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EFFECT OF MODIFICATION BY RARE-EARTH METALS ON STRUCTURE AND PROPERTIES OF STEEL H11 PRODUCED BY ELECTRIC SLAG COKE CASTING

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ABSTRACT

Creation of metal materials with a given complex of physical and mechanical properties can be implemented using a complex approach, which combines obtaining a given chemical composition, production technology and strengthening treatment, which provide obtaining the required phase composition and a certain structural state of the materials. The properties of alloys are determined not only by chemical composition and microstructure, but also to a large extent by the type, size, shape and nature of the phase distribution of different nature and origin. The application of various technologies, including high-energy ones, allows you to control the macro and microstructure, strength and operational characteristics, changing the structural and energy parameters of steel. More and more attention is paid to the patterns that exist between the composition, structure and properties of alloys obtained in non-equilibrium conditions, due to the use of technologies using high energy effects in the process of producing materials. Control of structure formation in melts and alloys under conditions far from thermodynamic equilibrium. The possibility of improvement of physical and mechanical properties of alloys by their production in non-equilibrium conditions is shown. This serves as a basis for obtaining alloys with a given complex of properties. The purpose of this work is to establish the regularities of the formation of the structure of instrumental materials under multifactorial complex effects under the conditions of electrometallurgical technologies. In the course of operation, technological modes of producing castings with electric slag chill casting were established, providing the most favorable process of melting the electrode in the crucible. Modification with rare earth metals of the cerium group changes morphology and reduces the number and size of non-metallic inclusions, which acquire a predominantly globular shape. It leads to significant increase in reliability of a product, due to increase in impact strength which increases from 0, 13 MJ/m^2 (at not modified) up to 0, 30 MJ/m^2 (after modifying).

Keywords: electrometallurgy, electric slag remelting, non-metallic inclusions, modification.

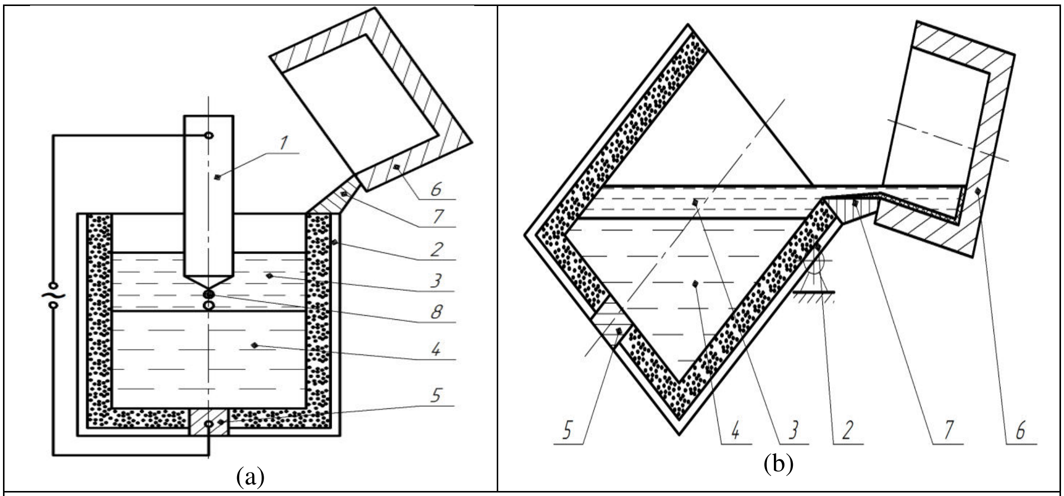
INTRODUCTION

Creation of metal materials with a given complex of physical and mechanical properties can be implemented using a complex approach that combines obtaining a given chemical composition, production technology and strengthening processing, which provide obtaining the required phase composition and a certain structural state of the materials. The properties of alloys are determined not only by chemical composition and microstructure, but also to a large extent by the type, size, shape and nature of the phase distribution of different nature and origin [1-5].

The application of various technologies, including high-energy ones, allows you to control the macro and microstructure, strength and operational characteristics, changing the structural and energy parameters of steel. In this work, the possibility of controlling structure and phase formation in the conditions of electroslag technology is considered. The possibility of recycling high-alloyed steels of different structural class in order to obtain castings of various purpose with a high complex of operational properties is considered. Therefore, the purpose of this work is to establish the regularities of the formation of the structure of instrumental materials under multifactorial complex effects under the conditions of electrometallurgical technologies [1, 6-9].

MATERIAL AND METHODS

A complex of equipment was used to implement electric slag casting into a chill. In this case, it includes: an experimental installation consisting of a rotary crucible and an electrode holder; process equipment, which includes a chill and a consumable electrode. The power source is a welding transformer, which provides an output current of up to 10000 A. This equipment is designed to obtain a liquid metal of the same chemical composition as the consumable electrode, accumulate it in a melting vessel with subsequent overflow into a casting mould-cockyl, of the required configuration (Figure-1).



(a)

(b)

1 - consumable electrode; *2* - melting crucible; *3* - liquid slag; *4* - molten metal; *5* - bottom electrode; *6* - mold; *7* - crucible spout; *8* - liquid metal droplets

Figure-1. Scheme of metal production in electric slag crucible furnaces: *a* - production of a liquid metal; *b* - metal pouring into mold.

Electric slag remelting of the electrode, which can be made from rejected forgings of the corresponding grades of steels, is carried out at alternating current. The consumable electrode is lowered to contact with a seed, which is made of a mixture of metal chips, an appropriate composition and flux in a certain proportion. Pre-calcined flux AH-295 (Table-1) is filled into space between electrode and wall of working zone. The process was carried out at a dry start. The modes under which electrosmeltremelting was carried out are given in Table-2.

Table-1. Chemical composition of flux AH-295, %.

CaF_2	Al_2O_3	CaO	MgO	SiO_2	C	Fe_2O_3	S	P	TiO_2
11-17	49-56	26-31	6,0	2,5	0,10	0,5	0,05	0,02	0,05

Table-2. Electric slag remelting modes.

Type of Remelting	Beginning of melting		Smelting end		Deoxidant
	***I*, кА**	***U*,V**	***I*, кА**	***U*,V**	**Al, %**
Electroslag chillcasting	1,2-1,5	50	2,5	50	0,15–0,2

After turning on the voltage after 5-7 minutes, the flux melts to form a liquid, current-conducting slag bath and the melting process of the electrode (Figure-1, *a*) begins.

The primary voltage is 380 V; the secondary voltage is 40-70 V. The cables from the transformer to the terminals of the electrode holder and the cable to the current supply plate of the crucible are movable-water-cooled. Chill is installed on brackets of movable crucible and is fixed by hooks. The crucible is turned using a reduction motor and a screw gear.

In the process of producing castings, aluminum deoxidation of A7 (99, 7% Al) in the amount of 0, 15-0, 20 % was used. After accumulating a predetermined amount of metal by means of a rotary device, the crucible was turned over, and the metal was poured into a chill fixed in the upper part of the crucible (Figure-1, *b*). The metal temperature before overflowing into the chill was 1 550-1600 ° C. Splitter castings weighing 18-20 kg (Figure-2) were removed from the chill at a temperature of 800-700 ° C and placed in a sand bath. Slow cooling of castings is caused by the fact that steel H11 belongs to martensitic class steels, with high stability of super cooled austenite. As a result of cooling in the air, a martensitic structure is formed and large stresses arise that can lead to cracks [10, 11].

Figure-2. Casting of H11 steel splitter obtained by electric slag chill casting (× 0,25).

It is known [1, 2] that performance largely depends on the type, size, distribution and shape of non-metallic inclusions (N-M I). N-M I affect the structure and chemical heterogeneity of steels during crystallization, phase recrystallization, etc. In addition, N-M I has a significant effect on the stress concentration of elastic deformations, the greater the lower the inclusion modulus. As modulus of elasticity decreases, actuations are arranged in row TIN, Al_2O_3, SiO_2, (Fe, Mn) S, CaO [2]. The N-M I form plays a significant role. Inclusions with pronounced cut and sharp ribs have a stress concentration more than 1, 5 times greater than spherical ones of the same value. This is due to the fact that the level of stress intensity is largely determined by the minimum inclusion radius. In the case of acute N-M I cuts that have a low modulus of elasticity, stress intensity can increase dramatically with a certain orientation of N-M I.

The formation of the crystal structure is mainly determined by heat and mass transfer processes occurring in the transition zone of the solid-liquid state, which consists of melt and dendrites. The density of N-M I n varies due to their coagulation. With a diffusion mechanism, bimolecular coagulation is most likely when the rate of change (n) is mn^2, where m - coagulation coefficient.

A significant reserve in improving the properties of steels is the control of the amount, morphology, and properties of N-M I, through various smelting technologies. One way to influence the nature and morphology of N-M I is by modification.

When examining the microstructure of stamped steel obtained by electric slag chill casting, large non-metallic inclusions of rounded and sharp-angle shape are observed, which degrade the properties of steel [3]. In order to change the nature, morphology, decrease the number and size of non-metallic inclusions, modification of stamped steel H11 rare-earth metals in the composition of michmetal was carried out [4].

When determining the mechanism of modification of stamped steel with michmetal, it is necessary to take into account the possibility of formation of refractory compounds between N-M I, impurities that are in liquid metal and introduced elements. When introducing rare earth metals, it is possible to form refractory compounds: sulfides, oxysulfides, etc. The probability of the formation of a compound when rare earth metals were introduced into liquid steel was determined by the magnitude of the change in Gibbs energy during chemical reactions using the HSC Chemistry:

$3Ce + 4FeS \rightarrow Ce_3S_4 + 4Fe$	- 955,982 kJ/mol
$2Ce + 3FeO \rightarrow Ce_2O_3 + 3Fe$	- 855,530 kJ/mol
$2Nd + 3FeO \rightarrow Nd_2O_3 + 3Fe$	- 846,049 kJ/mol
$2La + 3FeO \rightarrow La_2O_3 + 3Fe$	- 830,042 kJ/mol
$2La + 3FeS \rightarrow La_2S_3 + 3Fe$	- 718,903 kJ/mol
$2Ce + 3FeS \rightarrow Ce_2S_3 + 3Fe$	- 637,079kJ/mol
$2Ce + Cr_2O_3 \rightarrow Ce_2O_3 + 2Cr$	- 635,370 kJ/mol
$2Nd + Cr_2O_3 \rightarrow Nd_2O_3 + 2Cr$	- 626,546 kJ/mol
$2Nd + 3FeS \rightarrow Nd_2S_3 + 3Fe$	- 624,655 kJ/mol
$2La + Cr_2O_3 \rightarrow La_2O_3 + 2Cr$	- 610,249 kJ/mol

The above reactions are possible at a temperature of 1 580-1 600 ° C, as indicated by the calculation results. As can be seen, reactions between rare earth metals, iron oxide and iron sulfide take place in the first place. As a result, refractory compounds are formed: oxides, sulfides of rare earth metals. When cerium group modifiers are introduced into liquid metal, formation of complex calcium, aluminium, cerium, lanthanum oxysulfides is observed. The resulting rare earth metal compounds are not wetted, tend to coarse N-M I and form agglomerates that float to the surface during melting.

Studies of the morphology and distribution of N-M I after modification indicate a decrease in their number by almost half, as well as a decrease in size and shape of a predominantly globular species (Figure-3, *a*).

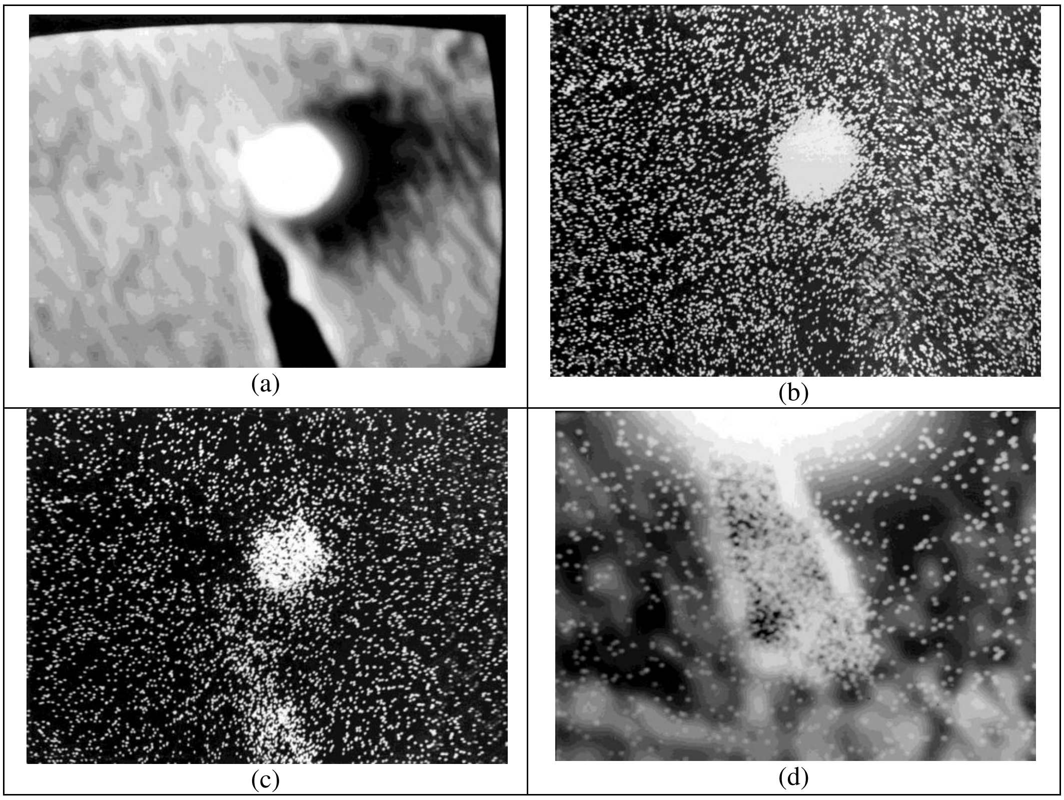


Figure-3. Non-metallic inclusion in characteristic X-ray radiation: *a* - the form of inclusion × 2,000; *b* - silicon × 2,000; *c* - oxygen × 2,000; *d* - aluminium × 3,000.

A study of N-M I in characteristic X-ray radiation indicates that the aluminosilicates acquire a globular form (Figure-3 *b*, *c*, *d*).

Consideration should be given to the technology of adding additives to the melt. Aluminium and mishmetal of cerium group were introduced in the form of monolithic fragments in calculated amount. Before entering liquid steel, they pass through a slag bath, the length of which is approximately 100 mm. When passing through liquid slag and entering the surface of a metal bath, aluminum was dissolved in the slag and reacted with oxygen. The modifier granules, while on the surface of the metal bath and interacting with the slag, also passed into the corresponding compounds and, thereby, their fraction falling into the liquid metal was significantly reduced. During remelting, liquid slag interacts with the surrounding atmosphere and steel, which leads to an increase in its oxygen, nitrogen, and other elements.

Heat treatment was carried out according to conventional conditions. Hardness after annealing of castings was 207-228 HB. One of the main tasks of obtaining high-quality castings from high-alloyed steels is to reduce dendritic liquation due to the values of the distribution coefficients of alloying elements, the value of which is less than one (k < 1). In steels with a carbon content of more than 0, 4%, the liquation of Cr and Mo develops to a greater extent. The degree of liquation in castings having a columnar structure is less than the degree of liquation characteristic of the zone of equiaxed crystals, since it significantly depends on the rate of crystallization and the shape of the crystals formed [5]. The formation of the columnar structure of castings contributes to the creation of minimal chemical heterogeneity. Low liquation values are characteristic of casts with a continuous transcrystallization zone. The increase in dispersion of the dendritic structure further leads to a decrease in segregation on the 20-30%.

It is important to note that the macrostructure of castings obtained by electroslag chill casting has a transcrystalline structure (Figure-4), which contributes to a decrease in liquation and, as a result, an increase in physical and mechanical properties.

Hardening of cast blanks was carried out from temperatures 10-15 ° C lower than recommended for this steel. After hardening, grain corresponding to No. 10-9 was preserved. After heat treatment, the cast structure retains some heterogeneity (Figure-5).

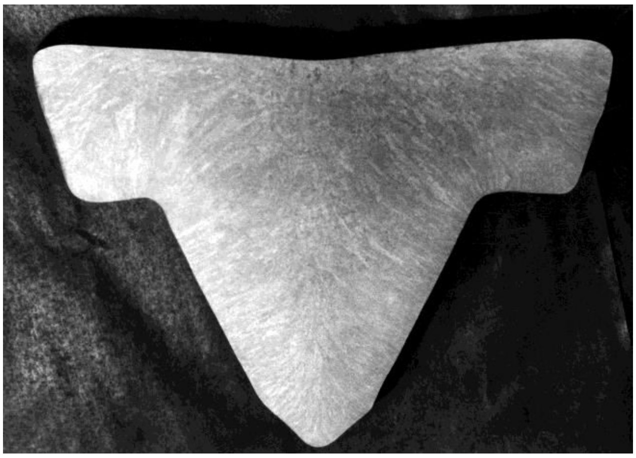


Figure-4. Spreader macrostructure having transcrystalline structure (× 0, 25).

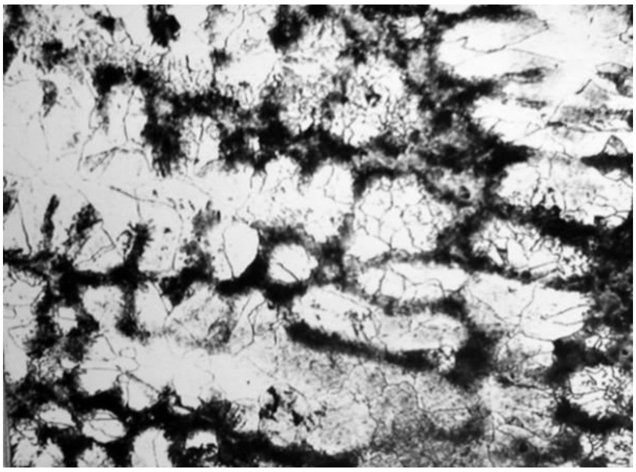


Figure-5. Inhomogeneous microstructure of H11 steel produced by electric slag cockyl casting, ×250.

The mechanical properties of the cast samples are lower than those of the deformed metal (Table-3). Significant differences are observed in toughness and ductility readings.

Table-3. Mechanical properties of steel H11.

No п/п	Type modifier	Quantity, %	HRC	σ_B, MPa	$\sigma_{0,2}$, MPa	δ, %	KCU, MJ/m^2
1	No modifier	-	45-46	1322	1128	2,9	0,13
2	Misch metal	0,2	44-45	1609	1367	5,5	0,28
3	Misch metal	0,3	45-47	1735	1420	7,5	0,30
4	Forged	-	45-47	1820	1545	8,0	0,50

It should be noted that the strength, toughness and ductility of the samples without modification and after modification have significant differences. This indicates the effect of the additives used on the structure and properties of the cast metal. Of interest is the fact that the heat resistance of the castings is not inferior to the heat resistance of the metal to be deformed, and the strength is at about the same level. Properties of steel with a small degree of deformation have a high stable level. The mechanical properties of the castings have almost the same characteristics regardless of the direction of cutting the samples. This is due to the general microneodonicity of steel, which has a decisive effect on its properties.

CONCLUSIONS

In the course of the work, it was found that the introduction of rare earth metals into the liquid melt in the process of electroslag cockyl casting helps to reduce the degree of contamination with non-metallic inclusions. Technological modes of production of castings with electric slag chill casting providing the most favorable process of electrode melting in crucible are determined. Current value during start is 1, 2-1, 5 A, and during steady-state mode of remelting 2, 5 A at voltage of 50 V.

Modification of steel H11 rare earth metals of the cerium group changes morphology and reduces the number and size of non-metallic inclusions, which acquire a predominantly globular shape. This leads to a significant increase in the reliability of the product, due to an increase in toughness, which increases from 0,13 MJ/m^2 (not modified) to 0, 30 MJ/m^2 (after modification) and ductility - the elongation increases by more than 2 times, compared to the non-modified metal.

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