustment of the heat balance of melting is carried out both by increasing the degree of CO afterburning of waste gases and by preheating the metal charge in the working space of the unit.

The technology of converter melting with increased consumption of scrap metal up to 32-36% in the conditions of PJSC "Kamet-Stal" provides for its preliminary heating due to the heat of oxidation of planted lump coal with gaseous oxygen.

The total energy consumption for the processing of scrap metal depends on the degree of its oxidation and contamination by non-metallic inclusions (NW) and is, according to various estimates, from 1.4 to 1.7 GJ/t. The lower limit corresponds to the use of "clean" scrap (the so-called "integral" contamination of ferrous metals does not exceed 2% of the mass of scrap), and the upper limit corresponds to scrap with ferrous metals > 5%.

In conditions of limited resources of high-quality scrap metal, briquettes from steel shavings are introduced into the metal charge of converter melting (in the conditions of PJSC "Kamet-Stal", 8-12% of the mass of scrap metal). Iron waste of briquettes during melting is usually 3-5%. The percentage of liquid metal yield from briquettes and the efficiency of their use as a substitute for steel scrap depend on the content of lubricants and coolants (MOP) on the surface of the chips, the degree of its oxidation, the composition and content of HB.

The processes of heating and melting of briquettes of steel shavings with different initial content of HB, fractional composition and amount of MOR, dynamics of formation of iron oxides on the surface of the shavings during their preliminary heating were studied. High-temperature experiment methods were used.

It was found that in the examined samples of briquettes, the value of KZY = 2.1-7.8%. The rate of oxidation of iron briquettes (without creating a protective gas environment over their surface) is maximized upon reaching temperatures of 460-580 ^{0}C and subsequently decreases due to the inhibitory effect of the layer of oxides formed on the surface of the chips. With high temperature gradients according to the thickness of the oxide layer, a thermal conductivity coefficient of approximately 0.2 W/m·K and a volumetric heat transfer coefficient of 35-40 W/m^3·K, the heating of the chip briquettes is slower than that of "pure" steel scrap.

The average chemical composition of the metal obtained from the shavings was determined and the macrostructure of the slag's taken from the surface of the bath during briquette melting was determined in order to determine their influence on the chemical composition of the primary converter slag and establish the nature of the interaction with the converter lining in the first period of melting.

The cooling effect of iron oxides is approximately three times higher than that of non-oxidized steel scrap. The increase in the content of iron oxides on the surface of scrap metal during its preliminary heating (, %) somewhat limits the possibilities of processing its increased amount in the converter. The energy-efficient limit of heating, determined on the basis of the increase in enthalpy of scrap (kJ/kg) during its heating at $\Delta T_б$, ^{0}C, can be approximately determined by the empirical expression:

$$\Delta K_{нагр} = \left(0{,}5 \cdot \Delta T_б + 26 \cdot 10^{-5} \cdot \Delta T_б\right) / 52{,}1$$

The obtained data were used for the development of rational modes of preliminary heating of the metal charge with the use of briquettes in their composition in 250-ton converters. The impracticality of heating scrap to a temperature below 410 ^{0}C is shown.

The energy efficiency of using briquettes made of steel shavings was determined taking into account the specific energy consumption for their production (0.231 GJ/t), collection of shavings and logistics (0.24-0.30 GJ/t). When calculating the influence of briquette quality upon preliminary heating of scrap metal, the chemical heat content of the briquettes was taken into account. The range of changes in the energy capacity of the metal charge during its preheating is established, taking into account the enthalpies of the corresponding reactions and the level of KZI of the briquettes. It is proposed to determine the energy intensity taking into account the expression:

$$E_{П} = C_{ТВ} \cdot \Delta T_б + \left(1 - \frac{K_{ЗИ}}{100}\right) \cdot \left(7345 + 274{,}5 \cdot \%\text{C} + 196{,}5 \cdot \%\text{Si} + 21{,}4 \cdot \%\text{Mn} + 124{,}5 \cdot \%\text{P}\right)$$

where $C_{ТВ}$ is the specific heat capacity of scrap metal, MJ/kg ^{0}C.

УДК 669.162

ANALYSIS OF THE COMPONENTS OF THE SLAG -FORMING MIXTURE FOR ONE – STAGE REMOVAL OF CAST IRON IMPURITIES

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Oxygen-converter way of steel production currently occupies a leading place for the volume of melted steel. It is a fleeting process and refining metal from some impurities is limited in it. Therefore, it is prospectively to take operations of metal refining from main aggregates (blast furnace, oxygen converter) to transitional containers (cast iron buckets) [1-3].

After solving the problem of removing the sulfur from cast iron in metal there will be two main elements left in the steel melt- silicon and phosphorus. Excessive waste of them creates a lot of disadvantages in the process of using such cast iron. For example: addition waste of slag-creating materials, increasing the amount of converter slag, increasing the waste of metal with this slag.

Due to different thermodynamic and kinetic conditions, these processes (oxidation - with silicon and phosphorus, restoration - with sulfur) should be used with a refining slag, which has a high absorption capacity for sulfur and phosphorus, and also has a low melting point and viscosity.

According to spoken, we are interested in the development of the variant of the component composition of the slag -forming mixture.

During numerous studies it has been found that lime slag at the temperature of the cast iron 1350-1400 °C is a solid conglomerate from the slag and the metal phase. The supplement to the original mixture of the dilution component (for example Na_2CO_3) will reduce the melting point and the viscosity of the slag. It will allow not only to remove sulphur and silicon, but also to remove phosphorus. This is the question of finding a rational balance of CaO, Na_2CO_3 and O_2, caused by the volatility of sodium carbonate during interacting with liquid cast iron.

To identify the optimal balance of the components of the mixture, experimental processing was carried out, some of which are shown in Pic. 1 and 2, where the basicity $B = (CaO+Na_2CO_3)/(SiO_2+AL_2O_3)$, viscosity $\eta = f(\Delta E, \rho)$. ΔE, ρ - parameters of interatomic interaction [4].

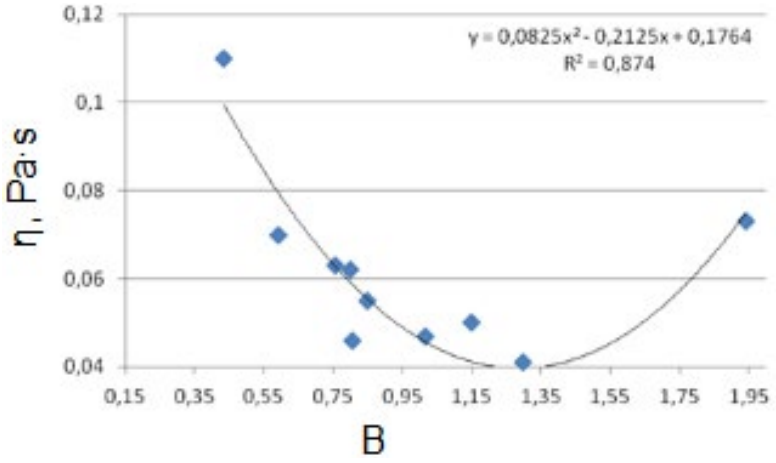

Fig.1 The influence of basicity of sodium bicarbonate –containing slag on its viscosity

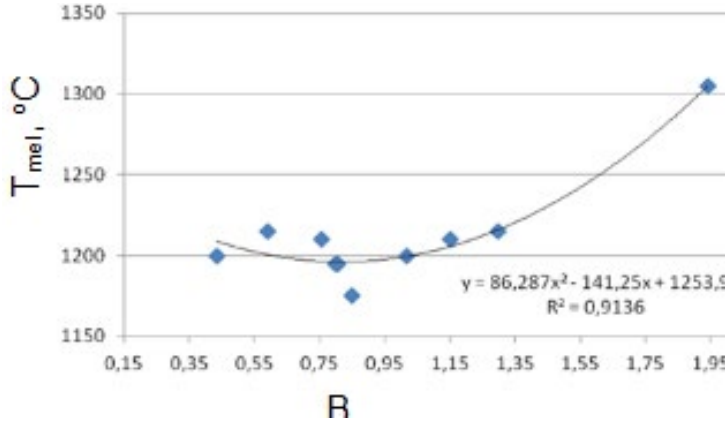

Fig. 2 - The influence of the basicity of the sodium bicarbonate –containing slag on its melting point

Conclusion. With the help of the theory of directed chemical communication, it was studied the influence of the basicity of the soda – containing slag on its physic-chemical properties. It was also studied the optimal balance of the components of the refining slag.

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UDC 621.785.6.669.14.018.252.3

PROPERTIES OF STEEL CASTINGS WITH A DIFFERENTIATED STRUCTURE

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The effect of overheating of the melt before casting on the formation of the structure and fracture characteristics along the cross-section of the castings was studied using the example of 25Л and 30ХГСЛ steels. Casting temperatures for both steels were 1570 ºС, 1620 ºС and 1670 ºС, while there were different cooling rates during crystallization - the usual 2-5 °С/s and fast, which was about 300-350 °С/s. Conventional cooling conditions are metal casting in sand molds, and quick cooling is in copper water-cooled molds under conditions of predominant one-sided heat removal from the end part of the castings during crystallization. At the same time, to ensure directional solidification, the side surfaces of the mold, except for the heat-dissipating one, were thermally insulated. Samples for research were made from the metal of the central parts of the castings along their length.

Metallographic studies showed the formation of the main structural zones in steel castings in the cross-section: the surface of small equiaxed crystals, the transcrystallization zone with the formation of columnar crystals, the transitional zone of branched and the zone of large equiaxed crystals. At the same time, the length of these zones changes depending on the thermokinetic conditions of crystallization of castings, namely, the increase in the length of the zone of near-surface small crystals and the zone of transcrystallization during rapid cooling of the melt. The gradient of the studied structure across the cross-section of castings is clearly demonstrated by the change in grain size (DSTU 8972:2019) depending on the temperature and time conditions of steel crystallization. The

maximum grain dispersion is achieved in the surface volumes of the castings under conditions of rapid cooling and significant overheating of the melt to 1670 C. As it approaches the center of the castings, the grain size increases on average by 4-5 numbers for 25Л steel and by 6-8 numbers for 30ХГСЛ steel . Under the conditions of normal cooling and overheating of the melt to 1670 ºC, a significant increase in grain size in steel castings is observed in general, as well as in the depth of castings by an average of 4 numbers (steel 25Л) and 6 numbers (steel 30ХГСЛ). Such differentiation of the structure creates prerequisites for significant differences in their resistance to brittle fracture depending on the different structural zones of the cast products, depending on the intensity of heat removal and the degree of overheating of the melt.

The results of determining the impact viscosity on standard samples with a Menage cut across the cross-section of steel castings showed that the rapid cooling of the melt at the same time causes a significant increase in the values of the impact viscosity across the cross-section of the castings and is 50-35 J/cm^2 for steel 25Л and 40-20 J/cm^2 for steel 30ХГСЛ, even under conditions of overheating of the melt up to 1670 °C. Under the conditions of normal cooling, there is a significant decrease in the values of impact viscosity across the cross-section of castings from 30 to 15 J/cm^2.

The described conditions of crystallization, hardening and structure formation create a significant amount of phase-structural inhomogeneities in the studied metal, which can play a decisive role in ensuring a certain resource and reliability in the operation of cast steel products. The connection of the temperature-time parameters of crystallization and structure formation of castings with a gradient structure on the characteristics of their destruction in the temperature interval of the viscous-brittle transition was investigated. It was established that an increase in the superheat temperature of the melt in the range of 1570 ºC - 1670 ºC causes, in the case of its rapid cooling during crystallization, a significant increase in the impact toughness of steels across the cross-section of castings in the entire range of test temperatures (+20 ºC... -60 ºC) from 6-21 J/cm^2 to 46-56 J/cm^2 for 25Л steel and from 14-19 J/cm^2 to 42-43 J/cm^2 for 30ХГСЛ steel. With normal cooling and with normal overheating of the melt to 1570 ºC, the maximum values of impact viscosity in different volumes of castings under the same test temperature conditions vary within 34-4 J/cm^2 for 25Л steel and 38-13 J/cm^2 for steel 30ХГСЛ. Thus, it was established that the rate of heat removal during crystallization affects significant changes in the fracture characteristics (KCU) in different macrovolumes of steel castings.

UDC 669.162.2.04 : 001.8

ANALYSIS OF THE EFFICIENCY OF TECHNOLOGIES AIMED AT DECARBONIZATION OF THE BALST FURNACE PRODUCTION

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The report discusses the results of thermal energy and exergy analysis of the potential of new and existing technologies for reducing carbon dioxide emissions and coke consumption, the possibility of increasing iron production due to the injection of hydrogen and hydrogen-containing fuel additives into the furnace, the use of metal additives, increasing the blasting temperature, reducing heat losses, and improving gas distribution in blast furnace.

With the use of the mathematical model of the complete energy balance of blast furnace smelting, developed in ISINASU, an assessment of the impact of the potential of new and existing technologies on the reduction of CO_2 emissions and technical and economic indicators of blast furnace smelting was performed.

CO_2 emissions in blast furnace production can be reduced by 25-30% by making changes to blast furnace smelting technology, and they depend on investments, the raw material and energy base of the metallurgical enterprise, and the level of existing blast furnace smelting technology. However,

such a reduction in CO_2 emissions due to the use of hydrogen and hydrogen-containing fuel additives may not be economically beneficial from the point of view of increasing the price of metal products. Today, the use of pulverized coal fuel is the main factor in reducing the cost of production of cast iron in advanced practice.

Therefore, the report provides calculations for the reduction of CO_2 emissions and changes in the consumption of coke and iron production with a decrease in the consumption of pulverized coal fuel and an increase in the consumption of hydrogen and hydrogen-containing fuel additives, and their combinations.

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

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

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

UDK 669.162

REGIME PARAMETERS FOR THE PRODUCTION OF BLAST-FURNACE SMELTING PRODUCTS

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On the basis of a critical analysis of works aimed at improving the mode parameters of the output system of blast furnaces, an assessment was made in the first approximation of the impact of changing the mode of output of smelting products on the condition of the coke nozzle in the furnace (more precisely, on the distance between the levels of air lances and cast iron jets), as well as on stability of the cast iron temperature at the outlet. Each of the parameters of the release mode - the number and duration of releases, the interval between them, the geometry of the channel of the cast-iron fly and the location of the fly on the circumference of the furnace are related to each other, but they can affect the operation of the blast furnace in different ways.

It is shown that progress in blast furnace production is associated with certain changes in the design, parameters, and operation of the output system of furnaces. The latter include increasing the uniformity of placement of cast-iron flywheels around the circumference of the horn; the tendency to decrease the angle of inclination of the channel of the cast-iron fly with an increase in the absolute and relative depth of the sump and the transition from a temporary change in the diameter of the drill bit and, accordingly, the channel of the fly to the algorithmization of the selection and permanent correction of this diameter in accordance with the change in the properties of the smelting products and the release mode.

It is shown that maintaining the maximum possible distance from the zone of the air jets to the "gas - slag" interface in the coke nozzle before opening the iron fly is achieved due to the convergence of the mass rates of accumulation and release of melts. Therefore, the rational release technology should not be considered as the one in which the increase in the duration of the release is achieved by reducing its mass rate, but the one in which the long release is maintained with similar rates of accumulation and release of melting products.

If the number of cast-iron flywheels and their location around the circumference of the furnace are related to the construction of new or modernization of existing furnaces, then the geometric

parameters of the cast-iron flywheel itself may change during the furnace campaign, depending on the selected mode of smelting product releases. The scheme according to which the length and shape of the channel of the fly depends on the method of supplying the closing flying mass corresponds to the modern view of the geometry of the channel of the cast iron fly. A "short" fly appears with a limited amount of locking mass and helps speed up the release, an elongated one with a mushroom-like growth slows down the release.

A conclusion is made in favor of the direction in which increasing the productivity of blast furnaces is associated with an effort to bring the rates of accumulation and release of smelting products closer together, since in this direction conditions are created for maintaining the smooth operation of the furnaces and stabilizing the quality of cast iron.

Based on the analysis of domestic and foreign experience, the requirements for the constructive design of the outlet system of blast furnaces were formulated. In order to ensure drainage in the coke nozzle during the construction of new and modernization of existing furnaces, the distance in plan between cast-iron flights should be maximal. The length and angle of inclination of the channel for the formation of a cast-iron fly in the furnace fence must be coordinated with the volume and profile of the furnace, as well as its operating conditions.

It is shown that when the productivity of the furnace increases and the number of releases increases, the preservation of their duration and speed of output of melting products eliminates additional disturbances of the blast furnace process and is accompanied by a decrease in fluctuations in the temperature of cast iron.

Changing the release regime by bringing together the mass rates of accumulation and release of smelting products creates conditions for a simultaneous decrease in the content of silicon and sulfur in cast iron, while in the normal conditions of the blast furnace process, the behavior of the specified impurities is the opposite - as the temperature increases, the content of silicon in cast iron increases, and sulfur decreases.

UDC 669.18.046.5:669.013.083.133

ANALYTICAL STUDY OF THE MAIN MECHANISMS OF THE DESTRUCTION OF FUSED PERICLASE-CARBON REFRACTORS UNDER THE INFLUENCE OF AGGRESSIVE ENVIRONMENTS AT ELEVATED TEMPERATURE WITH THE PURPOSE OF INCREASING THEIR SERVICE LIFE

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In modern conditions, the operation of a significant amount of metallurgical technological equipment and certain of its structural elements, especially those used under the extreme influence of aggressive environments and temperature regimes, approaches the ultimate limit of projection strength. This aspect is of particular importance in Ukraine in relation to metallurgical enterprises, given their difficult economic situation and the lack of the possibility of deep modernization of existing technological equipment. The most critical structural element for metallurgical units in terms of service life is the refractory lining. Thus, in modern conditions, the issue of developing complex methods of monitoring and timely detection of areas of local destruction of refractory elements of technological equipment arising due to the influence of an aggressive working environment and the additional influence of high temperatures is relevant.

According to the conducted research, the destruction mechanisms of fused periclase-carbon refractories (FPC) used in oxygen converters and other metallurgical equipment have been clarified. It was confirmed that the mechanisms of destruction are different for different areas of the lining, which is due to the different nature of the physical and chemical influence of the environment that contact with the refractory. According to the established macro picture of the destruction of refractories, it was

determined that the most aggressive is the impact of metallurgical slags, which causes the formation of a decarburized transition zone in the volume of the refractories. In this way, the contact of the carbon bond with the periclase grains deteriorates and structural destruction is observed. This is expressed in the formation of cracks and cavities, which cause the destruction of the refractory material at the border of contact with the slag melt.

Given the physico-chemical structure of refractory FCP (the presence of a carbon bond), the electrical resistance of the section of the refractory material under investigation was chosen as a parameter for determining the depth of destruction. Analytical expressions were developed based on the information about the change in the resistance of FCP refractories as a function of temperature and carbon content to calculate the value of the electrical resistance of the area under investigation for a change in its profile. Based on the results of the obtained dependencies, the method of "Operational assessment of the degree of destruction of refractory carbon-containing materials used for the production of liquid steel" was created. The developed method involves measuring the electrical resistance indicators of the section of the refractory lining in accordance with standardized methods using standardized measuring devices and calculating the profile of its destruction using analytical expressions. A characteristic feature of the technique is the possibility of determining the real depth of the lining destruction without taking into account the thickness of the slag garnish. Application of the technique can contribute to increasing the life of refractory lining by 3-5%, which is 0.3-0.5 UAH/t of liquid steel (at prices as of 01.12.21).

UDC 669.184

JUSTIFICATION OF DESIGN PARAMETERS OF BLOWING DEVICES OF 250-TON OXYGEN CONVERTERS IN CONDITIONS OF PRE-HEATING OF SCRAP METAL

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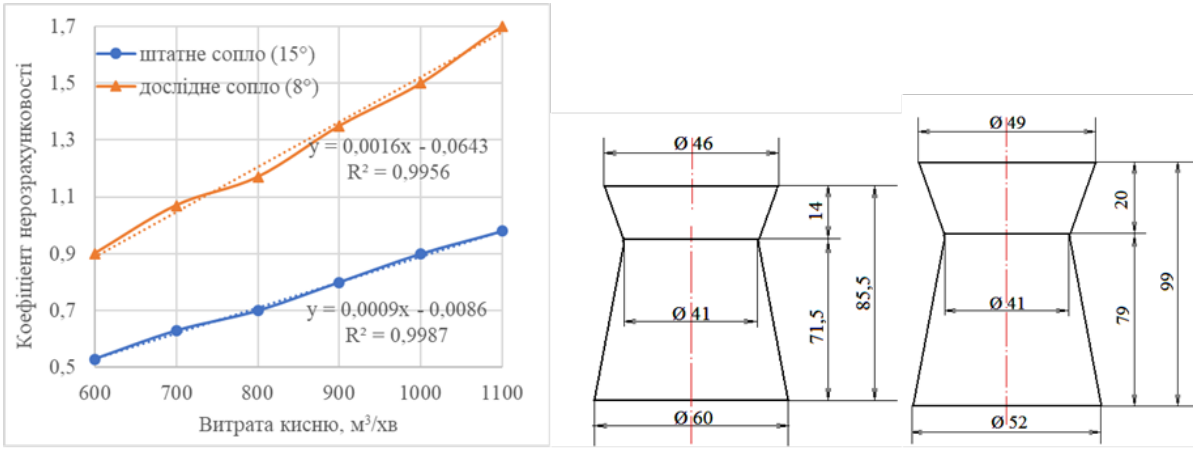
In the current raw material conditions and existing smelting technology, one of the main areas of improvement of oxygen lance tips for 250-ton converters should be considered the development of 5-nozzle lance tips with the configuration and location of Laval nozzles, which meet the requirements of scrap preheating and optimization of slag formation by of the blowing cycle, provided that the oxidation of the bath is reduced.

When developing the design of 5-nozzle nozzles PJSC "DMK" (now PJSC "KAMET-STEEL") according to the method [1], the need for preliminary heating of scrap was taken into account. In this mode, the oxygen consumption is 650-750 m3/min. In the main period of oxygen refining, the oxygen consumption is 950-1000 (1100) m3/min. It should be noted that without the use of a fleet of lancets designed for various procedures (heating scrap, refining iron, etc.), researchers have to make compromises, since the operation of the lancet in the calculated mode (coefficient of uncalculability in = 1) with significant fluctuations in oxygen consumption is impossible.

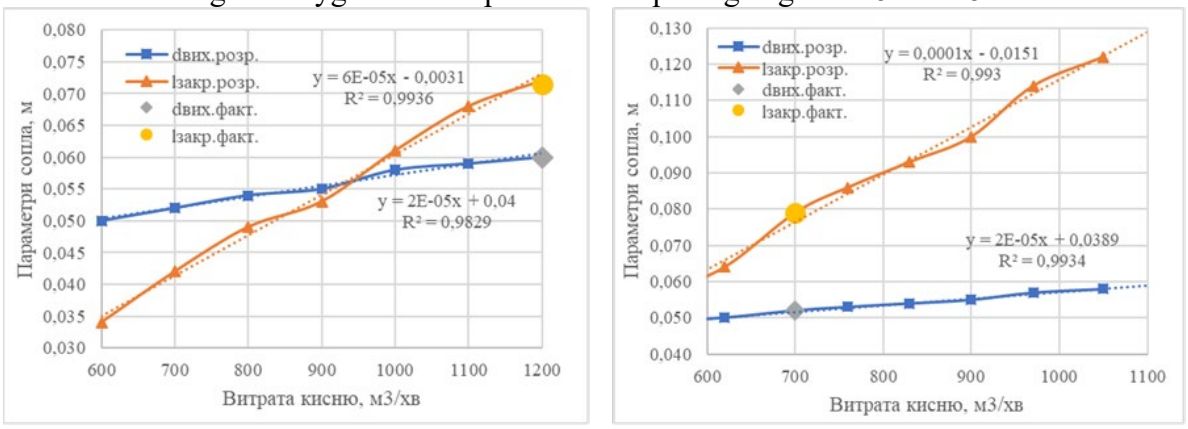
Figure 1 presents data on the change in the coefficient of uncalculability depending on the oxygen consumption for a 5-nozzle lance. It is shown that the standard lance works in the calculated mode with an oxygen consumption above 1100 m3/min. On the one hand, this design allows for more complete use of the potential energy of the oxygen jet during oxidative refining, and on the other hand, if it is necessary to preheat the scrap, purging occurs with overexpansion of the oxygen jet (n = 0.60—0.65), which can lead to nozzle heat up. The issue of overexpansion is still debatable, since there is an opinion that the operation of the nozzle with a miscalculation coefficient of less than 1 is acceptable [2].



a b c

Figure 1 – The value of the coefficien of uncertainty (a) in the working range of oxygen consumption for a 5-nozzle tip with regular (b) and experimental (c) nozzles

The proposed design of the nozzle tip works effectively in scrap heating mode at 650-750 m3/min. and has n = 1-1.1. At an oxygen consumption of 900-1000 m3/min. the coefficient of uncalculability is within 1.3-1.5, which is a completely acceptable value [3]. The shape of the nozzle of the standard and experimental 5-nozzle tip is shown in Figure 1b, c. The nozzle of the experimental tip has a smaller opening angle of the diffuser and is somewhat elongated compared to the regular design. Figure 2 shows the calculated parameters of the subcritical part of the nozzle of the 5-nozzle tip for the studied range of oxygen consumption at the opening angle of 15° and 8°.



a b

Figure 2 – Calculated values of the subcritical part of the nozzle with an opening angle of 15° (a) and 8° (b)

Figure 2 shows that reducing oxygen consumption requires shortening the length of the postcritical part of the nozzle, which is fully correlated with literature data [4, 5].For the standard nozzle (Fig. 2a), due to the excessive opening angle of the nozzle for the scrap heating mode, l_{zakr} should be 40-45 mm, which can complicate the existing technology of manufacturing a 5-nozzle tips.A less radical decision was to reduce the opening angle of the nozzle (Fig. 1b), which made it possible to slightly increase the length of the nozzle and increase the stiffness of the blow.

Thus, nozzles with experimental tips, at the available pressure in the shop, work reliably in the oxygen consumption range of 650-950 m^3/min and allow increasing the oxygen consumption at the beginning of blowing to 1000-1100 m^3/min and more, if necessary.

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UDC 669.184

DETERMINATION OF THE CLOGGING INDEX OF BRIQUETTES MADE OF STEEL SCRAP

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The metallurgical value of scrap metal, which is used as a component of metal charge in steelmaking processes, is primarily determined by the yield of liquid metal. The latter, in turn, depends on the degree of clogging (contamination) of scrap metal prepared for remelting by various types of inclusions and impurities.

To determine briquette clogging, employees of the Dnipro State Technical University developed a technique that involves remelting a batch of briquettes in an induction furnace in a controlled environment protected by inert gas, followed by determination of the chemical composition of steel and slag. As a result of carrying out balance floats, an integral clogging index is obtained, which takes into account the presence of moisture, solid waste, harmful and harmless impurities in the briquettes.

To confirm the reliability of the results obtained using the DDTU method, a series of experiments was conducted, which consisted in the selection of averaged samples from different batches of briquettes, the sorting of samples into fractions, and the remelting of samples reduced to 200 g in a Tamman furnace. Data on the fractional composition are presented in Fig. 1.

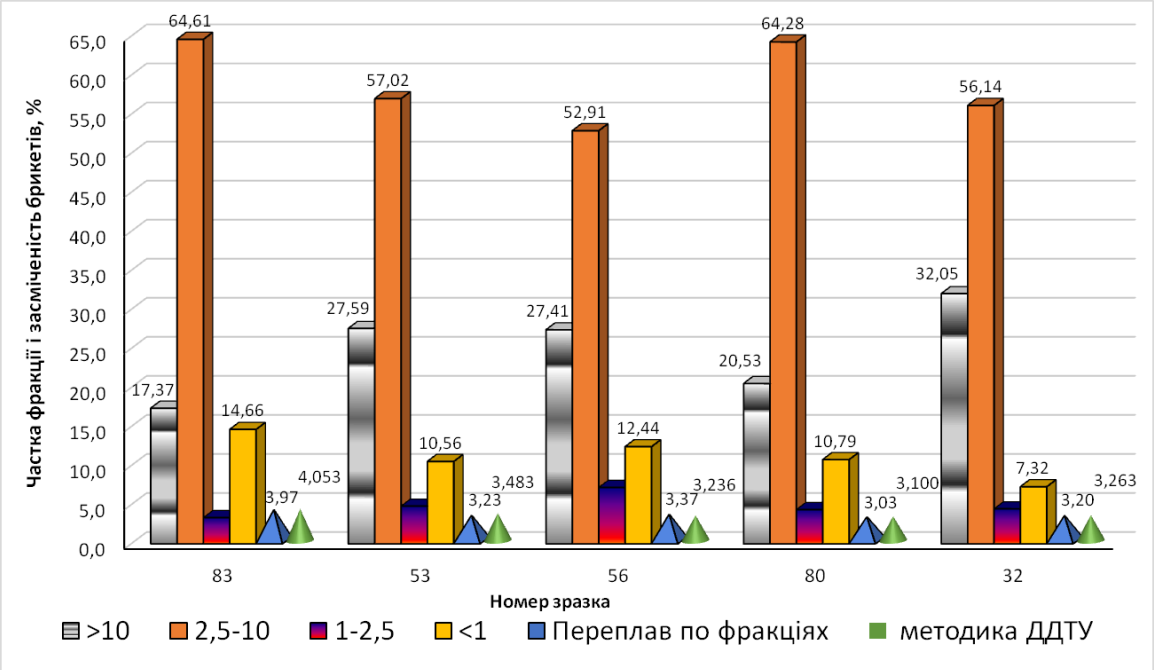

Fig. 1 - Ratio of fractional composition and clogging in different samples of briquettes

Figure 1 shows that chips of fraction 2.5...10 mm (52.91...64.61%) are predominant. At the same time, the share of the fraction smaller than 1 mm is in the range of 7.32...14.66%. It is shown that the indicator of clogging according to the DDTU method correlates quite well with the results of remelting by fractions.

The results of determining the percentage of clogging by fractions are presented in Fig. 2.

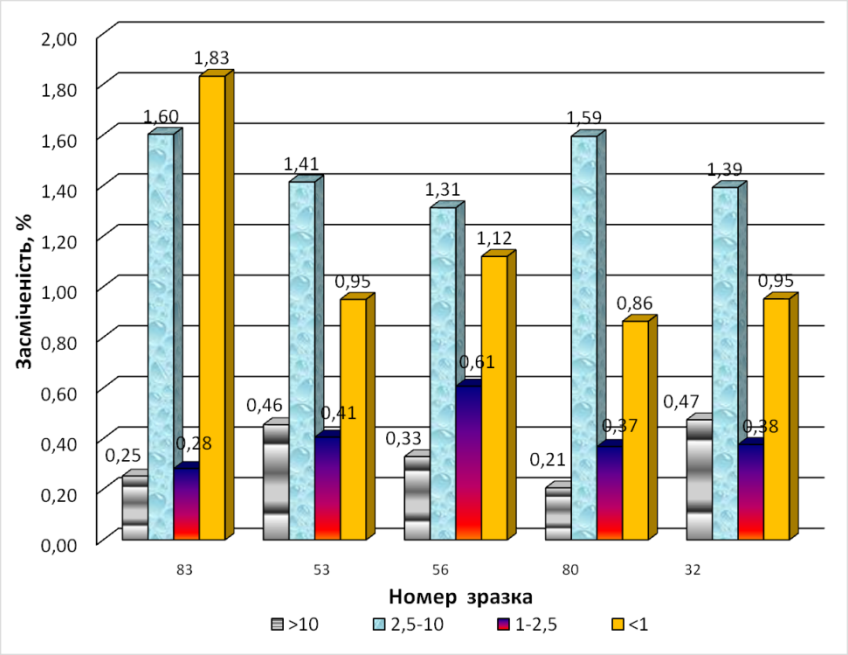

Fig. 2 – The proportion of briquettes clogged by fractions

Figure 2 shows that the main share of clogging falls on fractions of 2.5...10 mm and <1 mm and is 72-86% of the total number of pollutants. It is worth noting that the share of clogging from the <1 mm fraction approaches, and in some cases even prevails, the corresponding indicator for the 2.5...10 mm fraction, the number of which is 4...8 times greater.

Thus, the presence of a fraction <1 mm, which, according to the results of laboratory studies, mostly consists of iron oxides, can be considered one of the determining factors affecting the indicator of briquette clogging. However, the heterogeneity of briquettes not only in different batches, but also within the same batch, requires further research to obtain multifaceted information about the sources of briquette contamination and possible ways to reduce it.

UDC 669.168.046.6 : 669.74.003.12

ASSESSMENT OF THE POSSIBILITY OF THE DIRECT USE OF DOMESTICLY MADE MANGANESE FERROALLOYS WITH DEVIATIONS IN CHEMICAL COMPOSITION

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The functioning of the domestic ferroalloy industry under martial law conditions and the limitation of supplies of high-quality imported raw materials make it necessary to resolve issues related to the production of manganese ferroalloys in accordance with regulatory requirements and the possibility of direct use of a certain amount of such products with deviations in chemical composition. In turn, ensuring the competitiveness of metal products produced by enterprises of Ukraine at the present time, along with improving the processes of smelting and non-furnace processing of steel, cause additional attention to the relevant parameters of the materials used, in particular, ferroalloys. Therefore, quality assessments and the use of domestic manganese ferroalloys are becoming relevant.

Manganese ferroalloys (ferrosilicomanganese brand MnC17 and ferromanganese brand FMn78) were chosen as the objects of the study, which are the most massive in terms of production volumes at domestic ferroalloy plants and used in metallurgical enterprises.

For the purpose of an improved theoretical assessment, the research used the "Ferrosplav" computer database created in advance under the leadership of Prof. Togobytska D.M., which included industrial data of ferroalloy production, as well as information on the physical, thermophysical and other technological properties of various grades of ferroalloys.

The research was carried out using a statistical method for the MnC17 group (total number of fuses - more than several thousand) and the FMn78 group (about a thousand edits) based on the data of their actual industrial production and with further generalization of the results.

Each brand of studied ferroalloys was analyzed separately for the content of manganese, carbon, silicon, phosphorus and sulfur and the deviation of these elements from the normative (according to DSTU 3547 - 97 and DSTU 3548 - 97) content was evaluated. Research was revealed the normalized content of manganese, silicon and phosphorus (each of the elements separately) in less than 1% of melts, and at the same time two elements (silicon with manganese, carbon or phosphorus) - in approximately 0.1% of melts (for the MnC17 brand). For the FMn78 brand, the non-standardized deviation for the content of silicon and phosphorus (each element separately) is set at less than 1% of melts. In terms of sulfur content, both brands of ferroalloy had deviations from the requirements of the relevant standards.

A calculation assessment of the possibility of using the researched grades of ferroalloys with non-standardized content of the listed elements in the conditions of the Dnipro metallurgical plant in the production of steel of the current grade assortment was also carried out. It was established that, in compliance with the technological production regulations adopted at the enterprise, the use of such ferroalloys, in the vast majority of cases, is possible and does not cause difficulties. The exception applied only to individual melts, where (taking into account the chemical composition of the steel) the use of additional materials, not foreseen by the technology, was required. Therefore, such ferroalloys, as an exception, can be used in the smelting of mass steel.

At the same time, it was found that during the formation of railcar delivery rates at the ferroalloy plant, different melts are mixed separately for each of the ferroalloy brands, and during unloading at the consumer company, additional averaging by chemical composition is not excluded. Therefore, it is not possible to detect in advance in such conditions a ferroalloy with a non-normalized content of elements.

UDC 669.09.26

TRANSITION OF METALLURGY TO HYDROGEN TECHNOLOGY

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A significant amount of CO_2 enters the atmosphere due to the production of iron and steel. Let's consider this on an example. At 2021, 21,165 million tons of pig iron were smelted in Ukraine. In total, 500 kg of conventional fuel containing 80% carbon is spent on smelting a ton of cast iron, i.e. 400 kg of carbon. For the smelting of the entire annual production of iron in Ukraine, carbon consumption will be $21{,}165 \times 0.4 = 8{,}466$ million tons. All this carbon during the production of iron and steel enters the atmosphere in the form of CO_2.

When carbon is oxidized by the reaction $C + O_2 = CO_2$, 3.67 tons of carbon dioxide is formed per ton of carbon that is oxidized. During the annual production of iron in Ukraine of 21,165 million tons, 31,07 million tons of CO_2 are emitted into the atmosphere.

D.K. Chernov carried out an in-depth analysis of the process of primary production of iron and came to the conclusion about the possibility of smelting steel in the blast furnace itself without using coke for this. However, the development of non-coke metallurgy took a different path.

One of the directions was the production of sponge iron, i.e. recovery in the solid phase.

Another direction of cokeless metallurgy is high-temperature processes of obtaining liquid metal, carried out in one stage

Thus, the development of coke-free metallurgy followed the separation of solid-phase and liquid-phase recovery into separate processes,

During the development of these processes, the main incentive was the desire to obtain iron (steel) without the use of coke.

In 2020, Metinvest Group started developing a long-term technological strategy taking into account environmental challenges. The company sees the technological future in electric steelmaking processes and the use of hydrogen. The construction of a single complex consisting of direct iron recovery (DRI) technology and electrometallurgical production for the processing of hot DRI is planned.

It is planned to prepare iron ore raw materials, the final product of which will be DRI pellets, metallization of pellets in mine furnaces using hot reducing gases, melting of metallized pellets in electric steel melting furnaces.

The theoretically necessary amount of reducing agent during the reduction of iron with carbon monoxide and hydrogen is determined from the reactions:

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$
$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$$

It follows that 0.75 tons of carbon monoxide or 0.05 tons of hydrogen are needed to restore a ton of iron. With the degree of use of CO and H_2 in the reducing unit at the level of 45%, the mass of reducing agents increases to 1.67 and 0.11 t/t of iron, respectively. The mass of hydrogen is more than 15 times smaller than the mass of carbon monoxide. Therefore, it is economically expedient to use hydrogen as a reductant, if its price is no more than 15 times higher than the price of carbon monoxide.

In order to reduce the carbon footprint in the atmosphere, the transition of ferrous metallurgy to hydrogen technology is mandatory.

The most rational hydrogen technology is the preparation of iron ore raw materials to obtain DRI pellets, their metallization in mine furnaces, and steel smelting in electric furnaces.

WAYS OF RESTORATION OF THE FULL FUNCTIONING OF THE BLAST FURNACE PRODUCTION OF UKRAINE DURING THE WAR AND POST-WAR TIMES

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Today, blast furnaces are the main producer of iron in Ukraine and in the world, since blast furnace production is the most efficient and economically profitable way of producing iron.

When preparing iron ore raw materials for the production of hot metal, the export component of the concentrate needed for the production of pellets at the mining and processing complex of Poltava and Dnipropetrovsk region should be reduced in the near future. During the production of agglomerate at the enterprises "Kamet-steel", "Zaporizhstal" and "ArcelorMittal Kryvyi Rih", it is necessary to develop measures for environmental protection of production - modernization with the equipment of dry gas cleaning equipment and improvement of the quality of the finished agglomerate, first of all, this concerns the enterprise "Kamet-steel" (Kamyanske) in view of the technical condition of the operating sinter plant. Taking into account the existing theoretical and research and industrial developments, it is advisable to use 30% pellets and 70% agglomerate when smelting iron. A

promising direction is also the development of technologies for waste-free pulverization of secondary raw materials - cold briquetting and granulation of small-fraction iron-containing wastes with their intensive formation by gas purification systems.

Coke substitute energy carriers in the production of iron in blast furnaces include pulverized coal fuel and natural gas. The cost of natural gas, which was supplied by the reverse means from Europe to Ukrainian enterprises, changed significantly depending on the season, so, for example, in 2021–2022, natural gas was used in the production of hot metal only in June and July. At the same time, when joint use in blast furnace production of pulverized coal fuel and natural gas, it is necessary to improve the efficiency of replacing valuable coke with these fuel additives. Such measures were implemented by specialists of the ISINASU at the "Kamet-steel" enterprise in 2021. They consisted in the manufacture and implementation of a fundamentally new for Ukraine design of the supply of fuel additives to blasting, which includes the supply of pulverized coal fuel and natural gas to separate spears of the tueres device [1].

Pulverized coal fuel, as the main substitute for coke, in the period until 24.02.2022 was produced mostly from coal of the lean fused grade of Russian origin. Since 24.02.2022, during the martial law and the complete rejection of Russian energy carriers, an urgent problem for metallurgical enterprises of Ukraine, in particular for the currently operating: "Kamet-stal", "Zaporizhstal" and "Arcelor Mittal Kryvyi Rih" (with the temporary loss of the "Azovstal" plants and "MMKI", Mariupol in 2022 and the temporary loss of control over the "AMK" (Alchevsk), "YEMZ" (Yenakieve) and "DMZ" (Donetsk) plants in 2017) the search for alternative types of fuel for blast furnace production began. In particularly critical periods of the operation of metallurgical plants, such as at the beginning of full-scale Russian aggression, blast furnace production used a technology without blowing fuel additives into the furnaces using wet blasting.

Therefore, the relevance of conducting research in this aspect is determined both by the work of Ukrainian enterprises in the conditions that developed during the war, and from the point of view of the post-war recovery of the metallurgical industry. Such research should include, first of all, the search for alternative grades of coal and (or) their mixture for the production of pulverized coal fuel, in particular - domestic long-flame gas coal and lean fused coal of North American and Australian origin. Thus, in June 2022, at the "Kamet-steel" plant, a successful trial smelting was conducted using pulverized coal fuel from a mixture of long-flame gas coal and coke ground fines with the use of natural gas together with pulverized coal fuel. And starting in September 2022, experimental blowing of sintering coal of Australian origin will be carried out at the "Kamet-stal" and "Zaporizhstal" plants.

In addition, researches in wartime and postwar times should include: improvement of methods of supplying natural gas during its seasonal use to the nozzle device and during the combined use of natural gas and pulverized coal fuel; improvement of loading modes of blast furnaces and gas mode when working on coke of poor quality [2] (a significant decrease in the quality of coke was observed at Ukrainian enterprises since 24.02.2022 – a 10–12% decrease in the hot strength indicator); for the conditions of "Kamet-steel" - improvement of decision-making support methods and systems regarding the management of blast distribution around the circumference of blast furnaces by creating directed circumferential unevenness of fuel additive consumption in order to ensure a uniform thermal state of the blast furnace zone [3, 4]; research into the combined blowing of blast furnace dust and pulverized coal fuel into blast furnace in order to increase the gas permeability of the charge by reducing the amount of iron-containing materials in the dry zone of the blast furnace and intensifying the creation of oxidized slag in blast furnaces for washing the blast furnace zone [5, 6]; the development of directions related to the injection of coke gas into blast furnaces, taking into account the existing theoretical, experimental and industrial developments of the ISINASU [7, 8].

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UDC 669.184

ANALYTICAL STUDY OF CHARACTERISTICS OF STREAMS EMERGING FROM NOZZLES OF DIFFERENT DESIGNS

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he oxygen-converter method of production of a liquid semi-product is quite complex and multi-stage, and is characterized by extremely high temperatures, which complicate its direct study. Fro this poin of view, the method of full-scale physical modeling of individual process operations remains accessible and quite widespread.

The main tool that implements and allows to control the oxygen converter process is the top blowing. It is carried out using a blowing lance equipped with nozzles. Depending on the enterprise, the number and type of nozzles may vary, and their parameters depend on the capacity of the converter and the technology of steel production. At the same time, in the rather complex batch conditions of work of Ukrainian enterprises, the task of improving the designs of nozzles, which allow intensifying the processes in the bath, remains relevant. For this reason, under the conditions of maintaining the oxygen consumption at a constant level, it is necessary to use such nozzle designs that will allow to achieve the increasing momentum of the jet acting on the metal bath. In this regard, an analysis of the possibility of using nozzles of the coherent type (includes coaxially located central and peripheral channels) for the specified conditions was carried out. It is known from classical physics that momentum depends on weight and speed:

$$I = m\omega \text{ , kg·m/s} \quad (1)$$

where m is the mass of the jet, kg; ω is the speed of the jet, m/s.

When providing equivalent blowing conditions (velocity 2 M at the exit from the nozzle), the mass of the jet is a variable in equation (1). Under the specified conditions, it depends on the diameter of the nozzle, the position of the lance and the involvement of additional mass of the surrounding gas to the jet (depends on the design of the nozzles).

According to the results of laboratory studies on the weighing of jets flowing from nozzles (cylindrical with a diameter of 1 mm to 3.2 mm; nozzles of the coherent type with different diameters of the central nozzle of 1.6 - 2.8 mm), an analytical expression of the dependence of the weight of the jet on technological parameters of blowing: nozzle position, gas supply pressure and geometric parameters of the nozzle. Empirically established jet momentum loss coefficients that depend on the geometric parameters of the nozzle have also become an important component of the analytical expression. The developed analytical expression has the following form:

$$G = 0{,}0034 \cdot P \cdot h_L \cdot (K_{center} \cdot d_{center}^{Kcenter} + K_{annular}(d_{external}^{Kannular} - d_{\text{int}\,arnal}^{Kannular}), R^2 = 0{,}9 \quad (2)$$

where P is the pressure of the blowing gas in front of the nozzle, kPa; h_L – the position of the lance relative to the bath in a calm state; K_{center} - momentum loss coefficient when blowing through the central part of the nozzle; $K_{annular}$ - coefficient of momentum loss during blowing through the outer annular part of the nozzle; $K_{center\_flowing}$ and $K_{annular\_flowing}$, accordingly, the flow coefficients through the central and annular parts; $d_{center}, d_{externel}, d_{\text{int}\,arnal}$ - respectively, the diameters of the central part and the external and internal diameters of the annular part of the coherent type nozzle. Expressions for calculating jet momentum loss coefficients in different parts of the nozzle:

$$K_{center} = 0{,}8103 \cdot d_{center}^{0{,}1092} \quad (3)$$

$$K_{annular} = 0{,}75 \cdot (d_{external} - d_{\text{int}\,arnal})^{0{,}1092} \quad (4)$$

$$K_{center\_flowing} = 0{,}5439 \cdot d_{center}^{0{,}18} \quad (5)$$

$$K_{annual\_flowing} = K_{center\_flowing} \frac{K_{annular}}{K_{center}} \quad (6)$$

UDC 669.02/09 : 669.18.046.58

DEVELOPMENT OF THE CHEMICAL COMPOSITION OF REFINING SLAG FOR THE LRF PROCESS

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For the LRF process, solid slag mixtures (SSM) are used, which consist of lime and fluorite (CaF_2 ≥85 weight %) in a ratio of 70÷75:30÷25%, respectively. Steel refining processes in the steel ladle are characterized by high intensity. This requires a high rate of slag formation and diffusion processes in the "metal-slag-gas" system. Therefore, the slag melt must have optimal properties, which will affect the rate of diffusion processes in the "metal-slag-gas" system.

The use of fluorite in the SSM for metal refining at the LRF is not justified, as evidenced by the results [1, 2]. It is necessary to reduce the content of fluorite in the SSM. The analysis of viscosity, electrical conductivity and the corresponding values of activation energies for the system was performed: 24÷41% CaO - 42÷48% SiO_2 - 9÷11% Al_2O_3 - 0.01÷12.5% Na_2O - 6÷24% CaF_2 according to [3]. It follows from the analysis that CaF_2, compared to Na_2O, has a more significant effect on the viscosity of the system than on the electrical conductivity, which is related to the depolymerization of $Si_xO_y^{z-}$ anions, according to the scheme:

$$(– Si – O – Si –) + 2F^- = 2(– Si – F) + O^{2-}.$$

The Na_2O has more effect on electrical conductivity than on viscosity, which may have an association with Na+ ions, which can desulphurize the metal to form the Na_2S compound.

Based on the results of calculating the activation energies of viscosity (Eη) and electrical conductivity (Eχ), the optimal chemical composition (wt. %) CaO≈30% was established; SiO_2≈42%;

Al_2O_3≈9%; Na_2O≈11% CaF_2≈6%, which has a homogeneous melt at a temperature of 1450° C, a viscosity of 0.38 Pa·s and an electrical conductivity of 0.4 $\Omega^{-1}\cdot cm^{-1}$.

The obtained results can be used as recommendations for replacing and reducing the use of imported fluorite in the composition of SSM for steelmaking.

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UDC 669.162.275.2:669.162.212

ASSESSMENT OF THE CORROSION ACTIVITY OF ALKALINE-CONTAINING BLAST FURNACE SLAGS IN RELATION TO REFRACTORIES

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The conducted studies showed that the interaction of primary and final blast furnace slags, containing a significant amount of alkaline oxides, with refractories at high temperatures leads to their destruction due to the formation of low-melting compounds and dissolution of refractories. Due to the chemical composition and properties of slag melts, the corrosion activity of slags in relation to refractories can be evaluated using the criterion of corrosion resistance of refractories to slag melts, which is chosen as the constant of the rate of impregnation of the refractory with slag (1), which allows the selection of refractory material for different zones of the furnace depending on the temperature conditions of its operation and the slag regime, as well as to evaluate the influence of the chemical composition of the slag, in particular oxides of alkali metals, on the resistance of refractories.

$$\lg K\left(\times 10^7, sm^2/s\right) = -5.126 + 2.234\cdot\Delta d + 4.059\cdot\Delta Z^Y + 73.443\cdot\Delta tg\alpha + 0.0356\cdot\Pi + 0.0042\cdot T \qquad (1)$$

where, ΔZ^Y, Δd, Δtgα are the difference parameters of refractory and slag; P - porosity of refractory,%; T is the operating temperature of the refractory, °C.

The analysis of the obtained data showed that each 1% of alkali metal oxides in the slag increases the rate constant of refractories impregnation by slag by an average of 7%, while an increase in the temperature of the slag by 10°C leads to an increase in the refractories impregnation constant by 12%. The influence of alkaline compounds on the amount of slag corrosion of refractories will be the highest in primary slags, where the content of alkali metal oxides can be more than 10%, which will lead to an increase in the rate constant of refractories impregnation by 70%, that is, almost twice. As the temperature increases and the chemical composition of the slag changes, the content of potassium and sodium oxides decreases, and therefore their influence on the wear of the lining becomes insignificant. The main factor affecting the refractory impregnation constant in the hearth zone is temperature. Therefore, the removal of alkaline compounds from the blast furnace with the final slag, and therefore an increase in their content in it, will not lead to a significant increase in the wear of refractories in the hearth area.

UDC 669.162.27.012.34 : 51.001.57.001.86

EXPERIENCE IN THE DEVELOPMENT AND IMPLEMENTATION OF MATHEMATICAL MODELS OF THE MATERIAL AND HEAT BALANCE OF THE BLAST FURNACE MELT IN THE CONDITIONS OF PJSC "MK "AZOVSTAL"

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The application of balance models in blast furnace (BF) production allows to determine the reserves for increasing the energy efficiency of blast furnace smelting and to assess the impact of changes in the technological parameters of the furnace operation on its technical and economic indicators. Control of material and heat flows during hot metal smelting is an important task from the point of view of the rationality of the chosen mode and its economy, since the physical and mechanical processes of blast furnace smelting, chemical transformations of the charge and interaction with the environment are ultimately reflected by material and heat balances.

On the basis of the collected data on the operation of the blast furnaces of PJSC "MK Azovstal", software was developed in ISINASU, that is based on the mathematical models of the material and heat balances of the blast furnace smelting. The calculation of the material balance is carried out according to the "accounting system" of V.P. Izhevsky, which received a positive assessment from blast furnace scientists, for example, N.A. Kostilyov, M.A. Pavlov and others. The thermal energy model of I.D. Semikin, which was developed for use in blast furnace production by A.V. Borodulin, was used to calculate the heat balance. The main difference between the balance thermal energy model of I.D. Semikin from other models is accounting thermal losses of the BF and calculating the degree of direct and indirect recovery. The software allows to calculate balances in automatic mode (collection the data from the APC system and calculation of material and heat balances for the selected period) and in manual mode (calculation of forecast periods to determine reserves for increasing the energy efficiency of blast furnace smelting).

Monthly calculations of the material and heat balances of the blast furnaces were performed to adapt the models installed in the APCS of the blast furnace workshop of PJSC "MK Azovstal".

Inconsistencies in the overall material balances of the furnaces (the difference between the total input of materials into the furnace and smelting products) and by components (iron, carbon, etc.) were determined. The general looseness of the material balances was determined in 2 variants: using the output data of blast furnace dust and sludge according to technical reports (actual output) and calculation - based on the iron balance. It was established that when using the estimated amount of blast furnace dust at all blast furnaces of PJSC "MK Azovstal", the amount of discrepancy between the income and consumption of materials lies within the credible range of error (<1.5%). The largest and smallest discrepancy in iron balance was -6% and +2%, respectively. According to the carbon balance, the amount of discrepancy in a separate period was from -9.0% to +2.5%, which may be related, among other things, to the inaccuracy of accounting for the removal of blast furnace dust, the chemical composition of the fuel, and the determination of the chemical composition of the blast furnace gas and, as a result, taking into account the degree of CO use. The degree of CO utilization is one of the most important input parameters of material and heat balance models, and the insufficient adequacy of its measurements carries the risk of obtaining insufficiently reliable calculation results. It should be noted that the laboratory values of measurements of CO utilization degree were used for the calculations, as significant differences (up to 1.5%) were observed between laboratory and automated measurements of the chemical composition of the furnace gas, which may be related to the peculiarities of the installation of gas analyzers and other technical reasons.

Using the results of the calculation of heat balances, a comparison of the discrepancy of the blast furnaces was made (the ratio of the calculated indicators to the actual ones). Based on the results of the calculations, the average blowing losses for each furnace were determined (6%, 9%, and 11%, respectively), which were used to adapt the heat balance model for blast furnaces. The limits of the

variation of the discrepancy between the estimated value of productivity compared to the actual value (within 0.90-1.05 of the actual value), coke consumption (0.95-1.06) and other indicators was established.

Mathematical models of balances were put into trial operation as part of the APCS of the blast furnace shop of PJSC "MK Azovstal" and were used to assess deviations from production norms, consumption of coke and conventional fuel, as well as forecast the possibility of improving the technical and economic indicators of smelting.

UDC 669.162

IMPROVEMENT OF THE PROCESSES OF PREPARATION, DESULFURIFICATION AND SUPPLY OF LIQUID IRON FOR CONVERTER SEPARATION

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The modern stage of production of metal products in ferrous metallurgy, which requires increasing productivity, efficiency and reducing costs at each of the metallurgical redistributions, especially in the production of high-quality steel grades, determines the need for a serious approach to the improvement of processes and components of the technological scheme of preparation and supply of liquid iron for converter redistribution. The process of preparation and supply of liquid iron for converter redistribution can be divided into the following technological zones:

- filling ladles with cast iron in the blast furnace and transporting them to the next technological zone;
- post-burning desulfurization of cast iron;
- cleaning of cast iron from ladle slag;
- storage of cast iron in the converter workshop, preparation and pouring of desulfurized cast iron into the converter.

In order to eliminate the negative impact of ladle slags on the efficiency and stability of the cast iron desulfurization process, it is recommended to add additives to the bottom of the ladle in the form of metallurgical lime production waste, which increase the basicity and sulphide capacity of the ladle slag, before starting to fill the ladles with cast iron. in the amount of 80 - 170 kg/t of slag (1.5 - 2.5 kg/t of cast iron).

To reduce the temperature loss of cast iron when filling ladles , it is recommended not to feed cold ladles for pouring , to reduce to a minimum the turnover time of ladles , to use covers installed on the neck of ladles after draining cast iron, and also to use heating of cast iron and ladles with blast furnace gas. The most preferable (from the point of view of iron temperature loss, shortening the cycle and organizing the supply of iron with the required sulfur content to each converter melting) scheme of organizing the supply of iron from the blast furnace to the converter shop is the technological scheme, in which the pig iron is poured into pouring ladles already in the blast shop .

According to the analysis, the most effective technology of cast iron desulfurization is monoinjection of magnesium, which provides high stability of production of cast iron with the required sulfur content, up to $\leq 0.001\%$.

The industrial experience of implementing the process of desulfurization of cast iron by monoinjection of magnesium in ladles of various sizes has shown that with an increase in the mass of cast iron being processed, the efficiency of desulfurization increases , the necessary specific consumption of magnesium and temperature loss of cast iron during the period of magnesium injection are reduced. The established regularities are justified by increasing the depth of magnesium injection and creating more favorable conditions for its dissolution and assimilation.

To increase the efficiency of cleaning iron from high- sulfur ladle slag, reduce iron losses during slag unloading and reduce the duration of the iron cleaning operation, it is recommended to

blow iron with nitrogen during the slag unloading process or use bubblers , which ensure the movement of the slag mass into the removal zone with thickening and sealing additives and use for unloading slag high-performance scraper-type machines.

UDC 621.7

OPTIMIZATION OF TECHNOLOGICAL MOLDING PROCESSES SEAMLESS PIPES IN MOLDS BY GRAVITY METHOD

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The method of gravity casting in a mold for the production of seamless pipes in foundry production has not found mass application due to problems with the formation of defects, including hot cracks, which requires further scientific research. The Physical and Technological Institute of Metals and Alloys of the National Academy of Sciences of Ukraine developed DSTU 9051:2020 [1], according to the definitions of which hot cracks are one of the defects in the section of discontinuities in the casting body. The tendency to hot cracks is called hot brittleness. It is known that the hot brittleness of alloys depends on the malleable or non-malleable form, the temperature of heating the form and the melt before pouring, and on its chemical composition. In this work, by optimizing the above technological processes of casting using the example of the AMg6M alloy, the following ways of solving the problem of hot brittleness were proposed:

1. It was found that for complete pouring of the form, pouring of AMg6M alloy into the mold must be carried out at a melt temperature of ~740 ^{0}C;
2. It was established that in order to avoid cracks, the inner mold must be heated to a temperature not higher than 500 ^{0}C;
3. It was found that under filling occurs when the temperature of the melt and the mold is insufficient before pouring or when the pouring speed is low;
4. It was established that cracks occur due to high overheating of the melt and long-term cooling of the casting in the mold;
5. It was found that vibration processing during pouring leads to an improvement in the pouring of the mold, compaction of the metal structure, but complicates the separation ability when separating the casting from the mold;
6. It was determined that shrinkage defects (shells, contractions, pores) occur due to a violation of directional hardening and insufficient feeding of the casting, due to overheating of the mold.

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UDC 669.184

OPERATING EXPERIENCE AND FACTORS AFFECTING THE STABILITY OF THE MAIN VAULTS OF REFLECTIVE FURNACES: THE MARTEN FURNACE AND THE DOUBLE-WARM STEEL MELTING UNIT

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The lining of the working expanse of the reflective type furnaces, especially the vault element, works in the most difficult conditions. In the course of technological operation have an affect: mechanical shocks; abrasion; chemical interaction of melting dust and slag; high temperature. The stability of the resistance lining for high temperature furnaces of reflective type from furnace of 100 to 300 tons can be from 400 to 1000 of the melt repetitions, for furnace more than 300 tons from 200 to 500 of the melt repetitions.

On furnace with intensiving blowing technology the bath with oxygen, the stability of the vault is from 200 to 300 of the melt repetitions. From the literature is known, that the stability of the vault varies from factory to factory. It depends not only on the construction of the furnace (primarily affected by the height of the vault), conditions of operation and maintenance, but also on the professional level and quality of the building structure of the vault. Too dense and uneven laying of bricks can increase the concentration of stress and compression in the arch section of the vault. Deviation from the optimal operating modes of the furnace and the quality of the building structure leads to a reduction in the stability of the vault. This has a negative effect on the production rate, the quality of the ferrocarbon semi-product, the increased consumption of refractories and the deterioration of the technical and economic indicators of production as a whole.

At the number of scientific works, it is noted that the alkaline vaults made of magnesitochromite or chromomagnesite were most widely using in reflective type furnaces. One of the main factors that affects the stability of the alkaline vaults is the temperature regime of the melting technology. The alkaline brick is characterized not only by fairly high fire resistance, but also by significant sensitivity to temperature fluctuations (temperature changes). Under temperature conditions in the range from 300 to 400 ^{o}C, the refractories of the vault of the furnace begin to constantly experience a variable load. The degree of influence will depend on the temperature of the vault and the duration of the melting technology. In addition, the alkaline refractories have a sufficiently high coefficient of expansion of bricks. As a result, when the arch of the vault is heated, the outer seams open, and high compressive stresses occur on the inner side - this leads to chipping of the inner part of the brick.

At the general, it is possible to note that the following can be observed under the conditions of operation of vaults made of basic refractories (magnesitochromite or chromomagnesite):

1. Bricks are poorly welded to each other, because of this they do not form a monolith;
2. Increased thermal conductivity and large masonry leaks (open seams) lead to higher (almost twice) heat loss from 1 m2 of the vault area;
3. The volumetric mass of a magnesitechromite brick is half times larger greater than that of a similar dynas brick.

It should be noted that the above factors and factors can have both an independent and joint complex impact. They can mutually reinforce each other in various combinations. This leads to a change in the nature of wear and variation in the resistance indicators of the refractory lining of the vault within wide limits at each metallurgical enterprise.

Electrometallurgy

UDC 620.046 : 669.15 : 620.17

EFFECT OF CHANGE IN ROUGHNESS ON MECHANICAL PROPERTIES OF 316L STEEL PRODUCED BY SELECTIVE LASER MELTING TECHNOLOGY

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Selective laser melting (SLM) is one of the modern methods of manufacturing parts and assemblies of complex geometry, which are difficult or impossible to reproduce in the conditions of traditional production. SLP technology allows several times to reduce the time and number of technological operations, and the number of necessary basic equipment, the number of which is measured in tens - to be reduced to a few units. One of the important tasks of SLP technology is to ensure the accuracy of the geometry of the products and a certain roughness of the surface, since their further mechanical processing is usually not foreseen.

The production of samples for tensile tests was carried out on a 3D printer Alfa-280 manufactured by ALT Ukraine LLC. The material used in this study was austenitic grade 316L stainless steel with a particle size of 10 to 45 μm. Chemical composition of 316L powder in % by mass: Cr=17.79; Ni=12.63; Mo=2.35; Mn=0.78; Si=0.64; C=0.016. Metallographic studies have shown that the average density of the samples is 99.83%, the microstructure is a dispersed dendritic and cellular structure of the γ-phase within the melt baths of individual tracks, as a result of which the part is created layer by layer.

In the working part of the samples for tensile tests, a defect was created in a controlled manner by increasing the working power of the laser during the construction of several layers, which achieved an increase in the roughness of the side surface. One group of samples was subjected to electrochemical polishing. After carrying out tensile tests, as a result of the study, it was established that in the group of samples without additional processing, the destruction started from the surface of the samples at the place of change in its roughness. The places of destruction of the samples subjected to electrochemical polishing were different and unrelated to the places of the created defect. The values of the strength indicators of the two groups of samples differed by 3-5%, plasticity by ~ 10%.

As a result of research, the effect of changing the surface roughness on the mechanical properties of 316L steel produced by SLP technology was established.

UDC 669.046 : 621.375

JUSTIFICATION OF RATIONAL MODES OF SLP TECHNOLOGY

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The modern method of additive manufacturing, called selective laser melting (SLM), allows the production of volumetric metal products layer by layer. This technology allows to ensure high quality of products (accuracy and uniqueness of geometry, high complex of mechanical properties, high density, homogeneity of microstructure and chemical composition), and a wide range of used materials allows it to find application in such fields as medical and dental, machine-building, automotive and aerospace .At the same time, a feature of SLP technology is that product quality depends on several thousand factors, which can be divided into main groups: equipment, material, process, detail, finishing. The main approaches to choosing rational modes are ensuring sufficient product quality and process productivity. The need for a systematic approach to product quality management stems from the diversity and interrelationship of external and internal factors affecting quality, from the continuity of its formation and maintenance.

The quality of the final products is most significantly influenced by the parameters of the SLM process itself. The main ones include the power of the laser, the speed and trajectory of the laser beam scan, the distance between the scan tracks, and the thickness of the layer of powder material. The paper investigated the influence of the specific energy of scanning heat-resistant alloy Inconel 718 on a 3D-printer of Ukrainian production Alfa-150 (ToV "ALT of Ukraine"). The influence of parameters of SLM technology on the quality of final products was determined and the analysis of the influence of technology factors on the quality of finished products was performed. The configuration of the melt

bath of one track is an arc, this shape is a consequence of the Gaussian distribution of the energy of the laser beam. A relationship was established between the depth of a single track and the specific linear energy, which is described by a linear equation with an approximation factor of 0.93. As a result of metallographic studies, it was established that when the tracks are covered by 25%, deep melting conditions are created, large elongated pores are formed at the root of the track, which are formed when the hole collapses (the so-called "lock slot"). At an overlap of 17%, a small number of small rounded pores is formed, at an overlap of 0 ... 8%, a structure with a minimum number of pores is formed. When the distance between the tracks exceeds the width of a single track at a given combination of laser power and scanning speed, cases of incomplete fusion of adjacent tracks are observed, pores with sharp edges are formed, which are stress concentrators - the most dangerous from the point of view of product reliability. Thus, the recommended overlap of tracks during selective laser melting, which is from 0 to 8% of the width of a single track at rational process parameters: P = 180 W, V = 800 mm/s.

UDC 669.295 : 616.31.001.86

EXPERIENCE IN MANUFACTURING DENTAL IMPLANTS USING 3-D TECHNOLOGY FROM A TITANIUM-BASED ALLOY

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To date, the 3-D technology of selective laser melting (SLP) has found application in various fields, including dentistry. The traditional manufacturing of dental prostheses, crowns, and bridges, which is performed on casts of teeth, is becoming a thing of the past. It takes a lot of time, is associated with unpleasant sensations and discomfort when removing casts in the traditional way. The work of dental technicians is very time-consuming and takes a lot of time to get a good result and is associated with significant costs of the material that goes into the chips. Manufacturing dental implants using SLP technology has significant advantages: ensuring optimal surface porosity in the form of a spongy structure with recommended parameters for intensive osteosynthesis and osseointegration; the formation of transition surfaces with a given geometry and roughness, thereby creating all the conditions that prevent the penetration of infection in the area of contact with the patient's soft tissues and skin; formation inside the implant of channels of a complex shape for the internal delivery of drugs, as well as thin-walled elements; thread formation with any profile, including variable diameter and pitch; creation of connecting surfaces for quick-change abutments. To obtain a digital model of the implant, you only need to conduct a 3D scan of the patient's dental cavity. And the creation of the product itself during additive manufacturing takes place layer by layer, by adding a portion of material according to a given model. The use of modern technologies allows to increase production volumes without increasing the number of personnel.

ALT Ukraine LLC developed and manufactured an ultra-compact Alfa-150D 3D printer with a working field size of 150×150×180 mm, which is equipped with a high-precision air-cooled ytterbium laser with a power of 200 W. Positioning accuracy of the laser beam is 0.15 μm. The thickness of the working layer is 20...100 microns. The work used titanium alloy Ti-6Al-4V chemical composition, weight %: Al=6.21; V=4.03; Fe=0.04; C=0.1; O=0.7; N = 0.02; Ti is the base. Samples of Ti-6Al-4V implants were made according to the preset recommended modes: constant laser power - 195W, laser beam scanning speed - 1000...1200 mm/s with a step of 50 mm/s, distance between beam passes - 0.09...0, 12 mm with a step of 0.01 mm at a constant scanning speed. Under these regimes, the metal density of the samples is more than 99.95%. The effect of current (0.5...2.5 A), voltage (12...20 V) and duration (3...6 minutes) on mass loss during electrochemical polishing was studied on implants manufactured according to the recommended modes. Based on the results of the research, equipment

was manufactured for the use of SLP technology in dentistry, the possibility of manufacturing dental implants with a surface in the form of a spongy structure was established, and recommended modes of manufacturing and electropolishing of dental implants were established.

UDC 669.046 : 621.575 : 620.17

THE INFLUENCE OF THE DIRECTION OF CONSTRUCTION AND THE THICKNESS OF THE WORKING LAYER ON THE MECHANICAL PROPERTIES OF SAMPLES MADE BY THE TECHNOLOGY OF SELECTIVE LASER MELTING

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

The work concerns the technology of selective laser melting (SLM), which is an iterative process consisting of three main stages: (1) applying a layer of powder with a thickness of 20 to 50 μm on the construction platform; (2) local melting of the powder layer by a laser source based on previously imported 3D-CAD data; (3) lowering the construction platform and restarting at point (1). The powder is usually applied with a polymer or rubber scraper.

The authors' research of the last two years was mainly focused on process control, including the influence of various parameters on process stability and the resulting microstructure and material properties.

The purpose of this work is to study the influence of different orientations of the structure in the direction of the X, Y, Z axes, and the thickness of the printed layer (40 μm and 20 μm) on the mechanical properties of cobalt-chromium alloy (Co-Cr-Mo) produced by the SLP method.

The material used in this study was a cobalt-chromium alloy Co-Cr-Mo with a particle size of 10 to 45 μm. The chemical composition of the Co-Cr-Mo powder in % by weight: Cr=17.79; Ni=12.63; Mo=2.35; Mn=0.78; Si=0.64; C=0.016

Based on the results of mechanical properties studies, the dependence of the material density on the process parameters was determined, and the rational modes of manufacturing samples were determined. The mechanical properties of the samples manufactured according to the same regimes with different construction directions for each of the studied thicknesses of the working layer were studied. It is shown that horizontal samples have 10-12% higher values of strength indicators and 25-30% lower values of plasticity indicators than vertical ones. It was established that samples with a working layer thickness of 20 μm have higher values of temporary resistance by 1.12 times and plasticity by 1.8 times.

УДК 621.791

MANUFACTURE OF LARGE-SIZED BIMETALLIC PRODUCTS STEEL-COPPER

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Steel-copper bimetals are quite widely used in various industries. The main purpose of copper in such bimetals is the improvement ofelectrotechnical characteristics of products. Producing a high-quality reliable joint steel-copper is complicated by a significant difference in the physical and chemical properties of these materials. In such a bimetal, one of the main requirements is limiting the area of penetrating iron into copper as a result of a sharp reduction in its electrical and thermal conductivity in the case. Moreover, there is a risk of formingperitectic compounds of iron with copper, leading to a decrease in the mechanical properties ofthe metal in the places of their location.

Without going into details of various ways and methods of producing bimetals steel-copper, it can be noted that the highest quality of joining these metals is achieved in vacuum-diffusion welding. Here, the minimum (10-30 μm) penetration due to diffusion of copper into steel and even lowerpenetration of iron into copper is provided. However, this technology is expensive and is used to manufacture products of relatively small dimensions.

When it is necessary to produce steel-copper billets with larger contact area and mass, other technologies are used. To provide passing of current through the bottom plate of DC arc furnaces, the design of the bottom current lead proved itself well, which represents a steel rod of 200-300 mmdiameter joined (welded) with a massive (up to 500 kg) cooled copper casing along the lower end. To produce such a current lead, in our opinion, the technology of electroslag surfacingis the most suitable. Various types of electroslag surfacingare known, which are characterized by the applied equipment and technology, as for example,surfacing of copper on a steel billet by electroslagremelting of a copper electrode in a current-conducting mould, mastered at the E.O. Paton EWI.

We conducted research works and mastered the technology of electroslagsurfacing in a refractory mould using consumable electrodes for realizing the electroslag process of non-consumable electrodes. Previously, the end surface of the billet is heated by the slag to a temperature close to the melting point of steel. Then, copper is supplied, which melts in a slag pool and flows to the surface of a steel billet. Further on, already on the produced joint steel-copper,remelting in the copper slag continues until a copper part of the required size is produced. The basic parameters that need to be provided during such surfacing are composition ofthe slag and its temperature during heating and surfacing, temperature of preliminary heating of the surface of a steel billet and surfacing rate.

The carried out examinations of the macro- and microstructure of the mock up of the full-scale bottom current lead showed that in such a surfacing, a clear separation of two metals along the line of their contact occurs almost without mutual stirring. During mechanical tests of metal from the fusion zone, the fracture of rupture specimens occurs over copper. The content of iron in the copper part at a distance of more than 30-50 mm from the joint line corresponds to its content in the source copper. In addition, copper is refined by the slag from non-metallic inclusions and undesirable impurities, which improves its electrical and thermal conductivity. The developed method allows producing a strong joint of copper with steel and can be used in the manufacture of large-sized steel-copper products.

TECHNOLOGY OF HIGH IRONFERROSILICOMANGANESE PRODUCTION

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The production of ferroalloys is characterized by various technological processes, the choice of which is determined by the chemical composition of the alloy and depends on the properties and cost of the raw material, reducing agent and coolant.Ferrosilicomanganese is produced by the carbon-thermal method in closed or hermetic ore-reducing electric furnaces with a maximum capacity of 81 MVA.From the practice of existing production, it is known that at the stage of ferrosilicomanganese smelting, the extraction of manganese and silicon does not exceed 82% and 45%, respectively. In addition, more than 90% of manganese ferroalloys undergo fractionation, which significantly reduces the yield of a suitable product as a result of the formation of a significant amount of substandard alloy, which in the production of ferrosilicomanganese is 10-18%. In addition, during the transportation of

ferroalloy by railway or other modes of transport, as well as during transshipment from the transport to the customer's warehouses, the process of abrasion of pieces of the alloy occurs. This significantly reduces the amount of fraction-worthy ferroalloy to the final consumer by 8-10%. In view of this, the issue of increasing the strength of ferrosilicomanganese without changing the chemical composition within the limits of ДСТУ3548-97 is currently relevant

The authors investigated the thermodynamic advantage of the combined reduction of manganese and silicon with carbon to form alloys of the Mn-Fe-Si system with an increased iron content, as well as the improvement of mechanical properties, which provided a rationale for the further implementation of an industrial company for the smelting of ferrosilicomanganese with an increased iron content.

The process was carried out in an ore reduction electric furnace by a continuous carbon thermal process. The industrial company was held for 16 days. In the composition of the initial charge, the number of iron ore ingots was varied to ensure the basic amount (Mn + Si) in the metal, which according to ДСТУ 3548-97 should be at least 82% with a minimum manganese concentration of 65%.Adjustment of the charge to switch to an alloy with a manganese content in accordance with the standard (65% Mn) was carried out by adding iron ore ingots to the charge. This made it possible to plan and conduct an active experiment to determine the time of change in the properties of the obtained metal and slag depending on the composition of the charge. As the iron content in the obtained alloy increased, the manganese content decreased. To increase iron in ferrosilicomanganese, the ratio of iron to manganese in the charge was adjusted from 0.01 ÷ 0.02 to 0.12 ÷ 0.16 due to the addition of iron ore billets with an iron content of more than 62% to the charge. The consumption of coils varied depending on the productivity of the furnace from 3 to 14 tons per shift.

Industrial testing of the ferrosilicomanganese smelting process with an increased iron content showed the following:1)the possibility of obtaining ferrosilicomanganese, in which the content of manganese and silicon meets the requirements of ДСТУ 3548-97;2)the use of iron ore raw materials with a low content of empty rock contributed to the reduction of slag multiplicity and specific electricity consumption;3)the output of suitable ferrosilicomanganese in the form of a commercial fraction (10-100) increases by 4-6%, which is associated with an increase in the strength characteristics of the alloy and a decrease in the amount of substandard fraction;4)the earlier appearance of the metal phase during the addition of iron ore ingots helps to improve the conditions for the recovery of manganese and silicon.

UDC 669.18

CHANGES TO EXPAND THE REFINING POTENTIAL OF STEELOUTLET CHANNELS OF BOW WINDOW IN ARC STEEL MELTING FURNACES

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At the present time, the prevailing concept is the construction of technology at metallurgical plants, which involves the maximum intensification of all steelmaking processes. Modern arc steel-melting furnaces have come close to oxygen converters in terms of productivity. This approach is inevitably accompanied, firstly, by an increase in oxygen consumption as the main intensifier of melting, and secondly, by deoxidizers, with the help of which excess oxidation of the metal is subsequently removed. With such a production scheme, an increased amount of deoxidation products is formed - non-metallic inclusions, which are then removed from the melt during secondary metallurgy. This means a significant shift in technology with the transfer of the burden of solving the problem of obtaining high-quality metal at the stage of secondary metallurgy. As a result, secondary metallurgy becomes excessively complicated, energy- and material-intensive, which leads to an increase in redistribution costs.

Deoxidation of the melt with carbon, the reaction products of which are removed into the gas phase, can contribute to the reduction of contamination of the melt with non-metallic inclusions. It is worth noting that in modern arc steel-melting furnaces, instead of classic chutes, there is an increasing tendency to use bay window devices equipped with steeloutlet channels, similar in functionality to the steeloutlet channels of oxygen converters. This makes it possible, along with cutting off slag, to perform refining and protective functions, which contribute to reducing the contamination of the melt with non-metallic inclusions and increasing the economy of deoxidizers.

Works [1, 2] show the possibility of implementing refining and protective operations by blowing inert gas into the working space of the steeloutlet channel of the oxygen converter to reduce the consumption of deoxidizers by 10-30%. In addition, a review of available literary sources indicates that information on the expansion of the functions of bay window steeloutlet channels is extremely limited and requires further research using modern methods of mathematical and physical modeling.

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CONTROL OF THE CRYSTALLIZATION OF THE ESR INGOTS USING NON-STATIONARY POWER SUPPLY MODES

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Methods of controlling the crystallization of electroslag remelting ingots (ESR) due to the forced periodic change of the thermal and hydrodynamic state of the metal pool due to non-stationary power supply modes have been investigated.

Experimental studies were carried out on a chamber-type electroslag during the melting ingots with a diameter of 80...220 mm from carbon steel, precision alloy 29NK and titanium VT1. Various variants of non-stationary power supply were used, which consisted in periodically changing the power of the ESR process, from working values to some minimum values, with different duty cycle of pulses and modulation level.

The possibility of realization of two fundamentally different processes is shown. If the duration of power supply pauses is small (from a tenth of a second to several seconds), so that the lower value is compared to the period of droplet formation, and the upper one does not exceed the time-constant of the slag pool, or during the pauses sufficient thermal power is released to melt the metal, then the periodicity power supply does not cause the periodicity of the melting of the electrode and crystallization of the ingot metal. In this case, the non-stationary power supply affects the hydrodynamic state of the pool, causing its mechanical vibrations, as well as the processes of metal droplet formation on the end of the electrode.

In the second case, if the duration of power supply pauses is long enough (from tens of seconds to tens of minutes) and the power released during the pause is insufficient for melting the metal, then this leads to the periodicity of the processes of melting the consumable electrode and crystallization of the metal, thereby causing layer-by-layer formation of the ingot along its height. In this case, it becomes possible to significantly reduce the volume of the metal pool, which has a positive effect on the conditions of metal crystallization and contributes to the suppression of liquation.

It is shown that the parameters of the non-stationary power supply are determined by the degree of inertia of the thermal regimes of the consumable electrode, metal and slag pools, and the skull crust.

At the same time, the limiting factor is the formation of the skull crust, which is more sensitive to changes in power supply regimes.

It was established that non-stationary power supply makes it possible to control the technical and economic characteristics of the ESR process and the structure of the obtained metal. The facts of reduction by 7...10 % of the consumption of electricity, and refining and homogenization of the structure of the metal of titanium ingots, in comparison with the metal of the traditional ESR, have been established.

The effectiveness of controlling the structure formation of ESR ingots through their layer-by-layer formation has been experimentally proven. It is shown that ingots obtained by the method of layer-by-layer formation have a dense structure, without porosity and non-metallic inclusions, are characterized by the absence of large columnar crystals and a zone of counter-crystallization along the axis of the ingot. At the same time, the maximum length of crystals is limited by the height of a separate deposited layer, and the dispersion of the structure is much higher than that of similar ingots of traditional ESR.

It was established that for the realization of layer-by-layer formation of the ingot, the periods of melting of the consumable electrode should alternate with pauses, when the electrode does not melt and is not supplied, but the electric current and the specified thermal regime are maintained in the slag pool. It is shown that the height of portions of deposited metal should be chosen within $(0.1...0.5) \times d_{ing}$, and the duration of electrode melting pauses should be calculated based on the conditions of solidification during this time of 75...95 % of the volume of liquid metal pool.

UDC: 621.74.046

THE LATEST FOUNDRY-INDUCTION METHOD OF BIMETALLIC AND THREE-LAYER PRODUCTS MANUFACTURING

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The possibilities of the existing processes of monometallic castings manufacturing in terms of extending the service life of parts that wear out quickly have been almost exhausted. The most promising way to solve the problem is to use bimetallic and multilayer products with a differentiated set of properties.

The urgent issue is therefore to create new hybrid methods of bimetallic and multilayer products manufacturing, based on traditional foundry technologies and fundamentally new schemes that use electromagnetic effects on metal, which provides a significant technical and economic effect.

The aim of the research is to create a highly efficient method of manufacturing wear-resistant bimetallic and three-layer products based on foundry processes under the action of electromagnetic fields.

The method is based on the principle of pouring a melt of wear-resistant cast iron on a solid thin steel billet, preheated under a layer of oxygen-proof coating under the action of an electromagnetic field. A steel billet and chromium cast iron as the material of a working layer to pour over have been selected for the experiment. It has been established that a reliable bond is achieved in the range of heating temperatures of the workpiece between 800 and 1200 ° C at a melt temperature of 1410-1450 ° C, which is the initial condition of the study. The induction heating of the plate should not exceed a maximum of 1350 ° C.

While employing this method to produce a reliable bond at the interface between the two materials, special attention has been paid to the uniform heating of the flat workpiece, which has been achieved by the correct choice of inductor configuration and processing modes.

For this purpose, the study considers two configurations of the inductor – flat ellipsoidal type that affects only one surface of the workpiece and spiral inductor solenoid type thatcovers four

surfaces of the workpiece. A power supply of up to 40 kW with a frequency of 60 kHz has been used in the study.

The research has been conducted using computer modeling methods and practical experiments. COMSOL Multiphysics has been used to model the interconnected hydrodynamic, electromagnetic and thermal processes of casting formation.

The technological process with the use of the solenoid-type inductor involves transportation and placement of the heated workpiece in the mold, as a result of which it becomes cooled to a temperature of 820 - 1200 ° C. The minimum time for transportation and placement of the heated plate is 8 sec, the maximum is limited to the lower temperature limit of production a diffusion bond, which is 40 sec.

The process of manufacturing bimetallic products using a flat inductor is accompanied by a heating time increase, but does not require transportation of the steel billet, which is more technologically efficient.

As a result of simulation modeling regularities of energy distribution from current strength and heating time have been established for two configurations of inductors. The distribution of temperature fields in a steel billet has been considered. The hydrodynamic features of melt pouring and casting crystallization have been established.

The developed foundry-induction method opens new opportunities for obtaining three-layer products with different physical and mechanical properties of materials such as "cast iron-steel-bronze", which is achieved by simultaneous pouring two melts on a steel billet.

According to the results of experimental testing, the effectiveness of the developed foundry-induction method for bimetallic and three-layer products manufacturing has been confirmed.

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

UDC 669.162.21: 669.162.262: 681.3.083.133

ALGORITHMIC MEANS OF THE SYSTEM FOR SELECTING THE OPTIMAL COMPOSITION OF BLAST FURNACE CHARGE BASED ON ITS PHASE TRANSFORMATIONS IN HIGH-TEMPERATURE ZONES OF THE FURNACE

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In order to solve the strategic tasks of forming the rational composition of the multicomponent blast furnace charge for the intended purpose and predicting the negative consequences of the use of secondary resources, which leads to unstable operation of the furnace and deterioration of the quality of pig iron, the Iron and Steel Institute of NASU has developed a new systematic approach based on the developed concept of modelling the processes of directed formation of melts of the required composition and properties.

With the help of a complex of developed mathematical and physicochemical models describing and linking the processes of distribution of charge materials in different zones of the furnace with technical and economic indicators of melting, and using vector optimization methods, algorithmic support for the system of choosing the optimal composition of blast furnace charge was developed, which allows:

- to calculate high-temperature properties of iron ore materials, complex of physical and chemical properties of primary and final slag melts,
- to predict the chemical composition of pig iron and blast furnace slag depending on the parameters of the charging charge taking into account the parameters of the blast mode;

- to assess the technological situation according to the controlled melting parameters and the formed system of technological constraints;

- to solve the problem of multicriteria optimization of the charge composition taking into account the technological requirements, justified from the point of view of the rational course of aggregate transformations in the furnace and the directed formation of melts of the required composition and properties with increased productivity in modern blast furnace melting conditions.

The information basis for the creation of predictive models for the calculation of physical and chemical properties of metallurgical alloys is the information, accumulated in the databases "Iron-ore materials", "Slag" and "Metal-slag" created at the Institute of Ferrous Metallurgy of the integrated base "Metallurgy".

Modelling of the properties of metallurgical systems of blast furnace melting and processes of formation and interaction of metal and slag phases is carried out using integral parameters at the level of interatomic interaction of components in melts, which allows to describe the relationship between the composition and properties of compounds in the system "metal-slag".

The main feature of the developed systematic approach to solving the problems of optimization of blast furnace charge composition is to take into account the laws of physical and chemical transformations of iron-containing materials in high-temperature zones of the furnace and the directed formation of melts, which is regulated by a system of reasonable technological constraints in order to ensure the required (high) performance of blast furnace melting.

The results of testing the algorithmic means of the system for selecting the optimal composition of the blast furnace charge on the actual industrial data of the blast furnace operation in modern conditions, operating with the use of pulverized coal and natural gas, allowed to formulate scientifically based recommendations on the component composition of the charging feed, taking into account the available raw materials and energy resources.

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UDC 621.74.08

MELT TEMPERATURE CONTROL

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For the most part, melt temperature control refers to the process of temperature measurement, which is not exactly the same thing. This state of affairs is caused both by non-compliance with the requirements of DSTU 3021-95 [1] regarding terms and definitions, and by the lack of a standard methodology for controlling the temperature of melts, which determines the relevance of scientific research.

In wartime, the energy saving factor is one of the determining factors for Ukraine. Therefore, saving energy resources in metallurgy is an important scientific and practical task, which is defined in the Energy Strategy of Ukraine for the period until 2035 [2].

According to [1], technical control is a check of compliance of the object with the established technical requirements. Accordingly, temperature control of liquid metals and alloys is the process of determining the compliance of the melt temperature with established requirements or norms. The essence of temperature control consists of two main stages - measurement and comparison. The first stage of temperature measurement of liquid metals and alloys is called primary information. On the second, primary information (temperature of liquid metals and alloys) is compared with pre-

established requirements, norms or maximum permissible values of temperature of liquid metals and alloys.

According to the location of the zone of the controlled state, the tolerance control of states is distinguished:

the temperature of the liquid metal is below the permissible value;

the temperature of the liquid metal is higher than the permissible value;

the temperature of the liquid metal between the upper and lower values allowed. The result of the check is not a number, but one of the mutually exclusive statements:

the controlled temperature of liquid metals is within the limits of permissible values, the control result is "the metal is suitable for pouring";

the controlled temperature of liquid metals is outside the permissible values, the control result is "the metal is not suitable for pouring".

Conclusions.

1. Based on the identification of commonalities and differences in the concepts of control and measurement of the temperature of melts, it is substantiated that measurement and control are not identical concepts.

2. It was established that the control of the temperature of melts is directly related to the concept of the quality of foundry products.

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UDC 669.1:621.7

PROSPECTS FOR THE DEVELOPMENT OF AUTOMATION IN METALLURGY

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In work [1] it was found that about 75% of accidental injuries in foundries occur for organizational reasons (human factor), and about 25% of all injuries occur for technical reasons (equipment failure). The above allows us to state that the problem of injuries in metallurgy and foundry production has not been solved, in most cases, due to the presence of the human factor. Therefore, solving the problem of minimizing injuries by automating foundry production is an urgent scientific and technical task.

In the future, there is a desire to completely eliminate the presence of humans in dangerous areas of metallurgical and foundry production, which can be realized by developing automatic, robotic systems for managing foundry processes with different degrees of autonomy. Among them, a special role is given to artificial intelligence, i.e. robots. Technologies that will ensure the autonomy of foundry equipment are currently prioritized according to the Concept of the Development of Artificial Intelligence in Ukraine [2]. The Strategy for the Development of Artificial Intelligence in Ukraine for 2022-2030 was developed to implement the Concept [3].

In [4], it is believed that automation and the use of computer technologies to improve work processes will be promising directions for the further development of the global foundry industry. Leading engineers - foundry men of the Chinese company ZHY Casting laid out their vision for the further development of the foundry industry in China in a trend [5], where it is noted the need to increase the level of mechanization and automation of steelmaking enterprises, as well as the expansion of the use of robots.

For example, after the use of robots at the Eagle Alloy steel plant (USA), the labor intensity of foundry production decreased from 55-60 to 40-48 man-hours per net ton of foundry products. Labor saving is about 15,000 hours per year [6].

Conclusions.

1. It was established that artificial intelligence, as a system of creating new knowledge and making decisions on this basis, in the field of metallurgy and foundry production, has not been developed and needs to be developed. The problem of understanding meaning has not been solved in artificial intelligence technologies.
2. It was found that research and development in the field of artificial intelligence is carried out without a forecast in advance and does not take into account possible risks from its use in the future.

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Metal Science and Heat Treatment of Steel

UDC 669.15-194.53 : 629.4.003.12

ANALYTICAL EVALUATION OF THE POSSIBILITY OF USING ECONOMICALLY ALLOYED STEELS OF THE PEARLITE CLASS FOR RAILWAY RAILS

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

From the literature analysis, it was established that steels used in the production of railway rails must be cooled at rates in the range of 0.63...18.2°C/s to achieve the pearlite structure. It is shown that for steel 75ХГСМ the required cooling rate is from 0.63...0.14°C/s, since the use of alloying elements Cr, Mn, Si, Mo increases the incubation period. Thus, the region of pearlitic transformation becomes more prone to move towards less intensive cooling rates. In M76T steel, the pearlite structure is formed at a cooling rate in the range of 9.2...18.2°C/s, in R350LHT steel - at a cooling rate of about 5°C/s. In Е76ХФ and Е76ХАФ steels, which contain chromium, after cooling at rates of 1 °C/s and

less, as a result of the disintegration of supercooled austenite, in addition to the ferrite-carbide mixture of the pearlite type, the formation of excess ferrite is observed. In E76F steel, the cooling rate required for the formation of the pearlite structure was up to 10°C/s.

Calculation studies of the influence of chemical elements on the final structure and mechanical properties of steel were carried out. Based on these studies, 3 experimental chemical compositions of steels were recommended for laboratory smelting and further research.

UDC 669.14.018.294.3 : 620.184.2.001.8

ANALYSIS OF REVERSE TREATMENT IN LABORATORY CASTING OF STEEL FOR RAILWAY AXLES

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Local variations of the chemical composition, that is, compositional inhomogeneities, play an important role in the thermodynamic stability and spatial distribution of phases in multiphase steels. The limited solubility of alloying elements in the solid state in steel leads to liquation during hardening. During crystallization, the solute is partitioned between the solid and the liquid to enrich or deplete the interdendritic regions.The morphology of the dendritic structure and the degree of liquation depend not only on the degree of supercooling, the gradient of the temperature field and the flow conditions of the liquid metal, but also on the chemical composition, namely on the concentration gradient of the melt.

As part of this work, the following experimental ingots of steel used for the manufacture of railway axles were produced and analyzed - steel grades OC according to DSTU 31334, F according to AAR M 101 and EA1N according to EN 13261.

The location of porosity and non-metallic inclusions allows us to assert that these places correspond to interdendritic spaces. In addition, it can be seen that in the central zone of the ingot there is a scattering of the smallest non-metallic inclusions. Of course, the smelting of axial steel in crucibles in laboratory conditions is somewhat different from the industrial production of a continuous billet, during the production of which additional steel cleaning is carried out, but some regularities were still discovered.

The following assumption was made - the formation of decarburized areas, including those without Si content, may be connected precisely with a more intensive degree of chemical element liquation, including strong gasification of these zones. However, further on in the text, the formation of such an area of abnormal structure will be called the "reverse liquation zone".

The formation of the so-called "reverse liquation" zone in the studied ingots is most likely related to the contamination and gasification of the steel.

At the same time, this defect is most clearly visible in EA1N steel, which is characterized by an increased content of Mn and a reduced content of C in comparison with axial steel grades OC and F. The relationship between the size of this defect and the geometric dimensions of the ingot, as well as the content of harmful impurities (S and P), and Al was not detected.

Thus, the formation of the "reverse liquation" zone in a stationary ingot made of carbon steel is significantly influenced by the content of C and the ratio of the content of Mn and Si.

It is shown that an increase in the ratio of Mn to Si content in EA1N, OC, and F axial steels contributes to an increase in the gas saturation of the steel and the emergence of abnormal structures. At the same time, the lower the C content in the steel, the lower the ratio of Mn to Si, and the formation of a defect. The significant effect of total deoxidation and S content in steel on the formation of inhomogeneity in the cross-section of the axial steel ingot and the micro-inhomogeneity of the structure of individual sections is shown.

UDC 621.762.2

FEATURES OF PHASE FORMATION OF A SINTERED MULTICOMPONENT COMPOSITE FROM A POWDER MIXTURE BASED ON THE TiH_2-Fe-Si-C SYSTEM

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This paper presents the results of studies of the features of phase formation during the thermal synthesis of a multicomponent composite material from a powder charge of the TiH_2-Fe_2Si_5-C system. Powder metallurgy methods were used for the production of a multi-component composite material. Titanium hydride powder (TiH_2), ferrosilicon powder (FS-65) and technical carbon (C) were used as starting materials. The use of titanium hydride powder ensures the activation of diffusion processes during sintering, and also makes it possible to additionally clean the interphase boundaries due to the formation of atomic hydrogen.

Alloying of titanium-based powder charges with ferroalloys increases the physicomechanical properties of the products and reduces the cost of the final product.

Thermal synthesis was carried out in a vacuum after high-energy grinding in a "drunken barrel" mill in two successive stages: heating to 600°C, with an isothermal exposure of 30 minutes, and to 1250°C, with an hour exposure.

According to the Fe-Si state diagram, iron and silicon can form three types of compounds: monosilicide - FeSi (33.3% Si); η-phase Fe_3Si_2 (25% Si); ε-phase Fe_2Si_5 (55.68% Si). At temperatures above 1100°C, Fe_3Si_2 and Fe_2Si_5 compounds decompose, forming Fe and Si. Due to the high affinity of titanium to carbon and silicon, these elements interact with the formation of titanium carbide TiC and titanium silicide Ti_5Si_3 phases, which are the main phases. There is also an arrangement of crystal lattices and the formation of a more stable FeSi intermetallide.

The use of ferrosilicon as an alloying additive leads to its active interaction with titanium hydride, which is accompanied by dissociation of the ligature with the formation of a complex heterophase system, the predominant phases of which are titanium carbide TiC, silicide Ti_5Si_3, and monosilicide FeSi.

UDC 669.14.017:620.18:669.15-194

ON THE FEATURES OF STRUCTURE FORMATION DURING ISOTHERMAL HARDENING AND CRYOGENIC TREATMENT OF 38CrNi3MoV STEEL

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The results of studies of the effect of isothermal cooling and subsequent cryogenic treatment on the formation of the structure, hardness, and wear resistance of 38CrNi3MoV steel are given. In order to increase the strength indicators of 38CrNi3MoV steel, isothermal hardening from the two-phase (γ+α)-region and the subsequent obtaining of a multiphase structure are proposed. The proposed mode of heat treatment involved heating to 750 °C and cooling to various isothermal holding temperatures.

According to metallographic analysis, the amount of troostite in the steel structure increases with a decrease in the isothermal holding temperature. Steel acquires the necessary hardness at a holding temperature of 450–400 °C. The structure of the 38CrNi3MoV steel samples processed according to the experimental regime consisted mainly of troostite, sections of bainite, and final austenite. The

bainite component of the 38CrNi3MoV steel contained particles of alloyed carbides, probably of the cementite type. Holding samples in the two-phase (γ+α)-region and subsequent cooling to isothermal holding temperatures promotes the release of specified carbides and stabilization of the final austenite, which is a component of the bainite-austenite areas.

The use of cryogenic treatment for the experimental mode of isothermal hardening of 38CrNi3MoV steel results in the transformation of the final austenite into martensite with a significant increase in the microhardness of the structural components ~ by 22 %. The transformation of final austenite into martensite during cryogenic processing was confirmed by electron-microscopic studies of the structure of 38CrNi3MoV steel samples: final austenite in the form of globules, needles, and packets turns into martensite of a similar morphology.

Micro-X-ray spectral analysis of the distribution of chemical elements (iron, chromium, manganese, nickel, molybdenum, vanadium) was carried out in different parts of the structure of the experimental samples. It was established that the quasi-eutectoid sections of the structure are characterized by an increased concentration of nickel, chromium, and molybdenum, in which final austenite is formed, and after cryogenic treatment, martensite is formed. Vanadium, as an alloying element, was found only in certain parts of the steel structure, which indicates the inhomogeneity of its distribution and accumulation in individual inclusions.

Tests of samples processed according to the experimental regime demonstrated ~ a 50 % higher surface wear resistance of 38CrNi3MoV steel compared to the basic technology. The developed mode can be recommended for the industrial implementation of the technology of hardening from steel 38CrNi3MoV for products of responsible use.

UDC 669.112.227.3: 669.15-194

A NEW METHOD FOR STUDYING PHASE AND STRUCTURAL TRANSFORMATIONS IN CARBON ALLOYED STEELS

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Comprehensive studies of the peculiarities of phase-structural transformations in the cooling process of alloyed steels 25Cr2Mo1V and 38CrNi3MoV taking into account the formation of residual austenite and adaptation of existing analytical models for the relevant calculations were carried out. On the basis of the developed mathematical model, a methodological approach was created and applied to analyze the structure of the experimental steels. The isothermal, thermokinetic and structural diagrams of austenite decomposition of alloyed steels 25Cr2Mo1V and 38CrNi3MoV were constructed. For steel 38CrNi3MoV the rates of formation of pearlite and bainite were calculated, and the change in the proportion of structural components depending on the actual temperature at continuous cooling at different rates was determined.

According to the developed methodology, the critical points were determined: for steel 25Cr2Mo1V – A_{C3} = 895 °C, A_{C1} = 810 °C, Ms = 350 °C; for steel 38CrNi3MoV – A_{C3} = 765 °C, A_{C1} = 710 °C, Ms = 285 °C. It was found that in steel 25Cr2Mo1V there is an area of increased stability of austenite between the pearlite and bainite components at a temperature of 600 °C. In 38CrNi3MoV steel the temperature interval of austenite stability between pearlite and bainite components is observed, and the formation of bainite and ferrite begins later and at lower temperatures compared to steel 25Cr2Mo1V. Differences in the elements of chemical composition of these steels determine the appearance of the structural diagrams, and the amount of residual austenite is taken into account by the developed method for the first time.

The created analytical model was used to analyze the structure of 38CrNi3MoV steel and its changes during cooling at different rates. According to the modeling results, the change in hardness

values during heating and tempering of 38CrNi3MoV steel was determined. It was established that during continuous cooling of 38CrNi3MoV steel at a temperature of ~ 450 °C there is an intersection of bainite and pearlite regions, in which these structural components are formed simultaneously. The areas of ferrite and pearlite transformations for 38CrNi3MoV steel are shifted compared to 25Cr2Mo1V steel, and austenite decomposition begins at lower temperatures.

According to the modeling results, it was found that for steel 25Cr2Mo1V it is possible to obtain a predominantly bainitic structure in a wide range of continuous cooling rates. At similar cooling rates, 38CrNi3MoV steel consists of a martensitic-bainitic structure, and therefore should be characterized by higher strength and surface wear resistance. The obtained results testify to the reliability of the developed analytical model, which is confirmed by the high compliance of the calculated structural components of the 38CrNi3MoV steel with the actual parameters of the structure, which are formed in industrial conditions after heat treatment.

UDC 621.774.35

PECULIARITIES OF THE FORMATION OF MESOSTRUCTURE IN STEEL MATRIX NEAR NON-METALLIC INCLUSIONS

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Peculiarities oflocalization of deformation in steel matrix near non-metallic inclusions under different conditions of loading from the point of view of physical mesomechanics of plastic deformation of the medium with nonhomogeneous structure were investigated.

In recent decades, a relaxation multilevel approach to the problem of plasticity of solids has been developed, since the description of the macromechanical characteristics of solids only on the basis of the theory of dislocations is insufficient. Therefore, studies of plastic deformation processes at the mesoscale level are being carried out, also using traditional ideas about the deformation behavior of metallic materials, including those with a heterophase structure. The goal of this work was to study the influence of nonmetallic inclusions on the localization of deformation and the formation of a fragmented mesostructure in a steel matrix in terms of the concepts of physical mesomechanics of heterophase alloys.

Plasticity of the steels with non-metallic inclusions, is deformation as a single structural whole is determined by the ability to intensify plastic deformation and effective energy dissipation. This assumes the mechanical interaction of steel structure elements (steel matrix and inclusions) through inclusion-matrix boundaries. Each type of steel is characterized by its own patterns of deformation processes, which are determined by the microstructure of the steel matrix, the deformation capacity of inclusions, and the cohesive strength of inclusion-matrix boundaries. In this case, the steel matrix bears the main load, and the inclusion particles prevent the movement of dislocations and disclinations, regardless of their level of plasticity.

The study of the deformation behavior of steels with non-metallic inclusions from the point of view of the physical mesomechanics of structurally inhomogeneous media showed the active role of inclusions and inclusion-matrix boundaries in the development of deformation localization and the formation of a fragmented mesostructure under different loading conditions. It has been established that the main processes and factors that determine the nature of strain localization near inclusions are long-range stress fields near inclusions, the appearance of moment stresses, the level of plasticity of non-metallic inclusions, the formation of mesobands of localized deformation near inclusions, the development of low-temperature and high-temperature slipping along the inclusion-matrix boundaries, which characterizes the level of plasticity of these boundaries.

UDC621.774.35

ON THE CAUSES OF CRACKING IN STRUCTURAL STEELS

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The voids development around brittle non-metallic inclusions and brittle cracking of the inclusions in steels have been investigated. One of the possible reasons of such inclusions behavior is the varying in the steel matrix and inclusions materials. The critical parameters of the microcracks formation are temperature-dependent. The critical parameters of the voids and brittle cracks and stages of microcracks development at temperatures 25–1250 °C.

Non-metallic inclusions are nature structural composition of steels. Steels with different nonmetallic inclusions after repeatedly hot and cold plastic deformation were investigated. The samples were exposed to stain in vacuum at temperatures 25 – 1250 °c and microfractures after definite deformations at each given temperature were investigated.

The differences in elastic and plastic properties of the phases with inclusions presence bring to stress concentrations appearing on the matrix-inclusion interface. The inclusions type influences on the mechanism of the micro crack formation. The voids are formed around inclusions which are badly-moistened by liquid steel: oxides, spinals, some silicates and sulphides. The critical parameters of the void's formation are temperature-dependent and determined by degree of the plasticity of metal matrix. When the temperature increases the critical sizes of inclusions and critical deformation degree also increases, but the deformation degrees interval, in which inclusions control the process of steel fracture, and rate of growth of the voids decreases.

Near non-metallic inclusions – titanium nitrides and oxides, some silicates and sulphides the voids do not arise. These inclusions are brittle, they are also well-wetted by the liquid steel. The critical parameters of the crack's formation are temperature – dependent. When the temperature increases the critical sizes of inclusions and critical deformation degree also increase, but the interval of deformation degree, in which inclusions control the process of steel fracture decreases. The rate of growth of the brittle cracks in inclusion is bigger than the rate of growth of the voids (viscous cracks) at all temperatures, but other parameters depend on the types of inclusion.

The distinctions in the microcrack formation mechanism seem to be connected to the inclusion-matrix boundary structure, the inclusions moistening by liquid metal and the correlation between shear module of inclusion, matrix and inclusion-matrix boundary.

УДК 621.74.02:669.01

TECHNOLOGY OF PROCESSING OF IRON-CARBON MELTS WITH SILICON CARBIDE DURING THE SMELTING OF HIGH STRENGTH CAST IRON

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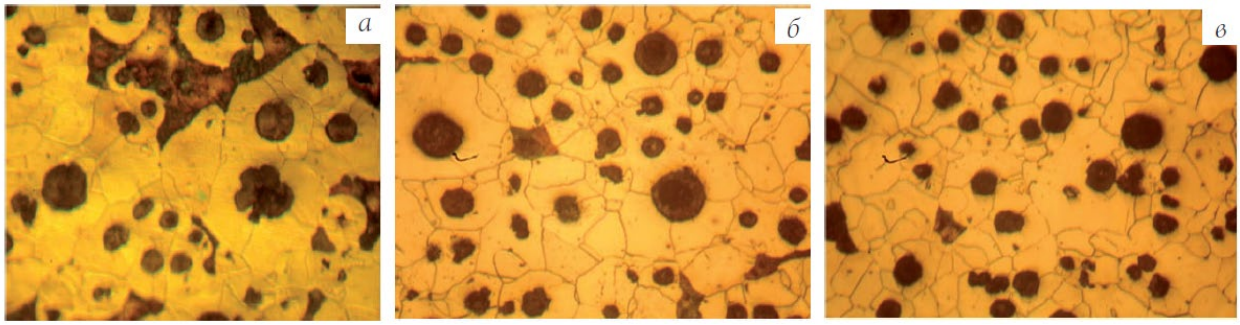
High-strength cast iron with spheroidal graphite (Ductile iron) is used in many industries, increasingly replacing products made of cast or forged steel, gray and malleable iron [1]. A feature of high strength cast iron is the spherical shape of graphite inclusions, regarding equally distributed in the structure.

The Department of Electrometallurgy has developed a technology for smelting iron-carbon alloys of various functional purposes using silicon carbide in the charge [2-5], which allows not only to alloy the melt with silicon and carbon, but also to set defining modifying effect.

The technology makes it possible to melt iron-carbon alloys of various functional purposes in induction furnaces.

During the conduction of the series of experimental and industrial melting in medium-frequency furnaces (company manufacturer - INDUCTOTHERM) and industrial-frequency furnaces (company manufacturer - BBC), it was noted that the experimental melting took place by the scientific-technical documentation of the enterprises. The chemical composition and structure of the obtained metal correspond to the specified technical parameters, technical conditions, and the National Standard of Ukraine (DSTU).

Metallographic analysis of the metal of the experimental fusions indicated that the structure of the metal in castings (containing 3.6-3.9% C and 2.4-2.6% Si) is represented by the ferrite-pearlite P6(F94) structure with finely dispersed, equally distributed inclusions of graphite with size and shape of the grain appropriated to the indicators of SGd15.25 and SGs4.5 (according to International technical standard of Commonwealth of independent states 3443-87). This fact proves the effect of silicon carbide (SiC) on the formation of finely dispersed graphite disposed to globularization in cast iron (Fig 1).



Fusions: a - comparative, b, c – experimental

Figure 1– Microstructure of Ductile iron

The mechanical properties of the obtained castings comply with the requirements of DSTU.

Applying the carbon carbide-silicon materials during the smelting of cast iron allows for obtaining castings in terms of structure and mechanical properties that are not inferior to foreign analogs [6].

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UDC 620.22: 691.73: 669.046.516

OPTIMIZATIONOF IMPURITIES PERMISSIBLE QUANTITY IN BrO3A3 ANTI-FRICTION BRONZE

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Investigationof silicon, iron, zinc, and lead impurities influence on BrO3A3 bronze in cast state mechanical properties (σ_B, $\sigma_{0,2}$, δ, KCU) results have been presented and their permissible concentrations have been established.

Impurities influence on mechanical properties has been evaluated according to experimental data, assuming that within each impurities mass content from 0 to 0.6% by mass, such dependencies are linear in nature and, therefore, can be described by linear equation of the following form:

$$y_i=A_1\cdot x_1+A_2\cdot x_2+A_3\cdot x_3+A_4\cdot x_4+A_5\cdot x_5+A_6\cdot x_6+A_7\cdot x_7, \quad (1)$$

Where: A_1 ... A_7 - regression coefficients;$x_1 \ldots x_7$ – mass fraction of bronze component (Cu, Al, Sn, Pb, Zn, Si, Fe), %.

Each impurity influence degree on bronze mechanical properties has been estimated by regression coefficients values in equation (1), which have been calculated as corresponding linear equations system solving result by the Kramer method.

According to research results, it has been established that silicon and iron content in studied bronze with 3-4% Al and Sn (each) should be limited by 0.2% (weight) each. At the same time, lead and zinc in any amount are unacceptable.

Impurities negative effect on investigated BrO3A3 bronze mechanical properties has been evidently explained by α-Cu solid solution doping degree increasing and β-Cu_5Sn chemical compound fraction as its second structural component increasing in above-mentioned impurity elements in bronze composition presence.

UDC 621.771.23 : 669.1.017

A PROSPECTIVE DIRECTION FOR IMPROVING THE PROPERTIES OF HIGH-TENSION THICK ROLLED SHEETS

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The problem of obtaining high-quality thick rolled products of high (30-40 mm) and ultra-high (100-200 mm) thickness dictates a special approach to its production, and the quality of rolled products is determined by the economic and technical possibilities of production.

The main way to improve the service properties of thick rolled products for the manufacture of metal products of responsible purpose is the creation of high-strength steels that have higher strength characteristics while maintaining a sufficient level of plasticity and viscosity compared to existing mass-produced steels.

On the basis of analytical studies, it was established that for the production of sheets with a thickness of more than 40 mm, domestic manufacturers use improved welded high-strength alloy steels containing up to 0.38 wt.% carbon. The limitation of carbon content is related to the need to ensure satisfactory weldability. The main alloying elements of these steels are manganese, chromium, nickel, molybdenum and silicon.

In order to obtain high plasticity characteristics and a sufficient supply of material viscosity, the sheets are usually tempered with high tempering. At the same time, the level of strength characteristics (σв - temporary resistance to fracture during stretching) is, as a rule, within 850-1100 MPa.At the same time, the value of the temporary resistance to the destruction of the metal of sheet metal for metalware for responsible purposes of foreign manufacturers reaches 1200 MPa and above, depending on the thickness of the sheet, with sufficiently high values of the yield and impact strength.

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

Thus, research aimed at the development of technological principles for obtaining high-strength sheet metal from low-alloy steel for the manufacture of metal products of responsible purpose is promising and relevant.

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UDC 669.13.017:620.18

FEATURES OF THE DISTRIBUTION OF ALLOYED ELEMENTS IN THE STRUCTURAL COMPONENTS OF NEW CHROMO-MANGANESE ALLOYS IN THE CAST STATE

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When studying the influence of the chemical composition on the formation of the structure and properties of new economically alloyed alloys (C = 2.2–3.1 % C, 5.7–15.8 % Mn, 12.6–15.9 % Cr, 0.83–1.15 % Ni, ≤ 0.25 % V) it was found that their crystallization begins with the precipitation of primary austenite dendrites and ends with the formation of eutectic colonies of austenite and carbides.

According to the data of X-ray diffraction analysis, carbides of the Me_7C_3-$(Cr, Mn, Fe)_7C_3$ type, cementite, austenite, and α-phase were found in the structure of the experimental alloys. The amount of austenite in the matrix of experimental alloys increases from 87 to 94 % with an increase in the content of carbon, manganese and alloying elements. Along with an increase in the amount of austenite, the microhardness of the experimental alloys also increases, which may be due to segregation processes occurring during crystallization and final cooling of the experimental alloys.

The distribution of alloying elements in the cast structure of experimental alloys was determined using local X-ray spectral analysis at the points at which the content of the main (C, Mn, Si), alloying (Cr, Ni, V) and impurity (Cu) elements of the matrix, as well as eutectic carbides was determined.

The minimum (k_{min}) and maximum (k_{max}) segregation coefficients (the ratio of the minimum and maximum content of an element to its average value in the corresponding structural component) are determined. It has been established that in the structure of the experimental alloys there are areas with both negative and positive segregation of the main, alloying and impurity chemical elements. The highest values of positive segregation coefficients were recorded for nickel, vanadium and copper.

The results of the analysis of the distribution of chemical elements between the structural components of the experimental alloys in the cast state indicate that with an increase in the content of carbon, chromium and manganese, the degree of alloying of the metal matrix and eutectic carbides increases, which ensures an increase in their microhardness, overall hardness of the material and, accordingly, its wear resistance. In particular, the latter was confirmed by friction wear tests on the surface of prototypes of chromium-manganese alloys at a temperature of 950 ºC and load of 500 N.

UDC 621.771.23.09

SKIN-ROLLING OF LOW-CARBON STEELS SHEETS FOR COLD STAMPING

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Skin-rolled hot-rolled 08КП, 08ЮА steels strips samples for cold stamping, have been studied. It has been established that with an increase in reduction during skin-rolling in the continuous pickling line, the plasticity of hot-rolled metal from boiling steel decreases. It has been determined that due to optimally selected technology for heavy plate steel processing, it is possible to minimize the mechanical properties worsening and to reduce the aging adverse effect. In order to increase the hot-rolled strips plasticity and obtain high-quality sheet steel for cold stamping, it is advisable to select the skin-rolling parameters taking into account the steel composition, the surface condition of the rolls, the skin-rolling speed, the strips temperature and other factors.

The analysis of mechanical properties showed that the non-uniformity of plastic deformation is lower in aluminum-stabilized steel than in boiling steel. Also, aluminum deoxidized steel, compared to boiling steel, is characterized by a more favorable σ_T / σ_B ratio for stamping.

The fractographic analysis confirms the better level of viscosity of the skin rolled hot-rolled metal: a viscous and mixed type of fracture is observed in 08ЮА steel in 80-85% of the investigated areas, and in 08КП steel - only in 35-45% of areas. Thus, the fracture type of hot-rolled sheet steel 08ЮА is a guarantee of service reliability during operation of parts made from it.

UDC 621.771.23.09

SKIN- ROLLING INFLUENCE ON THE THIN SHEET STRUCTURE AND MECHANICAL PROPERTIES

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The skin-rolling effect on the mechanical properties and structure of pre-heat-treated, hot-rolled, pickled in a continuous pickling unit 2.0 mm thick roll strips made of 08ps steel was investigated.Rolls of sheet steel were exposed to light annealing in bell-type furnaces at a temperature of 680–710°C, heating time 40–48 h, cooling time 60–75 h.The rolled strips annealed in bell-type furnaces were skin-rolled on a separately located skin-rolling mill with 1.5% compression.

It has been established that heat treatment in bell-type furnaces significantly improves the hot-rolled thin sheet steel plasticity.The results of microstructural analysis showed that a uniform cross-sectional structure with a ferrite grain of 25-30 μm in accordance with DSTU 2834-94 is formed in thin rolled steel. The mechanical properties of skin-rolled etched strips fully meet the requirements of DSTU 2834–94 strength group K270B not only for hot-rolled, but also for cold-rolled products: $\sigma_в$= 340 MPa, $\sigma_т$= 215 MPa, δ = 41 %, HRB 38.

Since hot-rolled and skin-rolled thin sheet meets the requirements for cold-rolled steel in terms of quality,it is possible to replace the expensive cold-rolled sheet with a cheaper hot-rolled one of the same quality. This will allow to reduce the consumption ratio of metal, save electricity and natural gas.

UDC 669.13.017:620.18

DETERMINATION OF PROMISING COMPOSITIONS OF THE CHEMICAL COMPOSITION OF WEAR-RESISTANT ECONOMIC ALLOYS BASED ON IRON

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An important contribution to the economy of our country is the export of rolled products and semi-finished products. The requirements for quality indicators of rolled products are growing every year, and reducing its cost is becoming an increasingly urgent problem. Rolls, ruler guides and piercing mandrels of rolled conditions are sliding tools of hot deformation, the operational characteristics of which affect the productivity of the technological process, the quality of commercial products and its cost.

Depending on the operating conditions, the rolling rolls of the pre-finishing and finishing stands are made of alloyed cast irons of type Cr16NiMoVT, 280Cr19MnNiMo, 300Cr21MnNiMo and the piercing mandrels are made of alloyed cast iron 300Cr32Ni3V or chrome-nickel alloy «nicorin» type (36.0–38.0 % Cr, 57.0–59.0 % Ni).In the last case, the rolling tool is characterized by a significant cost and, despite various methods of processing, has insufficient operational durability, which is tens of hours of working.

Modern trends in the production of wear-resistant materials instead of high-chromium cast iron indicate the use of chromium-manganese alloys, which additionally contain copper, titanium, and aluminum. In this regard, chromium-manganese alloys were chosen as the base material, which should

lead to a reduction in the cost of manufacturing wear-resistant products due to a decrease in the content of chromium, nickel and vanadium in comparison with 300Cr32Ni3V cast iron and an alloy of the «nicorin».

The element-by-element influence on the formation of a set of properties of cast irons in the cast state was studied for a selection of statistical data, which included 77 known compositions of cast irons and three experimental alloys. Based on the theory of directed chemical bonding and the computer program «Metal», an ambiguous effect of carbon, chromium, silicon, vanadium and copper on the formation of hardness, tensile strength and impact toughness of cast irons were obtained. It is shown that the parameters ρl (charge density) and $tg\alpha$ (gradient of change in the ion radius from its charge) should be used as the most informative indicators of theprediction of complex mechanical properties of cast irons, taking into account the overall effect of the chemical composition of the alloys.

Based on the simulation results, rational compositions of the chemical composition of iron-based chromium-manganese alloys were established in the following ranges: C = 2.6–3.0 %; Cr = 10.0–20.0 %; Mn = 10.0–15.0 %; Ni = 0.5–1.7 %; Si ≤ 1.3 %; V ≤ 0.3 %; Cu ≤ 0.3.

If necessary, as an additional reserve for improving the mechanical properties of iron-based chromium-manganese alloys, the use of molybdenum (0.95–1.2 %), barium (≤ 0.01 %) or titanium (≤ 0.02 %) is effective.

At the same time, the effectiveness of the use of Ca as a modifying element affects the morphology of non-metallic inclusions and determines the effectiveness of its use with the simultaneous introduction of Ba, since their synergistic effect on the quality of the alloy.

UDC 669.017 :669.14.018.294.2

PROBLEMS AND PROSPECTS OF MODERN RAIL STEELS

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Based on research in recent years, it is known that the strength of pearlite rail steels has reached its limit. In addition, an increase in carbon content can negatively affect the impact toughness and weldability of rail materials. For example, compared to the pre-eutectoid rail R200, the elongation of the post-eutectoid rail R400HT is reduced by 6% (in absolute terms). Therefore, there is an urgent need for other alternative materials. Bainite steel, which provides both high strength and excellent plasticity, is considered one of the most promising materials.

Low-carbon bainitic steels differ from ordinary pearlitic steels in that they contain few, if any, carbides. Bainite low-carbon steels, the strength of which is more than 1200 MPa, at the same time, have a high level of impact toughness, tribological properties, a favorable reaction to high deformation rates, resistance to fatigue, and are relatively cheap to manufacture. Such a complex of properties is achieved due to a very fine and strongly strengthened rail microstructure.

As is known, during the bainite transformation, the formation of a package of bainite rails occurs at the austenite grain boundary and further growth of the package occurs deep into the grain. The bainite packet consists of ferrite rails separated mainly by low-angle boundaries, while acicular ferrite nucleates heterogeneously on non-metallic inclusions inside the austenite grain and grows in different directions without forming distinct packets, otherwise remaining similar to bainite.

It has been established that the most effective way to increase the hardness of steels is to control their chemical composition by means of alloying, micro-alloying and reducing the number of harmful impurities. An approach to increasing resistance by manufacturing railway rails with a bainite structure is promising.

УДК 621.791.92

INHERITANCE OF METAL STRUCTURE IN ELECTROSLAG SURFACING USING CONSUMABLE ELECTRODE

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One of the types of electroslag technologies, which is quite successfully used in a number of industries, is electroslag surfacing. The scheme with the flow of thedeposited metal from the moltenconsumable metal electrode in the slag is the most widespread in the same way as this occurs at a conventional ESR.

It is well known that the properties of the metal produced during electroslag remelting in addition to the technological parameters of the process, including composition of the flux, melting rate, temperature of the slag pool, etc. depends on the quality of the remelted electrode. The more pure is the content of the material flowing to remelting from undesired impurities and non-metallic inclusions, the more homogeneous its structure and without defects, the higher is the quality of ESR metal.

In electroslag surfacing due to comparatively small volumes of the deposited metal and its sufficiently rapid solidification, in addition to the chemical composition and purity, the properties of the deposited layer may be affected also by the initial structure of the electrode metal.

To confirm this factor, the experiments and investigations were conducted according to the following procedure. In a mould of 120 mmdiameter using ANF-6-1 flux, electrodes of Kh12MF steel of two types – rolledwith a diameter of 70 mm and cast of the same diameter were remelted. The latter were produced by melting of a part of the same rolled billets in the induction furnace and by filling the liquid metal into the metal mould of the corresponding diameter. The thickness of metal deposited on the steel substrate was 40-50 mm.

The specimens for metallographic examinations were selected from the deposited ingots at a distance of 10 mm from the side surface and from the central zone. From the remelted electrodes, the specimens for investigations were selected at a distance of ½ of their radius. As a hereditary feature, the average size of grains (cells) of the structure of the source and remelted metal was accepted. Metallographic examinations were performed in the Neophot-32 microscope, the structure was evaluated by the criterion of the average size of cells.

According to the metallographic analysis, the structure of the metal that passed pressure treatment has about 2 times smaller grain size as compared to the cast metal (the average diameter of cells is 40-50 μm and 90-100 μm, respectively). The metal deposited with the use of a rolled electrode near the side surface, has a cell size of 50-60 μm, and in the center it is 90-100 μm. During remelting of a cast electrode near the side surface of the deposited layer, a structure with a grain size of 80-100 μm is formed, and 120-150 mm in the central zone. I.e., in the first case, the structure of the metal produced during surfacing is 1.5-2.0 times more dispersed.

The obtained results show the possibility of transferring structural features in electroslag surfacing from the remelted metal to the deposited metal. Based on this, it can be assumed that in order to increase the operational properties of products deposited from Kh12MF steel, it is preferable to use forged consumable electrodes instead of cast ones.

UDC 621.9.048

RECEIVING BORON-CONTAINING HIGH-ENTROPY ALLOYS AND COATINGS BASED ON THEM

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Such borides of transition metals as TiB_2, TaB_2, NbB_2, due to their special physical and chemical properties, high melting temperature (more than 3000 ºC), heat resistance and hardness are known to mankind as ultra-high temperature ceramics. Therefore, the creation of composites and coatings based on these metals is an urgent task.

This paper presents the results of obtaining and researching the high-entropy alloy $VNb_2TaCrMoWTi_{0.3}B_{0,6}$ and coatings based on it. The alloy was obtained by the method of arc remelting, using metals with a purity of more than 99.5 atomic percent and TiB_2 powder as the starting components. Melting was carried out with a non-consumable tungsten electrode on a copper water-cooling plate. Smelting was carried out in two stages: first, the metal elements were melted, then the ingot was broken into pieces to which TiB_2 was added and remelting was carried out.

X-ray structural analysis showed that the cast alloy $VNb_2TaCrMoWTi_{0.3}B_{0,6}$ consists of a solid solution based on a phase with a bcc structure and a boride with a structure of the W_2CoB_2 type, in which tungsten positions are mainly occupied by atoms with a large atomic radius (Nb, Ta, Mo, W), and positions of cobalt with small (V, Cr). The study of the morphology of boride using electron microscopy showed that it crystallizes eutectically and from the last portions of the melt, thus forming a closed net in a solid solution matrix. According to local chemical analysis data, the boride is enriched with vanadium, tantalum and chromium, and the solid solution with molybdenum and tungsten.

Electrodes were made from the obtained ingots and electrospark coatings were applied with varying energy of electric discharges. The deposition mode with a higher energy of single pulses (1.1J) provides a greater mass transfer of the electrode material to the substrate. An increase in the mass of the cathode is observed when the duration of the deposition process is up to 7-8 minutes. During further processing, the mass of the coating remains unchanged, and even decreases for the 0.52 J mode. This is due to the accumulation of defects and stresses in the applied layer and its destruction under the action of spark pulses. Changing the discharge energy during coating does not affect the hardness (10 GPa), however, it leads to an increase in thickness from 11-15 to 16-20 μm for energies of 0.52 and 1.10 J, respectively.

The microstructure and morphology of the obtained coatings were studied. The fact that as a result of the mixing of the base metal with the electrode, iron gets into the coating draws attention. The iron content is maximum near the substrate and minimum on the surface. According to the obtained microstructures, there are no defects or a transition layer at the interface between the coating and the substrate. The microstructure of the coating is homogeneous (single-phase) and not similar to the microstructure of the electrode from which the coating was applied. According to the data of X-ray structural analysis, the obtained coating is not single-phase and it forms an intermetallic of the Fe_7W_6 type (a=0.4960, c=2.5901 nm) and a bcc solid solution with a period of a=0.3030 nm. Also, as a result of the absence of a protective atmosphere, an oxide of the TaO_2 type is formed during coating application (a=0.4709, c=0.3065 nm). These three phase components are ultradispersed and uniformly distributed in the cross-section of the volume coating and do not manifest themselves in the microstructure. The discharge energy at which the deposition took place does not qualitatively affect the phase composition of the obtained coatings, however, with an increase in the discharge energy, an increase in the amount of oxide is followed.

UDC620.194.22

INVESTIGATION OF STRESS-CORROSION CRACKING UNDER CATHODIC PROTECTION OF LONG-TERM OPERATED PIPE STEEL X70

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Comparative studies of stress-corrosion cracking of base metal of pipes made of X70 steel were carried out, namely new pipe and after 20 and 40 years of operation. Certainly, itis possible to compare such pipes with a certain degree of convention, since the steel sheets from which they are all made belong to different batches and, quite likely, are made by different manufacturers, the technologies of which have some peculiarities. But the chemical composition of all steels complies with regulatory documents, they are manufactured using controlled rolling technology, have a ferrite-pearlite microstructure, and belong to the X70 strength category. The pipes are made in Ukraine according to the same technology, their diameter is 1420 mm, the wall thickness is 15.7 mm, and they are used for the construction of an underground gas pipeline in a region with a moderate climate. To protect against underground corrosion, complex anti-corrosion protection is applied: passive protection – with a tape polymer coating and active protection – electrochemical polarization.

The purpose of the research is to evaluate the electrochemical and corrosion-mechanical properties of the base metal of the pipes after exposure to operational factors and establish trends in their change.

The determined indicators of mechanical properties (strength limit σ_S, yield strength $\sigma_{0.2}$, relative elongation δ_5, and impact toughness KCV^{-15} and KCU^{-60}) of operated and unused pipes meet the requirements of BR 2.05.06. The corrosion potential of the new pipe was -0.71 V, and the corrosion potential of pipes operated for 20 and 40 -0.692 V years shifted to more positive values, to-0.624 Vand -0.692 Vcompared to the new one. The hydrogen recovery potential on the metal of the new pipe is -1.07 V. The hydrogen recovery potential of the pipes operated for 20 and 40 years is shifted to more positive values by 0.11 (up to -0.96 V) and 0.17 V (up to -0.90 V) compared to the new one. The limiting diffusion current, the values of which can be used to compare the corrosion rate of steels, is for a new pipe $1.82 \cdot 10^{-4}$, for pipes operated for 20 and 40 years – $1.82 \cdot 10^{-4}$ and $2.0 \cdot 10^{-4}$ A/m^2, respectively.

That is, according to the electrochemical properties, there is a tendency to decrease (by absolute value) the corrosion potential and the hydrogen recovery potential; the corrosion rate of all investigated pipes is practically the same. Susceptibility to stress-corrosion cracking was studied at the minimum -0.75 V and maximum -1.05 V protective potentials and was evaluated by the K_S coefficient (which was calculated as the ratio of the relative narrowing of the samples in air ψ_{air} to the relative narrowing in the solution ψ_{sol}). It was established that in the series: new pipe $\rightarrow$ operated for 20 years $\rightarrow$ pipe operated for 40 years at the minimum protective potential of -0.75 V, K_S values change as follows: 1.57 $\rightarrow$ 1.03 $\rightarrow$1.95; when the protective potential increases to -1.05 V K_S values change like that 1.53 $\rightarrow$ 1.6 $\rightarrow$ 2.44. Therefore, at the minimum protective potential for the operated pipes, K_S does not change monotonically, a certain decrease in the susceptibility to stress-corrosion cracking was noted at the minimum protective potential. At a potential of -1.05 V, there is a steady tendency to increase the susceptibility to brittle failure of both operated pipes, which increases significantly with the increase in the life of the gas pipeline.

Thus, the long-term operation of the underground gas pipeline did not cause changes in the mechanical parameters of the base metal of the pipes but contributed to the increase in susceptibility to stress-corrosion cracking at the maximum protective potential. It is likely that the influence of internal microdamage, which accumulate during the long-term operation of the gas pipeline, affects precisely the corrosion-mechanical durability of steel.

UDC 669.017.03

NFLUENCE OF HEAT TREATMENT ON THE STRUCTURE AND PHASE COMPOSITION OF HIGH CHROMIUM CAST IRON

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It is known that the properties of iron castings can be improved due to heat treatment to bainite in the solid state.

The structure, phase composition, hardness, microhardness of the structural components of heat-treated samples of 28Х32Н3Ф high-chromium cast iron were studied in the work

The analysis of the microstructure of samples of heat-treated cast iron shown, that there is agglomeration of secondary excess carbides, residual austenite undergoes disintegration into ferrite, chromium carbides Cr7C3 and cementite Fe3C. The most dispersion is characterize the structure of cast-iron after heat treatment at Tаустˑ=1050°C і τаустˑ=1 hour, Tізотˑ=350°C (τізотˑ=3 hours).

X-ray structural analysis revealed in all samples austenite and ferrite, the amount of which varies according to the heat treatment regimes, excess Cr7C3 carbides and cementite Fe3C.

After conducting a comparative analysis of the studied alloys, it can be concluded that the researched alloy has the best properties after heat treatment at Tаустˑ=1050°C і τаустˑ=1 hour, Tізотˑ=350°C (τізотˑ=3 hours).

UDC 669.01

INFLUENCE OF THERMODEFFORMATION HARDENING ON AUSTENITE GRAIN PARAMETERS

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It is known that the technological plasticity and deformation capacity of structural steels depends on the size of the austenite grain. This work researched the temperature dependence of the intensive grain growth of austenite ВСт3сп steel. The threshold of intensive grain growth is significantly influenced by the initial state of the metal in steels before rolling. To estimate the austenite grain size of VSt3sp steel, a quenching method was used: the samples were heated to different temperatures in the austenite region with a holding time of 2 min/mm (850-1250°C after 25°C) and hardened in the water. The use of this method made it possible to obtain, in samples 20x20x20 mm, the separation of networks of excess non-equilibrium ferrite along the boundaries of the former austenite grains. ВСт3сп steel is prone to stepwise growth of austenite grains when certain critical temperatures are exceeded due to the flow of aggregate crystallization, which is accompanied by the appearance of significant heterogeneity.

The gradual growth of austenite grains in ВСт3сп steel up to temperatures of 900-950°C is due to the retarding effect of a complex of particles, including unstable sulfides and silicates. Therefore, it would be assumed that as the particles of the intermediate phases dissolve, the interparticle distance increases, which increases the probability and possibility of their being surrounded by the boundaries of austenite grains, which move at rather low values of the activation energy (at high temperatures), leading to intensive stepwise growth of austenite grains. As the temperature rises and the dissociation of thermally unstable sulfites and silicates along the austenite grain boundaries causes carbon to be

squeezed out of the boundary areas into the middle of the austenite volumes, as a result, excess ferrite is released along the boundaries of the hardened samples.

The non-monotonic temperature dependence of austenite grain growth must be taken into account when choosing heating parameters for rolling during strain-thermal strengthening.

УДК 621.762.5

PREDICTION OF INDICATORS OF THE DESTRUCTION EFFORT OF "KYBOR" AND "KUBONIT" BRAND MICROPOWDER

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Composite material based on cubic boron nitride (cBN) is a ceramic containing a high content of cBN (from 45 to 100%) in its structure, along with a metallic or refractory bond. Polycrystals from cBN (PCBN) have high hardness, so they are used for processing other materials by the cutting method. These can be steel products, heat-resistant alloys based on Ni or Co.

Ultra-hard polycrystals can be obtained using the powder metallurgy method (powder sintering using high-pressure technologies). Each brand of polycrystal is characterized by its stable phase composition and a set of physical and mechanical properties determined by the technology of producing PCBN composites.

The technology of obtaining materials is significantly influenced by the raw materials (powders - their grain size, real structure, and composition of the charge). The starting powders have certain technical requirements that must meet production standards. So, for example, the strength indicators of powders of the brands "Kubonite" (KO, KR) and "Kybor" (KT) are determined for grinding powders (up to 40 μm), but such data are not available for micropowders (less than 40 μm). The reason is the limitation of existing methods for determining the strength indicators of fine-grained powder.

It is known that the strength of the composition depends on certain factors of the powders: the development of the surface of the powders, plasticity, the strength of the destruction of the grains (a sharp increase in the destroyed grains contributes to an increase in the number of contact planes between the particles, and as a result, an increase in the action of interatomic forces).

Therefore, the purpose of the work is to calculate and predict possible strength indicators (destruction strength) for cubic boron nitride micropowders of the "Kubonite" and "Kybor" brands.

The initial data for the calculation were taken from grinds of cubic boron nitride powders of the KT, KR, KO brands (granularity 200/160μm; 160/125μm; 125/100μm; 100/80μm; 80/63μm; 63/50μm; 50/40μm), and powders crushed kyborite (granularity 125/100μm; 100/80μm; 80/63μm; 63/50μm; 50/40μm). After processing the initial data with the polynomial regression function, the strength indicators for the KT, KR, KO micropowders of the following fractions were determined graphically: 40/28μm; 28/20 μm; 20/14 μm; 14/10 μm; 10/7 μm; 7/5 μm; 5/3 μm; 3/2 μm; 2/1 μm; 1/0 μm; 0.5/0 μm; 0.25/0μm; and crushed kyborite powders of the same fraction.

It was found that the smaller the grain size, the lower the strength indicators. The values change proportionally in the same way (for crushed powder "Kyborit", the grain strength is 2-3 times less than other brands). The breaking force for fractions with a grain size of less than 1 μm is < 0.1 N. The grains of the "Kybor" brand should have higher strength (KT), then - "Kubonite" (KR, KO), - and crushed powder "Kyborit". Using the example of fraction 40/28μm, the values are as follows:

-KT – 3.3 N;

- KR – 2.9 N;
- KO – 1.7 N;
- Crushed powder "Kyborit" - 0.9 N.

Thus, the possible strength indicators for cubic boron nitride micropowders of the brands "Kybor" and "Kubonite" were calculated and predicted. These data will make it possible to investigate

the dependence of the onset of powder destruction on the pressing pressure in further work. Determine the mechanisms of compaction of pressings in the working volume.

UDK 621.7.075

THE INFLUENCE OF MORPHOLOGY AND CHEMICAL NATURE OF ADDITIVES ON ELECTRICAL CONDUCTIVITY OF cBN -BASED COMPOSITE MATERIALS' WITH NbN BINDER

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Annotation Inthis work researched influence morphology (micropowders and whiskers) and chemical nature of additives for electrical conductivity HPHT-sintered (at P = 7.7 GPa, T = 2000 ℃) cBN-basedcomposites withNbNbinder. The influenceof morphology'simpurities on electrical conductivity of sintered samples is shown for the first time.It is established that sintered samples have semiconductor nature of conductivity and promising not only for cutting tool but for others applications (for instance, in atomic industry).

Methods Forall samples (cBN–NbN–Al sampleswithout additives and with SiCw, Si_3N_4w, Al_2O_3 and Al_2O_3w powders) were measured electric resistance in the range from room temperatures up to 400 ℃. Also was measured dependence of resistance on voltage applied to the sample before and after heating samples.

Results and discussion*Influence chemical the nature of additives for electric resistance of cBN-based CM's.* On the semiconducting character electrical conductivity testifies reduction values electrical resistance during heating samples [2]. Addition of whiskers with wide-bandgap semiconductor nature (SiC, Al_2O_3, Si_3N_4) improves conductivity samples, despite on their smaller conductivity. Resistance'sdependence from applied to the sample voltages before and after heating samples practically independent from temperature. This fact point on the structure homogeneity ofmaterial investigated samples.

*Influence morphology dopants on electrical conductivity*was studied forcBN-NbN-Al-Al_2O_3 and cBN-NbN-Al-Al_2O_3w systems. When adding Al_2O_3 w observed more significant fall electrical resistance than when adding Al_2O_3 powder (from 1.85 ±0.007 to 0.72±0.002 and from 1.35±0.05 to 0.17±0.006 mΩ· cm - for samples withwhiskers and micropowders, respectively). It may be associated with formation conducting phase at the " dopant-matrix " boundary (since area interphase boundaries significantly higher when adding powderthan when adding whiskers), which in turn leads to the improvement of the passage conditions electric current through the sample.

Conclusions

All investigated samples as in order of absolute value electrical resistance, as well as by the nature of temperature dependencies are semiconductors. Combination of such interesting properties – electrical conductivity with high level mechanical properties (HV up to 38 GPa, K_{1c}- up to 7 $MPa^{-1/2}$) and chemical resistance (processes oxidation samples are starting above 660 ℃) [2] indicate that these materials can be promising in such fields as nuclear physics and atomic industry (forinstance, asmaterialsforliquidcrystaltargetsforelectron-positronconversion).

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UDC 669.14.018.258

PRODUCTION OF STAMPED STEELS 4X3H5M3Φ AND 4X4H5M4Φ2 BY ELECTROSLAG REMELTING TAKING INTO ACCOUNT THE OPTIMUM MODES OF HEAT TREATMENT

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An electroslag remelting unit at the "Spetslityo" plant (Dnipro, Ukraine) was used to manufacture a research and industrial batch of matrices for hot deformation of M1 copper (GOST 859-2014). The obtained ingots (the weight of one ingot was 100 kg) were made of 4X3H5M3Φ steel. During the smelting of electroslag remelting for the production of experimental steel, it was decided to use the ligature of the Fe–Ni–Mo–V–Mn system and scrap steel of the 4X5MΦ1C stamp. The ligature of the Fe–Ni–Mo–V–Mn system was melted in an induction furnace and poured into a mold, resulting in ingots (ligatures) weighing 25 kg. The ligature was made taking into account the temperature of the melt in the furnace before the tapping of 1550 °C, the duration of refining did not exceed 20 min. During the research of the 4X3H5M3Φ steel, it was established that the recommended thermomechanical processing mode for it is not optimal. The hardness after complete annealing of the steel in the cross section of the workpiece exceeds 35 HRC. In addition to high hardness, the material also has a lamellar carbide component structure that is unfavorable for mechanical processing. Unfortunately, annealing at a temperature of 860 °C does not ensure spheroidization of the carbide component. Annealing of steel at a temperature of 680 °C is not advisable, since it does not change the structural carbide component in the absence of phase transformations. The hardness after complete annealing of the steel in the section of the workpiece exceeds 35 HRC.

In order to reduce stiffness and facilitate machining by cutting, it was suggested to carry out partial recrystallization, that is, incomplete annealing, during the manufacture of dies from stamping steel. Because only in the process of partial recrystallization of steel, a spheroidized carbide component is formed, which will lead to an improvement in the mechanical processing of the workpiece for the manufacture of dies of a stamping tool. A dilatometric analysis was performed to establish the critical points A1 and A3 of the 4X3H5M3Φ stamping steel. Based on the results of the study, the critical points of steel were established: A1 = 700 °C and A3 = 850 °C, which allows us to recommend spheroidizing (incomplete) annealing at a heating temperature of 750±20 °C. If the alloy structural steel 4X3H5M3Φ is incompletely annealed, its hardness was 33–34 HRC of the pearlite-sorbide structure (α-Fe) from the spheroidizing carbide component, which made it easier to carry out mechanical processing for the manufacture of stamping tools. Depending on the size of the 4X3H5M3Φ stamping steel sample (workpiece), a different time of isothermal holding at a temperature of 750±20 °C is selected. So, for a matrix-type workpiece with a diameter of 170 mm, the total exposure time should be about 5.5 hours. The workpiece obtained by electroslag remelting was subjected to heat treatment at 730–770 °C (incomplete annealing). The hardness of the steel was 33–34 NRS. After that, the workpiece was mechanically processed by cutting, cutters with plates of the T15K6 alloy in order to obtain matrices of the stamping tool.

The use of electroslag remelting technology when obtaining ingots makes it possible to reduce the energy-intensive technological operation - forging. The operational properties of 4X5MΦ1C steel at the "Spetslityo" plant (Dnipro, Ukraine) during hot plastic deformation of M1 copper (the profile of the product has dimensions of 6x102 mm) are not high enough. The main reasons for the low operational stability of the matrix and the retainer cover are related to the cast state, namely, their lack of plastic deformation and the lack of optimal modes of heat treatment of steel. The study of the microstructure of 4X5MΦ1C steel in the cast state showed its heterogeneity, the presence of a dendritic net and eutectic areas. The microstructure of the metal from the matrix of the 4X5MΦ1C steel punch tool consists of a sorbide structure with significant carbide heterogeneity: the presence of

areas of increased etchability (enriched with impurities) in the form of a net of dendritic structure. Deterioration of the cast structure of 4Х5МФ1С steel is associated with the production of ingots using traditional foundry technology. After thermal hardening (quenching at 1040±10 °C and tempering at a temperature of 600 °C), a large carbide component occurs. The use of electroslag remelting technology to obtain ingots at an increased crystallization rate will improve the cast structure and increase the mechanical properties of die steel. The reason was estimated to be the uniform distribution of chromium, nickel and vanadium alloying elements throughout the grain body of the dendritic structure with first-order branches. The presence of only a small amount of large inclusions of vanadium carbide VS was established.

From the developed cast steel 4Х3Н5М3Ф, for which the optimal heat treatment regimes were established, a stamping tool (matrix) for pressing M1 copper metal was made. The dimensions of the profile of the blanks with a rectangular cross-section were 6x130 mm. The developed matrices were installed in standard equipment for drawing non-ferrous metals. In comparison with the dies of the stamping tool made of 4Х5МФ1С steel (obtained by traditional foundry production technology), which is used at the "Spetslityo" plant (Dnipro, Ukraine), the dies of 4Х3Н5М3Ф steel made by the developed technology had great durability. The peculiarity of drawing copper using the die tool matrix made of 4Х5МФ1С steel is that in case of impurities of other metals, there is a sharp increase in temperature, which affects the material of the die steel matrix, microcracks are formed on its surface. This leads to premature failure of the die tool. By using the developed steel, it is possible to avoid this kind of failure of the stamping tool, because the structure of the material allows to be used stably at higher temperatures. For cast steel 4Х3Н5М3Ф, the optimal quenching and tempering regimes correspond to 1030±10 ºС and 590±10 ºС, respectively. To increase the heat resistance of the studied steel, it was decided to adjust the chemical composition, which corresponded to the 4Х4Н5М4Ф2 grade. And also increase the tempering temperature of the studied steel before primary recrystallization. It was established that the optimal tempering temperature of 4Х4Н5М4Ф2 steel is 1100±10 ºС and tempering is 590±5 ºС. Primary recrystallization of steel occurs at a temperature of 1110 ºС. It was established that the heat resistance of the investigated steel 4Х4Н5М4Ф2 increased by 30 ºС (at 650 ºС, HRC 40 at room temperature) compared to steel 4Х3Н5М3Ф. The paper presents the properties of cast steel 4Х4Н5М4Ф2 after full annealing according to the developed regime and step annealing according to the regime that was developed for steel 4Х2Н5М3К5Ф (EP - 930). At the same time, sufficiently high strength characteristics of 1390-1400 MPa were obtained. With incomplete annealing at a temperature of 750 ± 20 °C, the strength and yield threshold of the studied cast steel 4Х4Н5М4Ф2 were 900 and 800 MPa, respectively. The relative elongation and contraction were 15 and 12%, respectively. The impact viscosity was equal to 180 J/cm^2. The proposed mode of incomplete annealing at a temperature of 750±20 °C made it possible to increase the impact toughness by three times, reduce the hardness by 5 HRC, and lower the strength threshold by 500 MPa compared to the properties of EP-930 steel, heat-treated according to the mode proposed by Professor O. D. Ozersky and his students. However, the properties of forged steel 4Х4Н5М4Ф2 were much higher than the properties of cast steel and were: strength threshold - 1190 1200 MPa, yield threshold – 1050-1060 MPa, hardness 38- 39 HRC with reduced impact viscosity (130 J/cm^2). However, despite the increase in strength and hardness of the experimental forged steel, the workpieces for the production of large-sized parts were satisfactorily processed by cutting.

UDC 669-154:669.02/09.004.37

SCIENTIFICALLY - JUSTIFIED CHOICE OF ALLOYING ADDITIVE - THE KEY TO DIRECTED FORMATION OF THE PROPERTIES AND QUALITY OF METALLURGICAL MELTS

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Modern demands of metal consumers in the metallurgical market are mainly focused on the task of obtaining competitive special alloys and steels that meet strict foreign requirements and are able to work in variable conditions (operating factors, temperature changes, raw material impact factor). Smelting steel of the required quality is a complex multi-stage process that includes various metallurgical redistributions and ultimately aims to achieve the required chemical composition of the iron-carbon melt, sometimes within rather narrow ranges of changes in the concentration of the constituent elements, which lays the foundation for the formation of the appropriate set of physico-chemical properties. The use of the proofing stage on the "bucket-furnace" unit in the technological scheme of smelting iron-carbon melt opened the prospect of developing unique methods of adjusting the chemical composition of steel by methods of alloying, microalloying, refining, deoxidation, which expands the nomenclature of steels and alloys, and therefore the scope of their use.

The choice of an alloying additive is carried out depending on the target task, for example, the formation of a matrix (framework) of a metal melt [C, Mn, Si] or alloying [Cr, Ni, Ti] or microalloying [B, V, Mo] subsystems [1], which are aimed at increasing the physicochemical, thermophysical, operational characteristics. The selected model, concept or theory of the structure of the metal melt is of primary importance for the selection of the additive and the analysis of its interaction processes in the "metal-slag" system, since the limitations laid down in it further determine the effectiveness of its use and the accuracy of the calculated properties. As a basis for the scientific justification of the choice of additive, the concept of directional chemical connection [2] was chosen in the work, which reveals the physico-chemical essence of multiphase interactions through the integration of interatomic interaction parameters in the inextricable chain "Composition - Technology - Structure - Properties". In order to assess the expediency of using selected additives and the effectiveness of steel finishing processes, indicators of the distribution of elements in the "metal-slag" system Lel are proposed. When structuring the analytical expressions for the quantitative expression of the distribution of silicon and manganese, the significant parameters of the interatomic interaction of slag, steel, additives were taken into account in combination with technological factors in the out-of-furnace processing of bearing (ШХ-15) and structural (09Г2С) steels and their modifications, due to which a high forecast accuracy $R^2 \geq 0{,}9$: $L_{Si} = f\,(Z^y_{поч\ Me}, T_{плFeMn}/T_{сталі}, I_{прод})$; $L_{Mn} = f\,(d_{поч\ Me}, tg\alpha_{поч\ Шл}, T_{плFeSi}/T_{сталі}, T_{поч\ Me}, I_{прод})$. Expert evaluation of the models was carried out by comparing the obtained calculated values with the actual final distribution of elements.

The proposed approach demonstrates the effectiveness of using the physico-chemical apparatus of the concept of directional chemical bonding to describe complex metallurgical processes, in particular, the selection of a rational additive that forms the basis for obtaining a high-quality metal product of the required quality.

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SPHEROIDIZATION OF CARBIDES OF HIGH-SPEED STEEL DURING ANNEALING

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The production of thin sheet steel for high-speed cutting tools according to the existing technology is a time-consuming and low-productivity process. Therefore, there was a proposal to crush the carbide mesh only by annealing, excluding repeated rolling. For this, high-temperature rapid annealing was used.

The structural transformations that occur during high-temperature annealing at temperatures of 950 °C, 1000 °C, 1100 °C, 1200 °C and 1250 °C with durations of 25, 50, 75 and 100 minutes were studied.

High-temperature annealing at a temperature of 950 °C leads to partial dissolution of eutectic carbides. Increasing the exposure time to 100 minutes does not lead to noticeable structural changes. Annealing at a temperature of 1000 °C also causes partial dissolution of the network of eutectic carbides in the process of spheroidization. Increasing the annealing temperature to 1200 °C contributes to further crushing of the network of eutectic carbides and their dissolution. Annealing at a temperature of 1250 °C leads to the complete elimination of carbide heterogeneity.

Further low-temperature annealing at a temperature of 750 °C promotes even greater development of spheroidization of carbides and their subsequent coalescence. Annealing at temperatures of 1250 °C + 750 °C results in a steel structure with a uniform distribution of carbides.

The driving force of spheroidization is the concentration gradient of alloying components on the wisteria and the flat border of carbide inclusions. The solution is enriched with carbon and becomes supersaturated with alloying elements near the flat boundary. Areas with greater surface curvature will dissolve in the unsaturated solution, and areas with less curvature will grow due to the separation of the carbide phase from the saturated solid solution.

It was determined that the spheroidization and dissolution of carbides in the annealing process leads to an increase in the degree of alloying of the solid solution, which leads to an improvement in the heat resistance of the high-speed cutting tool.

Progressive Metal Processing Technologies

UDC 629.764

SECTION OF A SHEET METAL BY A SHAPED CHARGE JET OF A PYROTECHNICAL DEVICE IN ROCKET AND SPACE TECHNOLOGY

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In rocket and space technology, as well as other sectors of the national economy, there are such systems and structures, during the operation of which it is necessary to cut the metal shell. For example, when separating the payload body of a launch vehicle, separating stages, components and assemblies of spacecraft, cutting out hatches in emergency rescue systems, ejecting and cutting off parachute systems, cutting pipelines, cutting off the thrust of rocket engines of solid fuel devices.

This article discusses the cutting of a metal sheet with a shaped charge jet of a pyrotechnic device. After the detonation of the shaped charge, the lining is rapidly compressed, and due to the different speeds of movement of each of the points of its conical part in the direction of the cut, a compact monolithic mass of the moving parts of the shaped charge jet, the so-called pestle, is formed.

The speed of the pestle reaches 10 km/s, and the pressure on the obstacle is one or two orders of magnitude higher than the ultimate strength of metals. The cutting of the metal sheet of the structure occurs as a result of the action of pressure from the pestle of the cumulative jet on the metal obstacle.

Advantages of use: high reliability of separation of obstacles, low cost, small overall dimensions of the device, low weight of the structure, instantaneous separation of obstacles, devices operate in standby mode without periodic maintenance of the system, allows to ensure the tightness of the payload compartments.

UDC 621.771.01

DYNAMICS OF THE ROLL DRIVE LINE IN STATIONS WITH MULTI-THREAD ROLLING

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The peculiarities of the dynamics of sequential filling with a strip of three adjacent cages of a graded rolling mill are considered, due to the fact that the rolls contain four gauges each. We analyzed the oscillograms of the moment of elastic forces on the shaft between the gearbox and the engine in cages Nos. 7, 8 and 9. The capture of the first band is preceded by the idle mode of the state. At this time, the largest value of the dynamism coefficient is noted in the cages - 3.3, respectively; 3.2 and 4.0, which is explained by the effect of gaps. When capturing the next strips (during the continuation of rolling the previous ones), the dynamism coefficient decreased slightly - to 2.2 -2.9, and the torque fluctuations remain intense. This indicates the proximity of the first and second forms of self-oscillations, which helps to increase the level of dynamics.

When capturing each subsequent strip in the cages, there is a gradual increase in the static load M_{st}. This should be taken into account when calculating the maximum dynamic load M_{dmax} in cages. For example, according to the formula, taking into account how many gauges are occupied by rolling

$$M_{dmax\,i} = M_{sti\text{-}1} + K_i \cdot \Delta M_{sti}$$

Here $M_{sti\text{-}1}$ is the total static rolling moment of the previous strips;

K_i and M_{sti} - the relative coefficient of dynamism and additional static load in this cage when rolling the i-th strip. Obviously, in the case of multi-thread rolling, it is worth using the value of the dynamism coefficient, which is determined experimentally or by mathematical modeling when rolling each strip.

Another important result of multi-thread rolling is that by comparing the coefficients of dynamism when capturing the strip during idling with their value when filling the cages with the next strips (threads), it is possible to determine the technical condition of the joints of the main drive lines in terms of wear and gaps. Measurements showed that it is even more effective to record the delay time of the reaction of the sections of the drive line in the specified two modes of operation and to compare them. This time when capturing the strip from the idle mode is usually always longer due to the clearances, when rolling the clearances in the drive lines are closed and the time of the shock pulse passing through the sections is noticeably reduced.

Another feature of multi-filament rolling is that the frequency of fluctuations of the moment of elastic forces in the drive lines does not depend on which strip is in turn and how many of them are in the rolls. This means that the amount of metal and its stiffness in the rolls does not affect the frequency properties of the drive lines. This is important for mathematical modeling of dynamic processes.

Another feature of multi-thread rolling is that the frequency of fluctuations of the moment of elastic forces in the drive lines does not depend on which strip and how many of them are rolled. This means that the metal that is in the rolls does not affect the frequency properties of the drive line.

Thus, in multifilament rolling, there are peculiarities of determining the maximum dynamic load, frequency properties and technical condition of the equipment of the roll drive lines, which are recommended to be taken into account during calculations and diagnostic.

PREDICTION OF THE FLATNESS OF HOT-ROLLED STRIPS

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During the production of hot-rolled strips, several types of non-flatness can be formed:one-sided or two-sided non-flatness at the edge sections of the strips (“edge waviness”);non-flatness in the middle zone along the width of the strip (“warpage”);warping in combination with unilateral or bilateral marginal waviness (very rarely observed);local waviness, which, as a rule, has a small width and which can be located in almost any area along the strip width;latent flatness, which can appear when processing hot-rolled coils - cutting off the edges of the strip, dissolving into narrower strips or cutting the strips into sheets.

The conditions for the formation of flat products are determined by the following factors: the correct profiling of the work and backup rolls of all stands of the finishing group; a rational scheme for the distribution of deformations among the stands; thermal profile of rolls; rational planning of the sequence of rolling strips of different assortments (“assembly batch”); roll wear; the presence and rational use of control means for the shape of the inter-roll gap and the flatness of the strips (counter-bending of the rolls, the system of axial movement of the work rolls, etc.).

The results of our studies allowed us to develop a mathematical model for the formation of the cross-sectional profile and plane of hot-rolled strips. The model uses the following methods and dependencies to calculate the influence of the main factors: wear of the rolls - according to the method developed in the ISI; the influence of roll deflection - according to the method of M.E. Freidenson and I.Ya. Tarnovsky; the effect of flattening of the work rolls in contact with the strip - according to the method of V.P. Polukhin. The temperature of the rolls and its distribution along the length of the barrel of the rolls is determined by the statistical dependencies developed in the ISI. The possibility of losing a flat shape by a strip is determined by the criterion proposed by V.M. Vydrin.

The model takes into account the initial profiles of the work and backup rolls, the anti-bending force of the rolls, the use of cyclic axial movement of the work rolls to reduce the amount of radial wear. The wear of the rolls is calculated by summing up the initial data of the rolling parameters of the strips of the assembly batch when sequentially entering them. It is possible to use the measured values of the roll temperature and rolling force, or those calculated from more complex but more accurate models.

The model for calculating the cross-sectional profile and deviation from the plane of hot-rolled strips was tested under the conditions of industrial hotstrip mills. The results obtained indicate a satisfactory convergence of the calculated and experimental data.

The model makes it possible to optimize the deformation mode of strip rolling, roll profiling, to determine rational layouts of assembly batches of strips, including those for designed mills.

УДК 621.762:669.16

STUDY OF THE INFLUENCE OF HOT PRESSING ON THE STRUCTURE AND PROPERTIES OF POWDER ALUMOMATRIC COMPOSITES OF THE Al-TiC SYSTEM

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The phase and structure formation of alumino-matrix composite materials reinforced with titanium carbide during their synthesis and consolidation using hot pressing technology were studied. The influence of the content of the charge components on the density, porosity, hardness and electrical conductivity of hot-pressed composites was determined. Composite materials with different contents of aluminum and dispersion-strengthened additives were investigated: 45Al-44Ti-11C (%, wt.), 50Al-40Ti-10C (%, wt.), 55Al-36Ti-9C (%, wt.), 60Al- 32Ti-8C (%, wt.). Aluminum matrix composites were obtained by thermal synthesis and hot pressing. Thermal synthesis of composites was carried out in a vacuum induction heating furnace at a temperature of 950 ºC for 1 hour. Next, the synthesized samples were subjected to hot pressing, after preliminary heating at a temperature of 600 °C and holding for 20 minutes. A new approach to the creation of such powder materials boils down to the fact that dispersing additives (in particular, TiC) are formed by thermal synthesis from elementary powders. Due to the use of the effects of obtaining the necessary dispersed phases during thermal synthesis, which will allow purposefully influencing the growth rate of grains and artificially creating heterogeneity of the composite and thereby form a fine-grained microheterogeneous structure with high physical and mechanical properties.

The results of scanning electron microscopy (SEM) showed that the samples have mainly a two-phase structure - a gray field, on which light small particles are fairly evenly distributed. It should be noted that the number of light particles significantly decreases with the increase in the amount of aluminum in the samples. The results of the X-ray phase analysis showed the presence of titanium and aluminum carbide lines, along with which there are a number of lines belonging to the titanium aluminides Al_3Ti, Al_5Ti_3, Al_2Ti, $AlTi_3$, Al_5Ti_2, and judging by the intensity of the peaks, the content of the latter in the material is insignificant. In the case of samples made from a mixture of the composition 60Al-8C-32Ti (%, wt.), the x-ray pattern also contains lines of ternary titanium carbide Ti3AlC, the presence of which was detected even during SEM examination of this sample.

Determination of density and porosity showed that samples of all formulations were maximally compacted and did not have porosity after hot pressing. Hardness was measured on a Novotest hardness tester at the HRB scale. The hardness values for the given alumino-matrix composites range from 59-69.1 (for samples with 45-50 %, (wt.) Al) and up to 73.7-76 (55-60 %, (wt.) Al) in depending on the composition. The results of electrical conductivity studies indicate that all investigated composites showed low values of specific electrical resistance. For composites with 55-60%, (wt.) Al 0.168-0.142 Ohm*mm^2/m, correspondingly slightly higher values for materials with a higher content of the carbide component - 0.23-0.3 Ohm*mm^2/m (for composites with 45-50 %, (wt.)Al). Based on the obtained data, the given composites can be recommended for further research into the possibility of their use as materials for current collectors of moving vehicles (pantographs), which will help in solving the problem of increasing the service life of electrical contact sliding materials.

UDC 621.771.2

VIRTUAL SIMULATION OF ROLLING IN A WIRE BLOCK

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Modern technologies in metallurgy and mechanical engineering are based on the automation of design and the wide use of information technologies. Therefore, future specialists must acquire the competences of planning and conducting an experiment, as well as the use of computer systems of industry purpose during training. Modeling in the Qform software environment allows you to predict the behavior of metal under different conditions of plastic deformation, for example, when rolling a wire rod in a wire block.

The work considers the use of a set of Qform computer programs for simulating the rolling process of wire rod in the "oval - circle" gauge system. Such virtual experiments can be conducted on a computer model of a real object with built-in blocks for mathematical processing of simulation results. The computer model obtained with its help consists of three interrelated levels: the visual one, on which the means of visualization and interactive change of parameter values are located; logical, where the virtual experiment algorithm is located; and object, which is a technical object that is modeled.

The finite element method is used to simulate mechanical, thermal, physico-chemical and chemical-technological processes occurring in the center of deformation during pressure treatment. Its software implementation is based on a universal computing core that creates and solves systems of algebraic equations based on the division of physical bodies into elements for interacting environments.

For a comparative analysis, taking into account the real conditions of the process, rolling of wire rod with a diameter of 8 mm was simulated in three passes of the finishing block of the mill 400/200 of PJSC "KAMET-STEEL". In order to simplify the process of calculations, the oval and round shape of the cross-sections of the rolls and gauges were replaced by rectangles, the dimensions of which were determined by the method of the relevant headquarters. The results of the calculations show that the state of rolling between the cells of the continuous state is significantly influenced by the contact conditions in each of the deformation cells.

A change in the value of the coefficient of friction in one or more cells of deformation leads to a change in the speed conditions of rolling in each of the state cells. As a result, there is a change in the stress state of the roll along its entire length. Quantitatively, the effect of a change in the friction coefficient can be compared with the effect of a change in the size of the roll gaps, that is, such changes have a systemic effect.

UDC: 666.141.24:621.771.25:621.778

ABOUT THE EFFICIENCY OF CONSTRUCTION OF THE PROCESS OF DRAWINGWIRE ROD FROM CARBON STEELS ON THE BASIS OF PREDICTION MODELS

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Modern technologies for the production of cold-formed wire from carbon steels are based on increasing the efficiency of operation and loading of drawing equipment, the minimum duration of technological downtime, reducing the consumption of basic and auxiliary materials, in particular, energy carriers for heat treatment, as well as ensuring the ecological cleanliness of the production process. A rational determination of the mentioned technological factors in practice is impossible without a complete understanding of the influence of the chemical composition, structure and strength indicators of steel on its deformation hardening during cold plastic deformation (drawing).

Drawing involves the passage of the steel wire rod through a certain number of deformation cells (draws), after which a wire of a given diameter is obtained. During such processing, the properties of carbon steels change: strength indicators increase, and plasticity decreases. At the stage when drawing is impractical (destruction or non-compliance of the wire with the requirements of the standards), the

intermediate blank is subjected to heat treatment, which nullifies the effects of strain hardening and returns the mechanical properties to the level of initial values.

The processing of the array of data obtained from the results of many years of observations during the drawing of wire rod Ø 5.5–14.0 mm into cold-formed wire proved that the normalized strength of steels with different carbon content (0.03–0.88% C) and alloying elements is well can be calculated and allows creating various predictive models. Depending on the total relative compaction, chemical composition, structure parameters and mechanical properties, the maximum permissible hardening coefficients of steels by groups (low-, medium- and high-carbon) are established. The developed predictive models additionally allow the construction of drawing routes, the determination of the absolute values of single compressions, the speed of drawing and the strength of the wire after each of the deformation cells. In turn, this allows you to reliably set the permissible load factors for the electric motors of the drawing machine, determine their total power for the implementation of the production process, and also calculate the theoretical and actual productivity.

Thus, the possibility of preliminary predictive determination of the most important parameters of the drawing process allows for the effective construction of modern steel wire rod processing technologies at hardware plants, in particular, energy- and resource-saving schemes of cold plastic deformation without the use of additional heat treatment.

UDC 681.513.7:621.771.

RESEARCH OF THE ACCURACY OF THE AGC-ALGORITHM FOR ROLLING THICKNESS REGULATION UNDER HIGH-FREQUENCY DISTURBANCES

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It is believed that the use of the AGC-algorithm for strip thickness regulation provides full compensation for technological disturbances, in particular, thickness fluctuations at the inlet. However, in continuous mill, the strip thickness at the entrance of each of the finishing stands contains a high-frequency component caused by the eccentricity of the rolls of the previous stand. The ability of AGC-systems to compensate for such high-frequency disturbances depends on the speed of operation of hydraulic pressure devices (HPD).

In the work, the analytical justification of the transfer function of the AGC-system is carried out, taking into account the real speed of the HPD, on the basis of which its frequency characteristics are analytically determined.

In the range of the most common back-up roll rotation frequencies (ω=5 - 15 s–1), the frequency response is almost linear and, depending on the time constant T HPD and the ratio of the rigidity modulus of strip МП to the rigidity modulus of the rolling stand МК, varies over a wide range from A(5) = 0.05 (at ω = 5 s –1; T = 0.01 s; МП / МК = 1) to A(15) = 0.48 (at ω = 15 s –1; T = 0, 01 s; МП / МК = 4).

That is, the system, under certain conditions, can almost completely eliminate high-frequency thickness deviations at the inlet, reducing them by a factor of 20, and under other conditions, it can only partially compensate for their influence. In the last case, which is close in parameters to cold rolling of thin strips, the thickness difference at the exit of the stand does not exceed $\Delta h \approx 0.024$ mm, which meets the requirements for high-precision rolled products

Analytical conclusions are confirmed by the results of computer simulation.

UDC 621.771.26 : 621.778 : 330.123.72.083.133

RESOURCE-SAVING TECHNOLOGY FOR THE PRODUCTION OF STRIP-TYPE PROFILES BY DRAWING IN ROLLER DIES USING ACCELERATING CALIBERS

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The rolling-drawing process is used in the production of a large number of shaped profiles of complex configuration, including thin-walled, strip and periodic section profiles. This process, in comparison with drawing in monolithic dies, allows to reduce energy costs by 20-40 %, to increase deformation in one pass to 40-50 %, to reduce the number of preparatory operations (heat treatment, etching), to exclude the use of expensive lubricants for drawing. The conducted analytical studies have shown that in order to obtain the maximum b/h ratio in the production of tape-type profiles by drawing in roller dies, it is necessary to deform the initial flattened workpiece in accelerating calibers with a successive decrease in the angle of inclination of the crest.Based on the analysis of the influence of technological parameters of the drawing process in roller dies using accelerating calibers, a method has been developed for obtaining tape-type profiles of a wide size range from a round billet.Based on this method, two options have been developed for obtaining a belt-type profile with a cross section of 0,5x12,0 mm using accelerating calibers. In comparison with the previously experimentally obtained calibration, the developed options will reduce the number of transitions for obtaining a tape-type profile with a cross section of 0,5x12,0 mm from 9 to 7 or 5, respectively.The design of the rolling reinforcement has been developed, which ensures the stable course of the process of profile deformation in the accelerating calibers.

UDC 621.771.014.2

DEVELOPMENT AND IMPLEMENTATION OF THE TEMPERATURE-SPEED REGIME OF ROLLING ROUND PROFILES AT TZS PJSC "KAMET-STEEL"

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The product range and production technology of round profiles on the 900/750-3 state of PJSC "Kamet-Steel" are presented. The technological features of the transition of the TZS to the mode of operation in small-tonnage batches are shown. The nature of changes in technological factors during the production of round profiles of small cross-section (with a diameter of less than 110 mm) was analyzed.

It is shown that in accordance with the existing situation when rolling round profiles with a diameter of 40 mm to 110 mm in the cage "750-3" at the TZS, the temperature of rolling along the length varies within 70...100 °C. This ultimately leads to the formation of periodic defects along the length of the profile. The most common defect of rolling origin is at the front end of the first lattice and the rear end of the last lattice of the ingot - a "whisker". The analysis of the rolling temperature field and the measurement of the actual length of the "whisker" defect allowed to conclude that there is a direct relationship between these parameters.

Further research was aimed at determining the technological factor that most significantly affects the amount of expansion and at the same time, if necessary, can be immediately replaced by the state's technological staff. The analysis of the research works of previous years and the experience of rolling round profiles at the TZS made it possible to choose the following parameter - the frequency of rotation of the rollers of the finishing cage.

Experimental work was carried out to determine the relationship between the amount of DC voltage on the main drive and the frequency of rotation of the rolls of cages "750-1, 2, 3". Based on the results of the study, a graph of the rotation frequency of the rolls was drown depending on the readings of the voltmeter installed at the control post of the state clean cage.

An industrial experiment was conducted to determine the influence of the temperature-speed regime of the rolling process in the finishing pass on the deformed state of the roll during the production of round profiles with a diameter of 40 mm to 110 mm. Based on the processing of experimental data, a temporary regulation of the temperature-speed mode of rolling of round profiles with a diameter of 60 mm to 110 mm and a diameter of 40 mm in the cage "750-3" was developed and implemented. The economic effect of the implementation of the work results due to the reduction of the consumption coefficient of metal in the production of round profiles with a diameter of 60 mm to 110 mm was 2.36 million hryvnias/year.

Modeling and optimization of technological processes

UDC 519.854

APPLICATION OF THE ANT ALGORITHM TO SOLVING THE TRAVELER'S PROBLEM

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In the last few decades, researchers increasingly turn to natural algorithms for finding solutions to various applied problems. Nature has worked out these algorithms for millions of years in the process of adapting flora and fauna to the environment

The purpose of this study is to analyze the algorithm of the collective behavior of an ant colony during the search for food and to apply this algorithm to solving the salesman's problem, that is, to the problem of finding the shortest (optimal) route that allows the salesman to visit all given cities only once and return to the initial city.

The first version of the ant colony optimization algorithm (Ant Colony Optimization, ASO) was proposed by Marco Dorigo in 1992 [1]. After some time, several modifications of this algorithm were published, among which Ant Colony System (ACS) [2] and Max-Min Ant System (MMAS) [3] were recognized as the most successful.

In [4], an analysis of the system features of information exchange in an ant colony during the search for food was carried out. The iterative scheme of these three algorithms is presented, which simulate the natural behavior of foraging ants when searching for the shortest path to deliver food to the anthill. Algorithms are tuned to a specific example of the traveling salesman problem using tuning parameters that are chosen experimentally.

A computer program was developed to implement the three specified ant algorithms. The program allows you to: enter the number of cities, the number of ants, the maximum number of iterations through the interface window; configure each algorithm; optionally choose any of the three algorithms. The results of the program are: visualization of the shortest route found; the length of this route; the smallest number of iterations by which this shortest route is achieved; graphical dependence of the length of the shortest route on the iteration number.

A comparative analysis of the results of the program made it possible to draw the following conclusions:

1) With well-chosen algorithm setting parameters, iterative methods usually give results close to optimal quickly enough. However, each method will have its own number of iterations required for this, and these numbers may differ significantly.

2) The method of studying the traveling salesman problem using ant algorithms is more experimental than theoretical, since the result is highly dependent on the parameters of the algorithm

settings, however, theoretical research regarding the choice of these dependencies remains an urgent issue.

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UDC 62-551.454

ADAPTIVE MODELING OF THE TEMPERATURE CONTROL SYSTEM OF MUFFLE ELECTRIC FURNACES WITH A NEURON Fuzzy REGULATOR

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Electric resistance furnaces (chamber, shaft, hood, etc.) are widely used for heat treatment of products in metallurgy, power engineering, metalworking, ceramic and glass production, and other branches of Ukrainian industry.

In electric resistance furnaces, automatic regulation of the temperature regime is used, as well as automatic control of the operation of various mechanisms of the furnace unit. Increasing the level of automation of electric resistance furnaces has received significant development at present. This is due, on the one hand, to the processing of modern materials in them, which require regimes with complex schedules of temperature changes and high accuracy of its maintenance, continuous control and regulation of the composition of the atmosphere during the process, with the general complication of installations due to their aggregation, and on the other hand - strict requirements for the efficiency of operation of furnaces, as well as the desire to reduce the use of manpower during equipment maintenance.

For furnaces of continuous action (methodical, continuous, continuous) static and dynamic characteristics change with changes in productivity, i.e. with disturbances. Non-stationarity of static and dynamic characteristics of furnaces in the temperature regulation circuit requires special attention when selecting and setting regulators. In these circuits, continuously acting regulators operating according to P-, PI-, PID-regulation laws, as well as relay (two- and three-position) and pulse regulators are used. A good quality of regulation is usually ensured by the use of regulators operating according to the PI law of regulation, with adjustment of degrees of non-uniformity. However, in each specific case, the law of regulation must be determined based on the individual indicators of the object. Systems with adjustment of regulator settings when changing the operating mode of the furnace have improved dynamic properties.

The work implements adaptive control of heating products in an electric oven. The mathematical description of product heating processes is simplified in the form of two aperiodic links. One link - with a small time constant (temperature sensor), the other - with a large one (product heating time). Moreover, the greater the mass of the product, the greater the time constant in the transfer function.

The task of managing the heating of products with different masses consists in minimizing the heating time and ensuring an over-regulation of 4.3% (technical optimum).

The model of the control system includes a control object, a PID controller and a corrective link for changing the controller's gain coefficient - the ANFIS hybrid neural network.

Correction of the amplification factor is carried out using a hybrid network.

The hybrid network includes Sugeno's fuzzy derivation project. Fuzzification block with three membership functions of a triangular shape for the variable "Temperature change rate" (change range from 0.02 to 0.03 ºC/s). This range is divided into three sub-ranges: "Low Speed" mf1, "Medium Speed" mf2, "High Speed" mf3.

The membership functions of the output signal in the Sugeno algorithm are selected in the form of columns. The training of the neural network is carried out on pre-compiled input and output correspondence data.

The value of the speed of temperature change in the furnace is memorized within 10 s after applying the power supply voltage. These data characterize the time of the transient process in the system. Based on these data, the programmed FuzzyLogicController calculates the necessary change in the gain of the regulator, and the transition process is carried out with new values of the regulator parameters.

Research was conducted using a model made in the Matlab package.

When changing the constant time of the control object, the qualitative parameters of the furnace temperature control did not change.

Conducted studies on models and experiments on a laboratory furnace show that systems made with the use of fuzzy controllers may turn out to be indispensable in the automation of technological processes with incomplete information about their parameters due to the ease of their training.

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UDC 004.942:669.18

COMPUTER STUDY OF IMPURITY MIXING WHEN BLOWING INTO THE MELT THROUGH AN AXIAL TUYERE

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In the process of steel production, metallurgical enterprises add impurities to the melt. Blowing an impurity through a nozzle is one of the common methods of modifying the chemical composition of a liquid. This process has been studied in many works. The problem lies in the very slow diffusion of the impurity, which means long-term mixing with a constant loss of melt temperature. The speed of mixing is affected by both the number of blowing nozzles and their location. The defined process is analyzed in this work with the help of computer mathematical modeling, which is popular among scientists due to its low cost. Computer implementation allows you to save parameters and results of experiments in a database. Access to functional pages is provided through the web user interface. The website has a researcher registration subsystem and a form for adding calculated fields. As a result of

the experiment with an inert gas flow from 40 to 90 l/min and with the number of nozzles from one to three, it was found that the configuration with one nozzle in the center of the radius and two opposite nozzles with a total flow of 90 l/min has the shortest duration of mixing.

UDC 004.942:669.18

COMPUTER VISUALIZATION AND ANALYSIS OF THE INFLUENCE OF THE AXIAL TUYERE BLOWING MODE ON THE LADLE LINING EROSION

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The thickness of the steel ladle lining gradually becomes thinner with each casting. And the degree of erosion depends on the tangential melt speed. In steel production, they try to slow down this wear, because each lining repair costs considerable time and resources. Scientists paid attention to this problem in publications, in particular, on mathematical modeling of lining wear. A large number of conditions of this process are subject to research, in particular, the number and location of blowing tuyeres, as well as blowing power. Firstly, it is necessary to quickly mix the impurity in the melt, and secondly, to preserve the lining of the ladle. Computer visualization and analysis of this process involves its course and results in the form of calculated fields, in particular, wear. The fields are stored in a database and added and processed through a specially designed website. It allows researchers to register and fill in the experiment form, as well as add literature sources of data. The list of literature is used in almost all experiments to compare results. Simulation of the process at blowout rates of 40, 60 and 90 l/min and the number of blowout plugs (tuyeres) from one to three showed that the greatest scouring is predicted at the bottom, near the blowout plugs, and the transition to each higher blowout rate increases the scouring intensity by about 15%. Turning off the tuyeres after 1 minute of blowing significantly reduces erosion by at least 35%. If we consider the ladle wall, without disconnecting the tuyere, the flow rate of 90 l/min is the most destructive.

UDC 004.942:669.18

NUMERICAL STUDY OF STAGNANT AREAS OF THE MELT DURING BLOWING

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The problem of the existence of melt stagnant regions during inert gas blowing is the risk of its crystallization near the walls of the ladle under conditions of constant temperature decrease. A large number of scientific publications are devoted to solving this problem. One of the possible solutions is to optimize the number and location of melt blowing nozzles in order to minimize the volume of stagnant areas. Mathematical modeling and numerical study of the specified process made it possible to determine the best location of the nozzles and save on the costs of laboratory or industrial experiments. The computer implementation involves recording experiments using a database and a web user interface. Also, this implementation automatically forms graphs of dependent values. After registration, researchers have the opportunity to add the results of experiments in the form of calculated fields. As a result of research, it was found that regardless of the number of lances, a stagnant area is formed at the bottom near the wall of the ladle. There, the melt velocity varies from 1 cm/s to 5 cm/s.

UDC 669.184:004.42

COMPUTER SYSTEM FOR CALCULATING DESIGN PARAMETERS OF OXYGEN CONVERTER AND TOP LANCE

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The oxygen–converter process remains the main modern technology of steel production. The converter is the main unit in the production of steel, and the top–blowing lance is the main tool for the implementation and control of the converter process. Their production requires a careful pre–calculation of design parameters that will satisfy the constantly growing requirements for the process. The correctness and rationality of the design and manufacture of these units and devices guarantees the efficient implementation of the technological process, ensuring the trouble–free operation of the converter workshop.

The well–known basic methods of calculating the LD–converter and the top lance were developed by the leading educational institutions of Ukraine – Dnipropetrovsk Metallurgical Institute, 1976 (now the Institute of Industrial and Business Technologies of USUST); Zhdaniv Metallurgical Institute, 1978 (now Priazovsky STU); Dniprodzerzhinsk Industrial Institute, 1981 (now Dniprovsky STU) and others. These methods are relevant even now.

Algorithms of calculations according to these methods are quite complex and saturated with a large number of regularities, equations, reference data, tables, etc. and require a lot of knowledge and professional qualifications. Usually, such calculations are performed manually by steelmakers, and therefore take a lot of time and do not always give reliable results. The automation of calculations will greatly simplify and speed up the process of designing the converter and lance, ensuring much greater accuracy of the obtained results.

The analysis of the existing information showed an almost complete absence on the market of specialized software for automating the calculations of the design parameters of the LD–converter and top lance. Therefore, the development of such a computer system is an urgent design and construction task, which is important in the production of steel.

The JavaScript programming language, the Angular framework and the D3.js graphic library were chosen for the computer implementation of the given task. State management of software components is carried out using the Ngrx library, which implements the principle of unidirectional data flow. Using this approach makes it possible to store the state of all program components in a tree-like structure – storage. Having a single data source eliminates the need to solve the problem of data exchange between different components and simplifies program debugging.

A cascade methodology (Waterfall Model) was chosen – a sequential method of software development using the JetBrains WebStorm 2019.2 IDE.

No registration is required to use the application. All calculations take place on the user's PC without the use of a server. The operating environment of the software is a browser, operating system Linux / Windows 7, 8, 8.1, 10 / macOS.

Conclusions. As a result of the work, the calculation of the LD–converter and top lance was automated using modern technologies and software development approaches; an original design and logo of the application, and an intuitive user interface were developed; the program was tested on specific application examples; the test calculation of the LD–converter and the top lances of the converter workshop of PrJSC "Kamet–steel" was performed.

The developed application allows you to simplify and speed up the process of calculating the design parameters of the LD–converter and the top lance during their design and to carry out large amounts of calculations in a short time and to obtain more reliable results.

UDC : 669.168: 669.26.0018

PREDICTION OF PHYSICOCHEMICAL AND THERMOPHYSICAL PROPERTIES OF NICKEL-CONTAINING FERROALLOYS

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The need for nickel for smelting special steels is mainly met by electrolytic nickel (~ 99%Ni), the high price of which does not contribute to the development of the production of nickel-containing steels. In many cases, ferronickel can be used instead of expensive and scarce pure nickel, the cost of production of which (like many other ferroalloys) is lower than pure metal. At the same time, it is known that in the market of alloying materials there is a shortage of relatively cheap nickel and complex ferroalloys containing 10-30%Ni. In research has developed a fundamentally new approach to the description of the physicochemical properties of melts of ferroalloy production based on the methodology for calculating the criteria (ΔZ^y and Δd), characterizing the degree of difference between the charge and structural state of the melt as a chemically unified system from the mechanical mixture of the initial components.

Proposed semi-empirical models: melting point (T_p, C), density ($D*10^3$, kg/m^3), heat of melting (Q, kJ/kg), heat capacity (C, J/kg·k), thermal conductivity (*l*, W/(m*k)), heat capacity (C, J/kg*k) as f = (Z^y , d, ΔZ^y, Δd), to assess the properties of ferroalloys of ferronickel produced by Pobuzhsky Ferronickel Plant with content (mass%): 6%Ni, 0,2%Si, 0,1%C, 0,242%Cr, 0,32%Co, 0,48%Cu, 0,04%S, 0,03%P. Alloys of the new generation of the Fe-Ni-Cr system, containing: 10%Ni; 25-45%Cr; 2,0%C; 0,2%Si; Fe – all other. The developed analytical dependencies make it possible to predict the effect of changes in composition, expressed through the integral parameters of interatomic interaction, on the properties of various brands of nickel ferroalloys produced in Ukraine.

UDC 681.52

SIMULATION OF THE ACS OF METAL LEVEL IN THE CRYSTALLIZER OF CONTINUOUS CASTING MACHINE

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Maintaining the stability of the level of liquid steel in the crystallizer of continuous casting machine is one of the main requirements of the technology for obtaining high-quality steel billets. Stabilization of the metal level in the crystallizer ensures stationary conditions of solidification of the workpiece and its high quality, as well as safe operation of the installation. Exceeding the level of metal in the crystallizer can lead to the overflow of steel on the working area, and an unacceptable decrease - to the breakthrough of liquid metal due to an insufficiently formed shell of the workpiece after leaving the crystallizer.

There are the following methods of automatic stabilization of the metal level in the crystallizer:

- by changing the flow of metal from the ladle into the crystallizer at a constant workpiece extraction speed;
- by changing the speed of workpiece extraction from the crystallizer;
- combined method.

Note that the main disturbing influence for the metal level control system in the crystallizer of continuous casting machine is the billet withdrawal speed. It is possible to increase the accuracy of the system operation during the transient process in the presence of a disturbance due to the simultaneous

operation of two level stabilization channels - stabilization of the metal level by changing the inflow of metal from the ladle and stabilization of the level by changing the speed of drawing the workpiece.

The metal level in the crystallizer must be stabilized with high accuracy (permissible deviation Δh=15-20 mm).

Modeling of the system was performed in the Matlab / Simulink package. The sisotooltool included in the Matlab dynamic programming package was used to calculate the controller parameters.

Modeling of the ACS of metal level was performed in three schemes:

- when controlling the stopper (indignation - increase in the drive speed of the traction cage);
- when controlling the traction cage drive (indignation - increase in flow of material into the crystallizer);
-combined ACS modeling scheme of the metal level (indignation - increasing the drive speed of the traction cage, increasing the metal inflow into the crystallizer).

According to the results, the dynamic deviation in the ACS of metal level when controlling the stopper (scheme 1) was 13 mm, the time of the transition process was 10 seconds. The dynamic deviation in the ACS when controlling the traction cage drive (scheme 2) is 7.5 mm, the transition time is 10 seconds. In the combined system (scheme 3), the dynamic deviation is 6 mm, the transition time is 6 seconds.

Thus, dynamic level deviations are minimized in the combined regulation system. Therefore, such a system is the most suitable for solving the problem of stabilizing the metal level in the crystallizer of continuous casting machine.

УДК 621.744.52

STABILIZATION OF THERMAL-TIME PARAMETERS OF STEEL CASTING IN CERAMIC FORMS

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The most problematic areas when casting into ceramic molds are the processes of forming, tempering, filling molds and cooling castings, as well as preparatory engineering work related to the development of pouring and feeding systems. Therefore, conducting research aimed at improving the technological processes of forming, tempering and pouring is an urgent task.

Analysis of the data characterizing the influence of the molding method on the cooling of ceramic molds after tempering showed that the longest stability of the mold temperature is observed with the methods of molding ceramic molds into a granular support filler and a thermostat. Moreover, by changing the thickness or material of the heat-insulating layer of the thermostat, it is possible to adjust the duration of thermostating of the ceramic mold within wide limits, and thereby control the processes of casting formation and its quality.

As a result of the analysis of experimental data, the following dependences were established: the duration of maintaining the temperature of the mold on the thickness of the heat-insulating layer of the thermostat, and the rate of heating of ceramic shells in thermostats on the initial temperature in the tempering furnace.

It has been established that when forming into thermostats, the sufficient duration of hardening of ceramic shells at 950 - 980 ^{0}C is about 1 hour.

In the course of the analysis of experimental data on the effect of gas pressure on the density of steel castings, it was established that the surge of gas pressure is more effective than the surge of atmospheric pressure. Moreover, regardless of the method of insulation, the surges of atmospheric pressure in conditions of thermostating of forms work with almost the same efficiency.

As a result of the analysis of the data on the influence of the thermostating of the shell on the mechanical properties of the 08X14N7ML steel, it was established that the mechanical properties of the steel are at the same level regardless of the method of forming the ceramic shells and meet the

requirements of the technical conditions. Therefore, in production conditions, samples for mechanical properties for castings obtained in thermostats can be poured into unformed ceramic shells.

UDC669.18:621.746:537.84

SIMULATION OF THE PROCESSES OF MAGNETIC FIELD EFFECT ON THE METAL JETIN THE SECTION TUNDISH-CRYSTALLIZEROF CCM

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Theabstract presents results of physical modeling for the study of the efficiency of NdFeB permanent magnet assemblages in the conditions of continuous steel casting. An alternative method of energy conservation was tested, in which the magnetic field is created using sets of permanent magnets.

With using developed physical model and calculation methods, a comprehensive study was carried out to account for and compensate for the impact of heat losses on magnet sets in the area of the metal conduit (thermal insulation), accounting for demagnetization, determining the optimal location of the sets relative to the metal conduit, working out the methodology for using sets of permanent magnets of different configurations to study the behavior of a melt jet in the "beaker-doser-submergedentry nozzle" system under conditions of application of an external magnetic field.

Testing was carried out to verify and clarify the results of the experiments and to study the effect of a constant magnetic field on the metal jet at different diameters of the submerged entry nozzle, which were 28, 30, 32, 34, 36 mm.

Calculation data that can provide a stable non-disruptive melt jet using the magnetic Taylor number ($Ta < 41.3$ laminar Couette flow $41.3 < Ta < 400$ – laminar flow with Taylor vortices, $Ta > 1700$ – jet break) were verified. The importance of the obtained data is based on the fact that the rupture of the melt jet, especially considering the diameter of submerged entry nozzle, is unacceptable under the conditions of both continuous and semi-continuous casting. According to the results, the optimal value of the distance between the set of magnets and the wall of the submerged entry nozzlewas determined.

It was established that the range of the maximum possible push-off of the melt jet from the wall of the submerged entry nozzleis: for a glass with an inner diameter of 28 mm - from 0.7 to 3.5 mm (at the appropriate distance from the poles of the magnetic device to the outer wall of the submerged entry nozzle) 25% (7 mm) and 5% (1.4 mm) of its inner diameter); for a submerged entry nozzle with an inner diameter of 36 mm - from 0.9 mm to 4.5 mm (with a corresponding distance from the poles of the magnetic device to the outer wall of the submerged entry nozzle of 25% (9 mm) and 5% (1.8 mm) of its inner diameter) .

It was determined that when using a rotating magnetic field, using a set of permanent magnets of axial magnetization without gaps, it is possible to twist the outer layer of the jet, which is 5% of its diameter at a speed at the entrance to the submerged entry nozzle of 4 m/s. Such a result should ensure the formation of a compact jet and reduce its splashing and contact with the cavity of the submerged entry nozzle.

Environmental problems of ferrous metallurgy

UDC 669.02/09:669.168.046.58.001.57

SELECTION OF FACTORS FOR PREDICTION OF THE PROPERTIES OF MANGANESE SLAG MELTS

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During the production of manganese ferroalloys and the subsequent deoxidization-alloying of steel, up to 50% of manganese is lost, which turns mainly into slag, exacerbating the problems of ecology and the use of non-renewable resources. Therefore, it is necessary to search for highly effective waste recycling schemes and waste-free technologies, which allow returning a valuable chemical element to metallurgical redistribution. It is thanks to the study of the properties of ferroalloy slags and their forecasting methods that it is possible to create such schemes. This will provide an opportunity to create favorable conditions for the recovery of valuable oxides (MnO, MgO, SiO_2) from slag, reduce the costs of charge materials and reduce the amount of non-recyclable waste.

The analysis of the effect of basicity, as well as MgO and Al_2O_3 oxides on the equilibrium phase composition of silico-manganese slag was carried out. With increased basicity, the amount of free MnO increases, which facilitates the process of manganese recovery, but for SiO_2 ammount there is the opposite: the greater the basicity, the smaller its amount in the slag. A change in the amount of MgO has almost no effect on the amount of free MnO or SiO_2, but an increase in Al_2O_3 leads to a decrease in the amount of MnO, which complicates the process of manganese recovery.

It was established that low electrical conductivity plays a positive role in recovery processes, allows to increase the energy efficiency of the technological process due to the maximum concentration of power in the arc node, and to reduce energy costs. It is possible to reduce the electrical conductivity of the ore-reducing mixture by introducing into its composition materials containing oxides with low electrical conductivity, MgO, Al_2O_3, CaO and others.

Reducing the viscosity of slag in the production of ferroalloys has a positive effect on the speed and completeness of reduction reactions, determines the size of the metal drops remaining in the slag, facilitates the separation of alloy drops from the slag, and thereby creates favorable conditions for the intensification of the process. But the low melting point of the ore mixture is not a positive factor for the slag recovery process. Melted at temperatures below the recovery temperature, the ore part will move away from the high-temperature reaction zone without having time to react with the reducing agent, which will significantly reduce the efficiency of the process, therefore additives to the composition of the lime and coke charge should contribute to increasing its melting temperature, which means improving the conditions for manganese recovery which is confirmed by research results.

UDC 669.054.8

REDUCTION OF THE NEGATIVE IMPACT ON THE ENVIRONMENT BY THE COMPLEX USE ORGANIZATION OF DISPERSED IRON GRAPHITE WASTE OF METALLURGY

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The undoubted successes of electrometallurgy and hydrogen metallurgy significantly reduce greenhouse gas emissions into the environment. At the same time, there are still many other wastes

from metallurgical enterprises, which, getting into the air and water, accumulating at landfills, cause significant environmental damage. Such wastes include dispersed iron-graphite wastes (IGW). In their composition, they have graphite, iron oxides, metallic iron and impurities. They are formed in large quantities at all stages of iron production: desulfurization, overflows into mixers and ladles, etc. Some of them are captured by aspiration systems and can be successfully disposed of. Unfortunately, today technologies that allow extracting either the carbon or oxide part of the IGW prevail. The rest is again turned into waste.

On the basis of comprehensive studies of IGW, which included an analysis of the particle size distribution, morphology, microstructure, and their electrical properties, it was concluded that dispersed IGW have significant application potential from the point of view of combining magnetic properties and low electrical resistivity in them. Such a set of properties makes IGW a promising radio-shielding and radio-absorbing material.

The level of magnetic properties of initial IGW is relatively low (saturation specific magnetization, σ_s, is at the level of 20 $A \cdot m^2/kg$) with a very low specific electrical resistance ($\rho_v \approx 10^{-4}$ Ohm·m).

The results of many years of research have made it possible to develop a general technological scheme for the complex processing of dispersed iron-graphite waste. First, taking into account the uneven distribution of carbon-containing (non-magnetic) and oxide (magnetic) components in fractions of various sizes, this scheme includes the source material sieving and separating a fine, more magnetic fraction from it. Already due to this, it is possible to increase the level of σ_s. Secondly, by thermal treatment of the magnetic fraction by magnetizing annealing or carbothermal reduction, the specific saturation magnetization increases to ~80 $A \cdot m^2/kg$ in the first case and to ~180 $A \cdot m^2/kg$ in the second.

The carbon-containing component of IGW can be independently used as a raw material for the production of commercial graphite or introduced into the heat-treated fraction to obtain a given combination of σ_s-ρ_v. The magnetic fraction can be used as an independent radio- shielding and radio - absorbing material as well as a filler for composite coatings with such properties.

UDC 669.09.26

ON THE INFLUENCE OF METALLURGY ON CLIMATE CHANGE

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The climate is changing. The consequences of climate change are not gradual warming, but extraordinary natural phenomena: droughts, hurricanes, floods, storms, tornadoes.

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Scientific studies have shown that modern warming occurs due to an increase in the concentration of greenhouse gases in the earth's atmosphere. Greenhouse gases include such gases as carbon dioxide, methane, and nitrous oxide.

The first international document aimed at reducing greenhouse gas emissions was the Kyoto Protocol, an international agreement concluded with the aim of reducing greenhouse gas emissions into the air. The main goal of the agreement: to stabilize the concentration of greenhouse gases in the atmosphere at such a level that would not allow dangerous anthropogenic influence on the climate system of the planet. A quota for greenhouse gas emissions was established for each country. In the event that a state emits less than the allocated quota of greenhouse gases into the atmosphere, it can sell the excess to another state, which thereby gets the opportunity to emit more greenhouse gases. The Kyoto Protocol became the first global agreement on environmental protection based on a market-

based regulation mechanism - a mechanism for international trading of quotas for greenhouse gas emissions.

In 2015, as part of the UN Convention on Climate Change, 196 countries signed the Paris Climate Agreement, according to which all countries, regardless of their level of economic development, undertook to reduce emissions of greenhouse gases into the atmosphere.

Exceeding global warming by 1.5 degrees Celsius (which the IPCC has identified as the threshold for preventing the worst effects of climate change) will mean more severe droughts, extreme heat, floods and poverty, reduced species numbers (including mass coral extinctions), worsening food shortages and forest fires.

It is necessary to reduce the production and consumption of fossil fuels, intensifying the use of clean, renewable energy sources and energy-efficient technologies.

CO_2 emissions associated with human activity (anthropogenic factors) account for 9.1% of total carbon dioxide emissions into the atmosphere, but they cause a disturbance in the balance between CO_2 entering the atmosphere and absorption by the Earth. Anthropogenic emissions increase the concentration of carbon dioxide in the atmosphere, which is probably the main factor in climate change.

The total amount of anthropogenic emissions is estimated at 22413,2 million tons, including 49.3% energy, 20.0% motor vehicles, 7.3% metallurgy, 23.4%.

CO_2 emissions by world metallurgy in 2001 are estimated at 1620 million tons, in particular electrometallurgy 2.2%, oxygen-converter production 4.0%, March production 0.6%. Blast furnace production 51.2%, others 23.4%.

The reduction of CO_2 emissions by metallurgy can be the introduction of direct iron production (DRI) using hydrogen as a reducing agent and lead to a reduction of carbon dioxide emissions into the atmosphere by 740 million tons per year by 2050.

Hydrogen technology will become competitive no earlier than 2030. Steel corporations Arcelormittal and thyssenkrupp came to this conclusion.

For this, the cost of renewable hydrogen should drop to 2.2 dollars per kilogram, and the price of coking coal should not be lower than 310 dollars per ton.

UDC 622.22.553.4:519.85

OPTIMIZATION OF PARAMETERS OF PROCESSES FOR OBTAINING FINAL PRODUCTS DURING THE DEVELOPMENT OF PRECIOUS METAL DEPOSITS

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A feature of the effective exploitation of precious metal deposits is the optimal design of processes accompanying the extraction, enrichment, processing, which are aimed at obtaining the final product in the form of metal. There are several problems that form systemic principles and methodological approaches in the development of precious metal deposits:

1) Choice of decision-making tool. Today, more than 100 decision-making tools are used in practice. Joint accounting of qualitative and quantitative indicators seems to be difficult.

2) Complexity. When choosing a tool, it is necessary to consider economic, environmental, technological, social, legislative, regional aspects. The resulting solution should be economically feasible, environmentally sound, consider the links between enterprises, as well as regional features, in addition to meeting the requirements of current legislation.

3) Integrity and hierarchically. This implies the interconnection between all stages because the effective solution of one task cannot guarantee an increase in the efficiency of the entire technological

process in the complex. Thus, it is necessary to choose the optimal solution at each stage and only then move on to a new task.

4) Availability of decision support system. This means obtaining software tools that will increase the dimensionality of tasks, interpret the results obtained, and implement them in production.

5) Substantiation of the boundaries of the area of rational design includes the determination of the parameters under which a given amount of mineral extraction will be reproduced by establishing optimal connections in the operation of technological schemes by selecting and evaluating parameters. At the same time, the process of field development, as well as the result in the form of the volume of extracted minerals, is considered as an intermediate link in the system of generation of final products.

In design the technology of development of mineral deposits, along with economic factors, environmental factors should be considered. This is realized by building an economic and environmental development strategy. The most economically advantageous and environmentally safe development technology is compared with each other. Joint consideration of environmental and economic strategies allows for the economically preferable one to provide additional measures to minimize the technogenic load on the environment in the regions where minerals are extracted.

The processes accompanying the development of mineral deposits are optimized by changing the state of reserves. This is implemented considering the construction of a decomposition scheme that considers the relationship between alternative technological solutions. Alternative technologies are taken as vertices, and the distance between the vertices is the value of the optimization parameter for the specified technology. The optimization algorithms find the shortest distance from the initial vertex to the final one. The shortest distance corresponds to the optimal solution. It is proposed to apply the Dijkstra and Floyd algorithms for optimization of technological processes, and the Bellman algorithm for the development of strategies for the development and consideration of environmental aspects in the development of precious metal deposits.

As a result of the implementation of these approaches, it is possible to obtain a “Mineral Deposit Development Passport”. This passport will contain the parameters that allow to intensify the process of mineral extraction with the minimum cost of extraction and the minimum degree of man-made load of industrial environment.

UDC 622.281.406:502.1

EXPEDIENCY OF USING SUSPENSIONS-INHIBITORS BASED ON THE SODIUM GROUP FOR THE TREATMENT OF COAL MINING WASTE DUMPS

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Spontaneous combustion of the waste mass of coal mining waste occurs under the condition of access of oxygen and moisture inside the porous structure of the waste mass in the body of the waste heaps and leads to the formation of thermal zones of combustion concentrators whose temperature ranges from 80 to 1200^0C, which adversely affect the rare earth metals (REM) contained in the waste mass, creating thermal destruction, resulting in the complete destruction of REM and their complete unsuitability for use in the metallurgical industry. Of particular interest for the metallurgical industry is the production of aluminum 15–20 g/t, gallium at a content of 100 g/t, scandium 10–20 g/t. Therefore, with the use of suspensions-inhibitors it is possible to achieve not only the elimination of combustion processes of the dump mass but also to preserve in the future the REM with their complete conservation in the composition of the dump mass.

For the study, samples of coal mining waste were selected in the amount of 3 samples, as they contain useful chemical elements that are necessary in the metallurgical industry: Al_2O_3, Fe_2O3, CaO.

The selected samples were treated with suspensions using sodium-based soda solutions additives: $NaHCO_3$, Na_2CO_3 and NaOH.

The procedure for conducting experimental studies was carried out once. The general parametric characteristics of the fractions of the samples of the dumped mass did not exceed 15–30 mm, the specific gravity of all samples did not exceed 3–14 g. The suspensions were prepared as follows: distilled water was poured into each of the three 100 ml beakers and 50 g were added. $NaHCO_3$, Na2CO3 and NaOH, resulting in suspensions with a concentration of sodium agents of 50%. The samples of the dump mass were treated with a conventional spray gun (full-cone irrigation torch with minimum and maximum irrigation angles of 150-1250, the theoretical irrigation width was 35 mm) at an irrigation distance of 10 cm with three types of sodium solutions: hydroxide, bicarbonate and sodium carbonate. the finished treated dump mass was kept indoors for 30 days at an average air temperature of 20–21^{0}C. For further processing of the results of the experiment, general methods of statistical analysis were used. when checking the obtained data for homogeneity, the method of analysis using the parametric Student's t-criterion was chosen. this method of analysis allows to exclude from the sample questionable variants that may be erroneous and do not belong to the general data set.

The distribution of Student's criteria was carried out on the basis of proportional calculations by the effectiveness of the treatment of the waste mass with suspensions based on sodium solutions. The highest efficiency in the interaction with Fe2O3 was obtained when using a suspension based on sodium hydroxide –76 %; in second place is the treatment of the suspension with sodium carbonate of the chemical element K_2O –73 %; in third place is the treatment of the suspension with sodium hydroxide of the chemical element SiO_2–56 %.

Analyzing the data, it can be concluded that there was a significant statistical significance in the treatment of sodium hydroxide (NaOH) of the waste mass. The obtained results allow us to assert that the treatment with a suspension based on sodium hydroxide NaOH will have positive results in the elimination of oxidative processes in the waste mass with the participation of sulfur and pyrite, which are agents of spontaneous combustion of the waste mass, which will allow to preserve rare earth metals for their further use in the metallurgical industry. Thus, we will be able to solve two problems: the first is to eliminate the combustion of coal mining waste with the subsequent preservation of REM for their future use in the metallurgical industry; the second problem is to use coal mining waste as a potential repository of useful REM for the needs of the metallurgical industry.