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PROPERTIES OF ESR STEEL, MELTED TO A BIFILAR SCHEME USING HARD START CORRESPOND

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Type codes:
ESR – *electroslag remelting*

Summary. *The properties of cast electroslag steel 5XHM made to a bifilar scheme using a hard start correspond to the properties of the cast metal melted openly and allow to use die blocks instead of forged ones.*

It is experimentally found that scale being the press forging waste would be appropriate for use as a component of the exothermal mixture. The developed techniques for electroslag casting (remelting) using a hard start and exothermal alloyed flux make it possible to intensify the electroslag processes. Physical and chemical properties of the metal reduced from exothermal alloyed flux of 9ХФ, 9Х2МФ, 5ХНМ and 60Х2СМФ steel are the bottom of the ingot the same as in the midlle and at the top.

Key words: *scale, exothermal flux, electroslag casting.*

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Problem statement. One of the main problems facing at improvement of the electroslag processes is to increase their efficiency and discover new materials for their realisation. One of the solving lines to this problem is to use the effect exothermal reactions by introducing the exothermal mixtures into electrode materials [1, 2, 3, 4].

Existing electroslag processes (electroslag welding, electroslag remelting, electroslag casting) are conducted at hard or liquid start. At hard start the melting of a working flux and getting a slag bath of the desired volume run in the arc mode. This method is characterised by instability (frequent short circuits), uneven and long flux melting (low efficiency) [5].

At hard start the flux poured into a crystallizer is melted by a consumable electrode. In this case the flux is melted and the slag bath obtained by different methods: application of the electric conducting solid flux AH-25, or the exothermal pressed briqettes, or the selfmelting flux mixtures. Consumption of the selfmelting fluxes is usually low being within 2% of the working flux mass. The principal role of such fluxes is to provide a start for the flux melting by fast transition from the arc to arcless process. A complete flux melting therewith takes a lot of time, as a result of which the productivity of a furnace decreases. Overseas, in order to speed up the hard start they follow method [6] with uses the exothermal mixture containing the fluorspar, aluminium, ground scale and ammonium perchlorate. Since the mixture does not contain alloying elements and the amount of scale is small (20 – 30%), it does not let us to essentially reduce the time necesssary for a complete flux melting or increase the finished metal yield.

Electroslag casting of large ingots is carried out in the bifilar and three-phase furnaces using only a liquid start through siphon pouring of the scale, melted outside the furnace, into the bottom part of the pocket (during the electroslag welding), of the mould (during the electroslag remelting) or of the crucible (in the electroslag chill casting). However, the working time for the ingot melting with account of the time required for melting the flux in the flux-melting furnaces is far above than that with a hard start and loss of the metall in the bottom part of an ingot, which is rejected as discard, may range between 5 to 10% from the overall ingot mass [5].

Efficiency in the use of the press-stamping equipment for hot working of metal is restricted by insufficient resistance of the working tool as it directly contacts the hot metal, is subjected to high mechanical loads (800 – 1000 MPa) and greatly depends on temperature and power loads in operation [7].

At present time the engineering industry uses large press and hammer dies basically made from forged metal. Their manufacturing methods have a number of disadvantages [8]: low quality of ingots produced in the open steel- melting units; the raised anisotropy of mechanical properties of steel at hot plastic deformation. New opportunites in the manufacture of dies are provided by electroslag casting [9].

The present work aims to increase the efficiency of the electroslag processes with the use of exothermal fluxes conducting electrical current when in solid state and study the quality of metal made from die steel 5XHM (5CrNiMo) produced by a developed method for electroslag remelting.

Recearch objective. This work investigates the effect of exothermal fluxes which represent a mechanical metal-and-flux mixture including scale, aluminium powder, alloying elements (in the form of ferroalloys or powders) and a working flux (АНФ-6 or other).

At aluminium-iron oxides interaction proceeds the following exotpermal reactions:

$$3FeO + 2\,Al = Al_2O_3 + 3\,Fe + 880{,}9\ kJ/mole \quad (1)$$

$$Fe_2\,O_3 + 2\,Al = Al_2O_3 + 2\,Fe + 852{,}0\ kJ/mole \quad (2)$$

$$Fe_3\,O_4 + 8\,Al = 4Al_2O_3 + 9\,Fe + 3345{,}2\ kJ/mole \quad (3)$$

Comparison of the results of the reactions gives the following:

- exotermal reactions (1 and 2) require the least and the most amount of aluminium accordingly;
- iron is reduced at the most with iron protoxide (FeO);
- heat is released at the most when aluminium interacts with iron oxide (Fe_2O_3), and at the least – when with iron protoxide;
- intermediate position in amount for the iron reduced and heat released is with iron oxide – protoxide (Fe_3O_4).

The basic component in exothermal mixtures which are used in welding and metal-making industries is scale that usually makes 70 to 80% of exothermal mixture and its physical and chemical properties greatly affect the quality of the metal in welds or the metal to be made.

The scale, press-forging works, consists of 3 iron oxides [10]. A correlation between them generally depends on the conditions it appeared in, namely, on the type of the forging process, grade of steell to be forged, temperature and time of its formation. FeO mainly increases at the expence of the iron diffusion, is distinguished for its porous structure, comparatively low strength and less density as compared with base metal, and also it contains less oxigen and melted at the lowest temperature (Table 1).

Table 1

Physical properties of iron oxides

Iron oxide	Weight of molecule, g	Weight of oxygen in oxides, g	Cristal lattice	Temperature of fusion, °C	Density, g/cm^3
FeO	71,85	22,27	The cubic	1370	5,28
Fe_3O_4	231,55	27,64	The cubic	1527	5,20
Fe_2O_3	159,70	30,06	Hexagonal	1565	5,12

The researches [11] suggested that the scale formed while rolling of metal practically consists of two layers – FeO (92 – 95%) and magnetite Fe_3O_4 (5 – 8%); the scale being a reject of press forging at engineering plants contains 58 to 63% of FeO, 31 to 36% of (Fe_2O_3 + Fe_3O_4) enabling to make good use of the effects of the above three reactions.

Since the scale contains the iron oxides with different physical and chemical properties, it makes sense to identify the most suitable composition for scale in terms of its application in welding materials.

Alloying elements: nickel, chrome, silicon, molybdenum, tungsten concentrate in 3rd layer of scale, adjoining non-oxidized iron and raise stability of steel against oxidation at high temperatures. Adimixture (Impurity) Cr, W, Mn and Si are in scale as oxides, nickel - in metal condition, and quantity of formed scale diminish with increase of the carbon-content in steel from its decarburization and formation at a surface of reduaring atmosphere preventing formation of iron oxides. Hence, use of the scale received in rolling is most perspective.

Engineering factories have press- forging units where the scale is formed differently from that obtained in rolling, therefore investigated was the possibility for application of the furnace scale as a component of the exothermal mixtures in welding materials.

In order to find the effect of the forged steel grade on the chemical composition of steel, studied were the steels most commonly used for forging in the press shop at JSC „NKMZ“ (Table 2).

Table 2

Chemical composition of scale versus the grade of steel forged

Grade steel forged	Content of scale components, mass %									
	MnO	SiO_2	Cr_20_3	NiO	MoO_3	V_2O_5	Fe_{com}	FeO	Fe_2O_3+ Fe_3O_4	ΣO_2
1	2	3	4	5	6	7	8	9	10	11
35	0,67	–	–	–	–	–	71,3	60,3	34,0	–
	0,64-1,03	–	≤ 0,36	≤ 0,32	–	–	–	–	–	23,6
45	0,56	–	–	–	–	–	70,7	58,2	36	–
	0,64-1,03	0,36-0,79	≤ 0,36	≤ 0,32	–	–	–	–	–	23,8
25ГСА (25MnSiA)	1,07-1,21	1,62	–	0,23 -0,41	–	–	71,5	58,7-61,7	33,6 - 35,6	–
18Х2Н4МА (18Cr2Ni4MoA)	–	–	–	–	–	–	70,3	60,6	31,9	–
	0,32 -0,71	0,36 -0,79	1,97 - 2,41	5,09 -5,60	0,45 - 0,60	–	–	–	–	23,2

1	2	3	4	5	6	7	8	9	10	11
34XH3M (34CrNi3Mo)	0,85 -1,00	0,75 -0,82	0,83 - 1,12	2,33 -3,07	0,27 - 0,36	–	69,7 -71,3	58,3 -59,6	34,8 - 36,1	–
	0,64 -1,03	0,36 -0,79	1,02 - 1,60	3,50 - 4,10	0,37- 0,60	–	–	–	–	23,4
60X2CMФ (60Cr2SiMoV)	0,41	2,35	2,07	0,35	0,47	0,23	70,9	62,6	30,3	–
	0,26 -0,52	2,35 -2,78	2,63 - 3,07	≤ 0,38	0,37 - 0,53	0,20 -0,40	–	–	–	23,8
34XH1M (34CrNi1Mo)	0,71	–	1,68	1,52	–	–	69,7	61,2	31,2	–
	0,64 -1,03	0,36- 0,79	1,90 - 2,48	1,65 -2,16	0,30 - 0,45	–	–	–	–	23,0
Remarks: the numerator is a chemical analysis, and in denominator – aroted composition										

The level of oxidation for alloying elements was identified by comparing the rated limits for the oxide content on condition that its constituent element is completely oxidized (the values of conversion factors were taken from [12] and the chemical analysis data). Such elements as Mn and Si are oxidized almost completely and the content of their oxides in the scale is within the rated limits, while the content of oxides Ni, Cr, Mo, V is less than the lowest limit. Consequently, these elements were not completely oxidized when heated and forget. In scale they are also unoxidized. Thus, the scales taken after forging the ingots made of alloyed steel can be rationally used when it is necessary to alloy the metal with the mantioned elements without introducing their appropriate amount in the form of ferroalloys and metallic powder.

From Table 2 it follows that the scale composition as a function of the grade of the forged steel varies within fairly narrow limits. Total oxygen amount was estimated as to its content in oxides FeO and $Fe_2O_3 + Fe_3O_4$, whose value fluctuates 23,0 to 23,8%. Thus, with a view to use the scale in welding materials as component of exothermal mixture, principle it can be used from any low-alloy structural steel to be forged.

In electroslag welding [13] or electroslag remelting, a pocket or bottom of the crystallizer is filled with the electroconductive exotermal metal-flux mixture in the amount sufficient to get a slag bath of the desired volume and to proceed the electroslag processes.

For research to a bifilar scheme we carried out the electroslag casting in steel crystallizer 2 of stamp box 3 measuring 320×320×370 mm. Forged blanks of 80×200 mm in section and 2150 mm long from 5XHM steel [14] were used as consumable electrodes (Fig. 1).

a)

b)

Figure 1. View of electroslag casting stamping cube in the smelting process of bifilar scheme (a) and after melting (b)

The working flux was preliminary ignited at T 850-950 K for two hours. After the slag and metal bath got solid, the casting was taken out of a crystallizer and put into a furnace for isothermal annealing. The surface of a cast die block looked satisfactory.

The quality of the steels investigated was estimated according to following criteria: standard mechanical properties of the pieces cut out of different are as on the ingot and the forging melted openly; chemical composition and content of the non-metallic inclusions in the metal; macro- and microstructure. Since the die was subject to lodes with opposite signs, we also did the mechanical test at T 693-823 K. The results of the tests are shown in Tables 3 – 7.

Table 3

Mechanical properties of 5XHM (5CrNiMo) steel versus temperature of tests

View of ingot	Points of sampling	MPa	MPa	δ, %	ψ, %	KSU, kJ/m^2
1	2	3	4	5	6	7
Testing t^0 693K						
Forging (melted openly)	Midpart	1077/1012	1010/950	15/12	70/43	372/184
Die block (ESC)	Bottom					
	Surface	1091/1053	1031/995	15/11	57/49	205/204
	Centre	1008/985	940/933	12/11	51/51	229/213
	Midpart					
	Surface	995/998	902/914	13/12	51/46	233/221
	Centre	992/998	906/914	9/12	39/46	221/221
	Top					
	Surface	994/964	935/910	13/13	53/47	270/241
	Centre	994/964	917/895	13/13	37/35	245/225
ГОСТ 5950- 73		> 850	>750	>10	–	–
Testing t^0 823K						
Forging (melted openly)	Midpart	550/503	501/443	37/35	80/65	357/288

1	2	3	4	5	6	7
Die block (ESC)	Bottom					
	Surface	560 / 530	530 / 497	34 / 30	77 / 72	323 / 286
	Centre	542 / 514	513 / 475	25 / 23	77 / 71	262 / 245
	Midpart					
	Surface	560 / 530	539 / 497	34 / 30	77 / 72	323 / 286
	Centre	481	447	35	76	250
	Top					
	Surface	512 / 502	477 / 458	33 / 31	81 / 77	384 / 327
	Centre	511 / 493	481 / 467	31 / 27	73 / 76	294 / 327
Remarks: 1. Given are mean values of testing results for 3 samples. 2. Above the line – the testing results of the samples cut out along axis, under the line – across the ingot. axis.						

Table 4

Effect of electroslag remelting on chemical composition of 5XHM (5CrNiMo) steel

Item studied	Place selection tests	Content, %							
		C	Si	Mn	Cr	Mo	Ni	S	P
Electrode	–	0,55	0,28	0,60	0,55	0,16	1,64	0,017	0,019
Die block (ESC) (bottom end)	1	0,67	0,27	0,80	0,61	0,19	1,62	0,009	0,016
	2	0,66	0,24	0,80	0,61	0,16	1,73	0,010	0,017
	3	0,67	0,21	0,85	0,62	0,14	1,73	0,016	0,016
	4	0,69	0,23	0,87	0,62	0,12	1,72	0,010	0,014
	5	0,66	0,23	0,87	0,60	0,17	1,62	0,010	0,017
	6	0,69	0,27	0,79	0,58	0,18	1,61	0,008	0,019
Templet 1 (ingot bottom)	7	0,61	0,24	0,72	0,59	0,16	1,66	0,015	0,019
	8	0,64	0,25	0,76	0,60	0,17	1,54	0,016	0,018
	9	0,65	0,25	0,74	0,61	0,17	1,58	0,016	0,019
	10	0,68	0,23	0,73	0,65	0,18	1,60	0,013	0,019
Templet 2 (ingot bottom)	11	0,59	0,22	0,71	0,64	0,16	1,62	0,015	0,018
	12	0,58	0,21	0,71	0,59	0,19	1,54	0,013	0,020
	13	0,58	0,25	0,72	0,61	0,17	1,58	0,013	0,017
	14	0,62	0,23	0,76	0,65	0,17	1,60	0,013	0,018
Bottom	70 mm with end	0,58	0,26	0,64	0,60	0,017	1,62	0,009	0,020
Midpart	too	0,56	0,28	0,65	0,56	0,18	1,66	0,012	0,018
Top	too	0,55	0,28	0,62	0,53	0,17	1,62	0,009	0,017
ГОСТ 5950–73	–	0,50-0,60	0,15-0,35	0,50-0,8	0,50-0,80	0,15-0,30	1,40-1,80	≤ 0,03	≤ 0,03

Table 5

Selected characteristics of dispersion of mechanical properties

Processing kind	Mechanical properties	Anisotropy factor	Processing kind	Mechanical properties	Anisotropy factor
Temperature of tests 693 K			Temperature of tests 823 K		
Forging (metal of open melt)	σ_B	0,93	Forging (metal of open melt)	σ_B	0,92
	σ_T	0,94		σ_T	0,93
	δ	0,80		δ	0,80
	ψ	0,62		ψ	0,76
	KCU	0,50		KCU	0,42
Die block (ESC)	σ_B	0,97	Die block (ESC)	σ_B	0,98
	σ_T	0,96		σ_T	0,97
	δ	0,90		δ	0,90
	ψ	0,89		ψ	0,92
	KCU	0,90		KCU	0,91

Table 6

Fatigue strength of 5XHM (5CrNiMo) steel (longitudinal samples)

Work piece	For sample selection	Endurance limit, MPa
Forging (metal of open melt)	Surface	380
Die block (ESC)	Surface	300
	Centre	285

Table 7

Content of non-metallic inclusions in casting

Place ofampling		Content, %	
In height	In section	Sulphides	Oxides
Bottom	Surface	0,016409	0,0055653
	Center	0,010098	0,009757
Midpart	Surface	0,0167535	0,005967
	Center	0,010901	0,0099832
Top	Surface	0,012507	0,00786
	Center	0,01922	0,0085488
Forged ingot		0,02857	0,011016

To study the effect of the suggested melting method on the uniformity of chemical composition of the metal on the investigated ingot in height, we cut a piece measuring 320x320x60 mm out of its bottom part. In order to find a transition zone, chemical composition of the investigated metal was determined at 15, 30 and 60 mm from the bottom part of the ingot (Fig. 2).

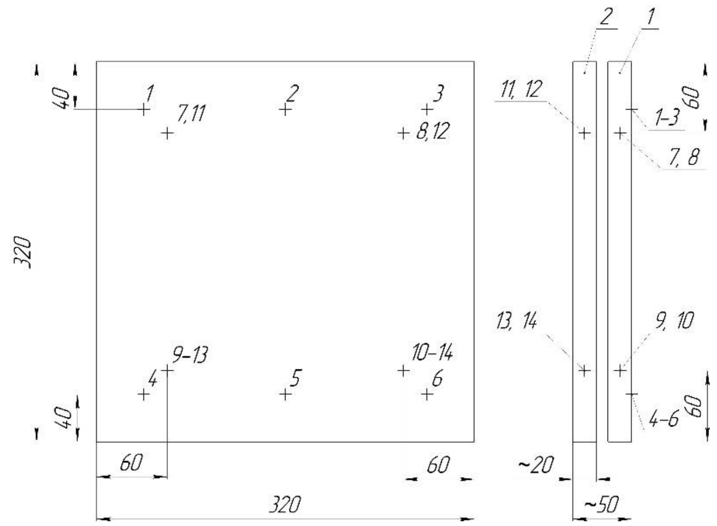

Figure 2. Sampling locations for chemical research methods stamping cube (end the blank view);
1 and 2 – the point from the ingot bottom

Hardness of the samples made of a forging (forging reduction ratio 8) and the die block after thermal treatment was 45 to 46 and 44 to 48 HRC respectively. The results of standard mechanical tests of the steels to be investigated as a function of temperature are given in Table 3.

From data of Table 4 it follows that the chemical composition of the reduced metal is characterised with a high uniformity and the lack of a transition zone.

For studying the macrostructure and removing the sulphuric mark, we cut the longitudinal central templet out of the ingot examined. The studies of macrostructure were carried out in compliance with GOST 1243-75 by identifying the liquational inhomogeneity as to sulphur and investigating the composition of macrostructure and defects in metal. The liquational inhomogeneity in the ingot bottom as to sulphur (Fig. 3) is shown as dots. The sulphur content in the ingot bottom is therewith less than in its midpart or top.

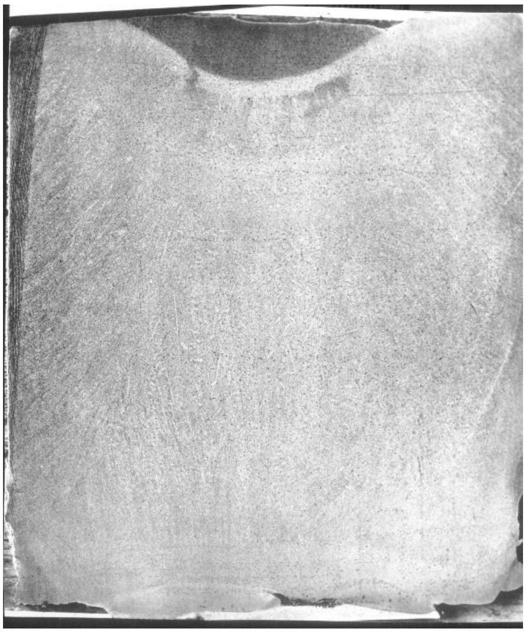

Figure 3. Sulfur distribution of 5XHM electroslag steel (central longitudinal stamping cube templet)

The macrostructure was examined after deep itching of the template surface in a 50% aqueous solution of the sulphuric acid heated up to 353 K (Fig. 4).

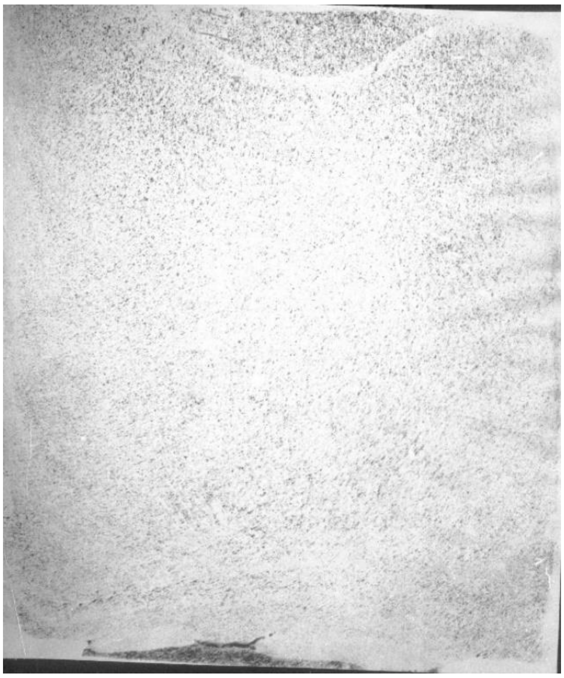

Figure 4. Electroslag steel 5XHM microstructure (central longitudinal stamping cube templet)

It was found that the cast metal in the ingot bottom is dense; cracks, cavities and other defects are absent, and the columnar crystals are directed nearly parallel to the template axis. In the middle and top clearly seen is a zone of the columnar crystals arranged at the angle of 45 to 60^0 to the template axis. There is a zone of the equiaxed crystals in the central part.

The tests of mechanical properties of the examined block [14] showed that they are similar to the forged metal made openly, and high values of the anisotropy factor (0,91 to 0,98) point to a high uniformity of the cast electroslag metal.

The estimation of the mechanical tests results was determined by the anisotropy factors (Table 5) calculated by the formulas given in work [15].

From Tables 3 and 5 it follows that with increasing test temperature the mechanical properties of the cast die block are similar to the examined cast metal made openly. High values anisotropy factor suggest rather high uniformity of properties of the cast electroslag metal.

Data on fatigue endurance stamp steels in the literature are limited. In present a work for definition of a limit of endurance research steels conducted tests of samples in diameter of 24 mm by car UP-20 under the scheme of a symmetric pure bend a method complete basis step overloads [16]. Thermal processing of fatigue samples was spent on the same modes, as samples on a static stretching and a shock bend. The results of tests resulted in tab. 6 show that cast electroslag metal possesses high isotropy on an endurance limit.

Micro researches of the metal contamination with non-metallic inclusions conducted to GOST 1778-70 with the increase of 400 and chemical analysis of the deposit produced by elektrolytically dissolving the samples made from the examined die block showed that the metal contained just a few non-metallic inclusions, while the forged metal was contaminated both with sulphides and oxides much higher than the cast electroslag metal (Table 7). The non-metallic inclusions as alumino-silicates containing minor amounts of iron protoxides and mangenese were therewith evenly arranged both in cross-section and height of the ingot.

The work [17] presents the results of an investigation into the influence of the exothermal alloyed flux on physical and chemical properties (chemical and gas-composition, content of non-metallic inclusions, microstructure) of the reduced alloyed metal in the bottom of the ingot of roll steel 9ХФ (9CrV), 9Х2МФ (9Cr2MoV) and 60Х2СМФ (60Cr2SiMoV), which correspond to the same values In the midpart and top of the ingot.

On furnace ESHP-10G in copper water cooled crystallizer height 2600 mm and diameter 800/850 mm ingot melt was made by a spent electrode of is fulfilled is shaky in diameter 500 mm and length 3500 mm from steel 60Х2СМФ (60Cr2SiMoV) with application elaboration a firm way of start [17].

On priming in crystallizer it has been filled up 200кg exotermal mixes and 400 kg flux АНФ-6. Electroslag smelt it was made on a following mode: a current strength – 20-22кА, tension – 60-65В. The set steady electroslag process mode has been established on an out-come of 30th minute [21]. Time melt of an ingot diameter 810 mm and height 1340 mm has made 6,5 hour; at melt of same ingot on ordinary hardstart – 8,5 hour, and at liquid start – 6,5 hour without flux fusion in flux-melting furnaces (1,5 hour). External and inside defects in a melted ingot were not found.

Conclusions. The effective way to increase the efficiency of electroslag processes is the use of exothermal mixture or exothermal flux (scale, ferroalloys and an aluminium powder in the amounts sufficient for exothermal reactions). As a component of the exothermal flux it makes it makes sense to use the scale which is a reject in press forging. The bifilar scheme for the electroslag process with a hardstart and an exothermal alloyed flux makes it possible to use the freed flux-melting furnaces for electroslag casting of large important parts. Properties of a cast electroslag steel 5ХНМ (5CrNiMo) meet the requirements placed upon mechanical properties of the forged metal melted openly. Application exothermal an alloyed flux and the developed way of electroslag casting (smelt) allows to intensify electroslag processes. Physical and chemical properties restored metal from exothermal an alloyed flux steels 9ХФ, 9Х2МФ (9Cr2MoV), 60Х2СМФ (60Cr2SiMoV) and 5ХНМ (5CrNiMo) in the bottom part of an ingot correspond to the same parameters of a middle and upper part of an ingot. The developed way electroslag smelt with use exothermic the alloyed flux allows to receive casting at different ways of conducting process with application of hard start.

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ВЛАСТИВОСТІ ЕЛЕКТРОШЛАКОВОЇ СТАЛІ, ПЕРЕПЛАВЛЕНОЇ ЗА БІФІЛЯРНОЮ СХЕМОЮ З ВИКОРИСТАННЯМ ТВЕРДОГО СТАРТУ

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Резюме. *Властивості литої електрошлакової сталі 5ХНМ, виплавленої по біфілярній схемі з використанням твердого старту, відповідають властивостям кованого металу відкритої виплавки й дозволяють застосовувати литі штампові кубики замість кутих.*

Експериментальними методами встановлено, що як компонент екзотермічної суміші доцільне використання окалини, що є відходом ковальско-пресового виробництва. Застосування розроблених способів еэлектрошлакового лиття (переплаву) з використанням твердого старту й екзотермічного легованого флюсу дозволяє інтенсифікувати електрошлакові процеси. Фізико-хімічні властивості відновленого металу з екзотермічного легованого флюсу сталей марок 9ХФ, 9Х2МФ, 5ХНМ і 60Х2СМФ у нижній частині злитка відповідають тим же показникам у середній і верхній частинах.

Ключові слова: *електрошлакове лиття, екзотермічний флюс, окалина.*

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Умовні позначення:
ЕШП *– електрошлаковий переплав*