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INVESTIGATION OF THE INFLUENCE OF TECHNOLOGICAL FACTORS IN THE SMELTING OF LOW-ALLOY STEEL ON RESISTANCE TO HYDROGEN CRACKING

In the last decade, the oil and gas industry has been in dire need of seamless steel pipes resistant to corrosion destruction, which is associated with the development of oil production containing large amounts of hydrogen sulfide and other aggressive impurities.

A key role in achieving high indicators of resistance to hydrogen cracking is given to the development and use of methods for controlling the type, quantity, size and morphology of non-metallic inclusions, forms of impurity presence, precipitation of non-metallic excess phases or strengthening structural components.

The authors analyzed the current technology for smelting and casting of 13HFA steel at the KSP Steel PB LLP enterprise and developed a set of technological measures for smelting, extra-furnace treatment and casting of 13HFA steel, ensuring a high level of resistance to hydrogen cracking.

A series of melts carried out according to the developed technological indicators ensured the achievement of the main HIC indicators at the level of CLR and CTR = 0 %.

The research was conducted within the framework of grant funding from the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan under the competition for grant funding for scientific and (or) scientific and technical projects for 2024–2026 under the project AP23487674 «Complex processing of bauxites of Kazakhstan with additional extraction of iron by alternative reducing agents in the implementation of the low-carbon development strategy».

Keywords: low-alloy steel, hydrogen cracking, smelting, out-of-furnace processing, continuous casting.

Introduction

In the last decade, the oil and gas industry has been in dire need of seamless steel pipes resistant to corrosion destruction, which is associated with the development of oil production containing large amounts of hydrogen sulfide and other aggressive impurities [1–4].

In Kazakhstan, the urgency of this problem was clearly demonstrated during the organization of oil production at the Kashagan field [1].

Analysis of the literature [5; 6] shows that in recent years, the requirements for the quality of products manufactured from high-quality mass steel grades have increased significantly. The requirements for the level and stability of the service properties of steel are constantly growing. There has been a multiple increase in the requirements for corrosion resistance, cold resistance, operational reliability and other service properties, provided that they are weldable. It is possible to note another important tendency, that if earlier, during development of steel, requirements were imposed mainly on the level of one of the properties, then at present and, especially, in the future, it is necessary to increase to the highest possible level the whole complex of properties, as a rule, difficult to combine, for example, strength, plasticity and stampability, strength and corrosion resistance [6].

The above-mentioned tendencies have led to the necessity of using fundamentally new approaches to achieve the required structural state, high indicators of technological, mechanical, physicochemical characteristics of metal. The key role among them is given to the development and use of methods for controlling the type, quantity, size and morphology of non-metallic inclusions, forms of presence of impurities, precipitation of non-metallic excess phases or strengthening structural components, which should provide [6]:

– a sharp decrease in the content of traditional non-metallic inclusions;

– elimination of the possibility of formation of non-metallic inclusions, which have a negative impact on technological, service properties of steel, including its corrosion resistance and sorting by various types of defects;

– obtaining non-metallic precipitates that provide an increase in the level and stability of mechanical and other service properties of steel;

– ensuring the required content and forms of presence of harmful non-ferrous and uncontrolled impurities.

It is important to note that the formation of certain non-metallic inclusions is largely determined by the adopted technological scheme of production, the type of charge materials and the type of manufactured metal products. For example, the formation of corrosion-active non-metallic inclusions (CANI) is associated with the technology of extra-furnace treatment, namely the conditions of the deoxidation and modification processes.

The mechanism of CANI formation is described in [5–12]. When introducing large portions of aluminum into overoxidized steel at the outlet, all possible combinations of aluminum and oxygen concentrations arise in various zones of the melt, leading to the formation of not only corundum inclusions, but also a large number of herzenite inclusions FeO Al_2O3 with high adhesion to the melt and extremely difficult to remove during subsequent extra-furnace treatment. When aluminum and silicon are simultaneously introduced into the overoxidized metal at the outlet, not only an excess amount of herzenite inclusions is formed, but also a large number of difficult-to-remove mullite inclusions $2Al_2O_3$ SiO_2.

Despite the fact that herzenite and mullite inclusions, under certain optimal parameters of modifying treatment with calcium-containing materials, are transformed at the final stage of extra-furnace treatment with the formation of inclusions of calcium aluminates CaO Al_2O_3 and 3CaO Al_2O_3, which are liquid at the temperatures of steelmaking processes and should be easily removed from the steel into slag, the required degree of metal purity for corrosion-active inclusions such as calcium aluminates is not achieved due to their significant quantity and the lack of time required for their enlargement and removal from the melt [8]. As a result, in the metal of continuously cast billets (CCB) and rolled products, CANVs of the composition CaO Al_2O_3 and 3CaO Al_2O_3 are found, which, despite the favorable morphology, did not have time to be removed from the melt. Also, large portions of lump aluminum, released at the tap, actively interact with the ladle lining to form magnesia spinels MgO Al_2O_3. Magnesia spinels, solid at the temperatures of steelmaking processes, are also poorly removed during out-of-furnace processing. On the surface of magnesia spinels, calcium aluminates are released at subsequent stages of phase formation, and at the last stages of solidification, sulfide inclusions precipitate on the surface of such multiphase inclusions, as on the substrate. Such conglomerates are corrosive and in this form are often found in NLZ and rolled metal [5–9]. Based on the above, it can be concluded that at present in Kazakhstan there is an urgent problem of developing a technology for producing high-quality rolled products and pipes that satisfy the entire range of properties required by consumers of these products.

Materials and methods

The authors analyzed the current technology of steel smelting and casting at the enterprise PB LLP "KSP Steel". The object of the study was steel grade 13HFA, regulated by GOST 8732 and GOST 8731.

Table 1 – Chemical composition of steel 13HFA, %

Chemical elements	C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	N_2
min	0,13	0,17	0,45	–	–	0,50	–	–	0,05	0,020	–
max	0,16	0,23	0,51	0,013	0,010	0,56	0,20	0,20	0,08	0,040	0,008

Steel was smelted in 60-ton electric arc furnaces (EAF) using a single-slag process with steel finishing in a ladle-furnace unit (LFU) and a ladle vacuum degasser.

The 60-ton electric arc furnaces were equipped with wall-mounted oxy-fuel burners, coal tuyeres, an eccentric bottom discharge system, and a system of bins for storing, weighing, and adding the necessary materials when tapping metal from the furnace. The lining of the furnace working layer is made of periclase-carbon refractory materials, which ensure a service life of more than 250 melts between repairs. If necessary, the lining of the walls is gunned with refractory masses using a special gunning machine.

The LFU was used to finish the steel according to chemical composition and temperature, desulfurize the steel, remove non-metallic inclusions, homogenize, modify, and microalloy. The plant was equipped with a system of bunkers for storing, weighing and adding ferroalloys, tribological devices for introducing wire with various powder fillers into the metal, a unit for blowing powdered materials (coke, lime) into the metal and onto the slag. For supplying argon for mixing, 2 slotted blow-off plugs are installed in the bottom of the steel-pouring ladle. The lining of the steel ladles is made of individual periclase-carbon products.

The metal charge for the EAF is received and processed in the charge preparation shop (CPS).

The following are used for carburizing the metal: carbon-containing material; coke breeze according to GOST 11255–75; electrode scrap (pieces no larger than 50 mm); scrap of cast iron parts.

Iron ore pellets with an iron content of at least 60 % are used as an oxidizer. Freshly fired lime with a content of active oxides CaO+MgO of at least 85 %, fluorspar according to GOST 29220 are used as slag-forming agents. It is permitted to use broken fireclay bricks that have been in use (crumbs, fraction 0–5 mm).

For deoxidation and alloying, ferrosilicon manganese according to GOST 4756 (FeMnSi), ferrosilicon according to GOST 1415 (FeSi 75A11), silicocalcium according to GOST 4762 (SK20, etc.) are used. For pipe steel grades, the following are also used: ferromanganese according to GOST 4755, aluminum AB - 97 GOST 295, screenings AKS (aluminum-corundum mixture), silicon carbide SiC, aluminum rod GOST 13843.

The fraction of materials fed through their feed system is 5–50 mm. The moisture content in slag-forming materials and solid oxidizers is no more than 1.5 %. The moisture content in ferroalloys and coke breeze is no more than 0.5 %.

The melt is charged based on obtaining a carbon content in the metal by the beginning of the oxidation period above the lower limit of the specified steel grade by 0.20–0.30 %.

To obtain the required carbon content in the metal upon melting in the furnace, coke nut (coke breeze) is added before the first batch. The total amount of lime and carbonaceous material added during the melting period is 30–35 kg per ton of metal charge. After 90–95 % of the metal charge has melted, a metal sample is taken for a complete chemical analysis.

After the wells have melted, the slag is foamed by blowing carbonaceous material through a tuyere or by adding carbonaceous material while simultaneously blowing the slag with oxygen. The fluidity of the slag is maintained by adding fluorspar.

The primary slag is removed at a temperature of 1520–1540 ºC. At this temperature, 60–70 % of the furnace slag is removed.

With a low carbon content upon melting, the metal is carburized by blowing graphite (coke fines) in a stream of nitrogen, or by adding electrode scrap, graphite, or coke to the furnace.

The beginning of the oxidation period is considered to be the moment when the bath temperature reaches 1540–1560 ºC.

Carbon oxidation is performed with gaseous oxygen introduced into the furnace through oxygen tuyeres. During the oxygen blowing process, the foamed slag is maximally removed by gravity, preventing metal from coming off.

The duration of the oxidation period and the intensity of decarburization were determined based on obtaining the carbon content specified for a given steel grade at a temperature of 1630–1650 ºC.

The mass fraction of sulfur and phosphorus in the metal before tapping was within the limits for the given steel grade.

After obtaining the specified carbon content and temperature, the melt was tapped. The metal was tapped from the furnace without slag.

The temperature of the metal before tapping was within the range of 1620–1635 ºC (1650 ºC during the first melt). The metal was tapped from the DSP with subsequent vacuumization at a temperature of 1650–1660 °C.

The addition of ferroalloys and slag-forming materials was carried out during the tapping of the melt through the bulk material feed system. Alloying of steel at tapping was carried out to the lower limit of the alloying element content.

The addition of ferroalloys began after the tapping of 3–5 tons of metal for DSP-60. The addition of slag-forming materials was carried out after the addition of ferroalloys. To direct slag under the metal stream during tapping, lime in the amount of 200–300 kg and fluorspar in the amount of 40-80 kg were added. The slag thickness in the ladle was maintained at 80-100 mm.

The metal temperature before the start of melt processing on the ACP was maintained at 1560–1580 ºC.

Metal processing on the ACP was carried out to adjust the metal by temperature and chemical composition, average the metal by temperature and chemical composition in the ladle volume, remove sulfur and non-metallic inclusions, degass the steel, and coordinate the operation of the EAF and CCM. The metal processing time was 30-40 minutes. Argon purging was carried out throughout the entire metal processing cycle.

The arc heating stage of the ACP was selected based on the required metal heating rate. When blowing without arc heating, the temperature decrease was 0.5–1.0 ºC/min.

The refining slag was induced by adding lime and fluorspar, and additionally, AKS was used. Coke powder was applied to the slag surface for deoxidation and foaming. Lump silicocalcium was used as a slag deoxidizer in an amount of up to 1.0 kg/ton of liquid steel. The slag basicity was maintained at a level of at least 2.2.

The metal composition was adjusted in the following order: homogeneous liquid-mobile slag was obtained in a ladle, ferroalloys were added, and the carbon content in the metal was adjusted by adding coke breeze, USM, or graphite.

The element assimilation coefficients were as follows: manganese 100 %; silicon 90 %; coke carbon 50 %.

Aluminum rod was fed through a trib-apparatus, through which powder wire was also fed to adjust the chemical composition for other alloying elements (vanadium, etc.).

After the introduction of aluminum, the metal was averaged by argon blowing for 3-4 minutes, after which the metal was processed with silicocalcium wire.

The temperature of the steel in the ladle was monitored after the start of blowing the metal. The last temperature measurement was made immediately before feeding the ladle for pouring. Intermediate control of the metal temperature was carried out every 5–10 minutes of operation under current, and after 10 minutes, when working without arc heating.

3–5 minutes before the end of steel processing on the ACP, the metal was overheated by 3–5 ºC above the set temperature, arc heating was turned off and the metal was cooled to the set temperature by blowing with argon.

At the end of the processing, a slag sample was taken for chemical analysis. After processing on the ACP, the steel is processed on a ladle vacuumizer. During the vacuuming process, the steel is purged with argon.

The processing mode included 4 stages:

– reducing the pressure to 175 mbar;

– reducing the pressure to 65 mbar. When the metal «boiled», the pressure was maintained at about 133 mbar until the bath calmed down;

– reducing the pressure to 5 mbar. During boiling, the pressure was maintained at about 27 mbar (20 Torr) or the pump was switched to the previous position in order to prevent the steel ladle from overflowing;

– reducing the pressure to a level below 1.33 mbar. The argon flow rate was 270 Nl/min to maintain the maximum possible foaming. The processing time was from 20 to 25 minutes to remove as much hydrogen, nitrogen, and oxygen from the steel as possible.

After vacuuming, the shut-off valve was closed and the pump was turned off. To dilute the CO accumulated in the chamber, nitrogen was pumped into the chamber. After the nitrogen was pumped into the tank, air was introduced until atmospheric pressure was reached. The argon consumption for the purge plug was reduced to 60 Nl/min.

Then the temperature was measured and the oxygen content was determined.

The final finishing of the metal was carried out by adding aluminum rod and wire with powder fillers using a tribapparatus.

After adding the wire, the metal was purged with argon for at least 5–7 minutes, with the flow rate set at 30 Nl/min or less, preventing the metal surface from being exposed.

The temperature was measured, the hydrogen content in the metal was measured, the argon supply was turned off, the metal surface in the steel-pouring ladle was covered with a heat-insulating mixture in the amount of 40–60 kg, after which the ladle was sent to the continuous casting machine.

A radial continuous casting machine with a bending sector radius of 10,000 mm was used. The cross-section of the cast blanks was a circle from 150 to 300 mm. The length of the blanks was from 5 to 12 meters. Continuous casting was carried out using the “melt on melt” method through submerged nozzles with a closed stream.

When pouring steel with a flooded stream through submerged nozzles, a slag-forming mixture (SFS) was introduced onto the metal surface in the crystallizer. The surface temperature of the workpiece after drawing before the shears was 900 – 950 ºC.

Results and discussion

Analysis of the influence of technological parameters of melting and casting of 13HFA steel on resistance to hydrogen cracking showed the following results.

At the stage of melting steel in the EAF, the following melting parameters were changed:

– oxygen content in steel before tapping from the EAF was reduced to 1300 ppm;

– lime and fluorspar feed was increased at the tapping of metal from the EAF.

The main technological parameters and the achieved results in melting steel in the EAF are given in Table 2 and Table 3.

Table 2 – Chemical composition of metal's output from EAF

Melt number	Chemical composition of metal's output from EAF, %								Temperature of metal's output from EAF, ºC
	C	Si	Mn	P	S	N_2	Cu	Mo	
5160162	0,03	0,01	0,05	0,08	0,15	0,008	0,17	0,15	1641
5160163	0,04	0,02	0,04	0,07	0,18	0,011	0,16	0,019	1641
5160164	0,04	0,01	0,04	0,06	0,13	0,008	0,16	0,016	1644
5160165	0,04	0,01	0,05	0,07	0,14	0,0059	0,17	0,014	1647
5160166	0,03	0,01	0,06	0,06	0,14	0,0077	0,17	0,019	1638
5160167	0,03	0,01	0,06	0,07	0,14	0,0077	0,18	0,014	1643
5160168	0,03	0,01	0,04	0,07	0,14	0,0071	0,19	0,023	1643
6160154	0,06	0,01	0,05	0,06	0,19	0,013	0,16	0,11	1631
6160155	0,05	0,01	0,05	0,07	0,23	0,012	0,15	0,014	1629
6160156	0,04	0,01	0,05	0,06	0,27	0,0077	0,14	0,013	1632
6160157	0,04	0,01	0,05	0,06	0,3	0,01	0,15	0,011	1625
6160158	0,06	0,01	0,05	0,07	0,24	0,0085	0,15	0,016	1626

Таблица 3 – Quantity of materials added to the ladle metal's output from EAF, kg

Melt number	CaO	FOMI	FeSiMn	SiAl	FeCr
5160162	301	50	304	204	313
5160163	303	51	304	204	312
5160164	301	51	307	207	310
5160165	301	52	275	202	312
5160166	301	52	305	203	310
5160167	302	51	310	204	317
5160168	301	52	307	202	299
6160154	304	58	264	203	301
6160155	308	55	266	202	300
6160156	306	57	229	233	251
6160157	308	57	259	235	251
6160158	306	55	260	235	252

These measures allowed to reduce the content of non-metallic inclusions in steel, reduce the consumption of lime and fluorspar during the period of secondary treatment, and as a result improve the results in terms of resistance to hydrogen cracking.

During the metal processing at the LCP, the following secondary treatment parameters were observed:

– the duration of metal stay in the ladle was reduced to 160 minutes (from the release of steel from the EAF to feeding to the continuous casting machine);

– the calcium content in the steel before feeding to the continuous casting machine was maintained at a level of at least 0.0020 % (with the recommended ratio of Ca/S = 1.5–2.0).

These measures allowed to reduce the contact time of the metal with the ladle lining, which led to a decrease in the content of magnesium oxide inclusions. It should be noted that during steel smelting, the ratio of Ca/S = 1.5–2.0 was not always maintained.

The main steel processing indicators are given in Tables 4–7.

Table 4 – Quantity of materials fed to the ALF, kg

Melt number	CaO	CaF2	FeSi	MT	Al	FeV
5160162	501	40	38	8		60
5160163	502	44	56	18		70
5160164	503	40	46	8		60
5160165	503	42	46	8		70
5160166	501	44	50	8		70
5160167	502	40	51	8		68
5160168	502	46			120	60
6160154	405	30	32	8		60
6160155	403	23	32	8		45
6160156	403	46		6		
6160157	406	44		6		
6160158	406	48		6		

Table 5 – Treatment parameters on the automatic transmission

Melt number	Duration of metal stay in ladle, min.	Durability of s/k, number of heats	Temperature of metal before sending to vacuum machine, ºC
5160162	73	53	1725
5160163	74	25	1685
5160164	235	13	1695
5160165	88	54	1676
5160166	79	26	1689
5160167	86	24	1685
5160168	100	14	1685
6160154	76	25	1734
6160155	99	27	1729

6160156	97	6	1730
6160157	103	40	1725
6160158	78	26	1725

Table 6 – Parameters of processing in a ladle vacuum degasser

Melt number	Vacuuming duration, min	Achieved vacuum, mbar	The amount of materials added to the ladle on the vacuumizer, m		Total duration of processing on the vacuum machine, min.
			After vacuuming		
			SiCA	Alwr	
5160162	22	0,88	55		60
5160163	20	0,84	55	40	65
5160164	20	0,86	60		59
5160165	20	0,88	60		48
5160166	20	0,82	60		57
5160167	20	0,88	60		41
5160168	20	0,87	65	10	54
6160154	31	0,9	150	47	72
6160155	30	0,91	150	45	58
6160156	35	0,95	140	44	55
6160157	30	0,95	130	45	56
6160158	30	0,85	130	42	61

Table 7 – Chemical composition of steel after processing in a ladle vacuum degasser, %

Melt number	Chemical composition of steel after vacuum treatment									
	C	Si	Mn	P	S	Cr	V	Ca	Al	N_2
5160162	0,13	0,2	0,47	0,09	0,09	0,51	0,052	0,0024	0,024	0,008
5160163	0,16	0,19	0,49	0,09	0,05	0,54	0,058	0,0025	0,031	0,0064
5160164	0,15	0,21	0,48	0,08	0,04	0,53	0,057	0,0034	0,032	0,0076
5160165	0,15	0,23	0,48	0,07	0,06	0,56	0,058	0,0023	0,029	0,006
5160166	0,13	0,2	0,46	0,06	0,07	0,51	0,058	0,0025	0,027	0,0067
5160167	0,15	0,22	0,5	0,09	0,08	0,53	0,062	0,0016	0,029	0,0074
5160168	0,14	0,19	0,47	0,07	0,04	0,52	0,07	0,0022	0,024	0,0071
6160154	0,13	0,3	0,45	0,07	0,07	0,53	0,054	0,0032	0,027	0,0076
6160155	0,14	0,31	0,47	0,08	0,08	0,5	0,052	0,003	0,027	0,0065
6160156	0,14	0,29	0,45	0,09	0,05	0,53	0,056	0,0038	0,031	0,0075
6160157	0,14	0,3	0,45	0,07	0,1	0,53	0,054	0,0034	0,029	0,0081
6160158	0,13	0,28	0,45	0,06	0,06	0,53	0,054	0,0036	0,029	0,005

Steel casting on the continuous casting machine was carried out with the following parameters changed:

– the parameters of the secondary cooling of the continuous casting machine were changed, with the aim of uniform cooling of the billet and reducing the temperature heterogeneity of the billet surface to 40˚C.

The main indicators of continuous casting are given in tables 8–10.

Table 8 – Continuous Casting Machine Casting Parameters

Melt number	Industrial ladle temperature, ºC	Liquidus temperature, ºC	Section of the work-piece D, mm	Temperature of metal in tundish, ºC			Pouring time, min
				Start of pouring	End of pouring	Δt	
5160162	1050	1518	210	1548	1338	10	18
5160163	1102	1518	210	1565	1558	7	73
5160164		1516	210	1548	1548	0	44
5160165		1517	210	1545	1543	2	73
5160166		1517	210	1545	1547	2	72
5160167		1518	210	1542	1544	2	54
5160168		1518	210	1550	1542	8	85
6160154	1139	1518	300	1565	1540	25	84
6160155		1517	300	1543	1553	10	52
6160156		1518	300	1545	1540	5	61
6160157		1517	300	1552	1540	12	73
6160158		1518	300	1553	1549	4	74

Table 9 – Technological parameters for casting 13HFA steel

<table>
<tr><td colspan="6">Primary water: ~1800 l/min (∅300). Water pressure 6.0 bar</td></tr>
<tr><td>section
∅300 mm</td><td>0.3 m/min</td><td>0,6 m/min</td><td>0,9 m/min</td><td>1,2 m/min</td><td>1,5 m/min</td></tr>
<tr><td>1 zone</td><td>29 l/min</td><td>60 l/min</td><td>90 l/min</td><td>120 l/min</td><td>151 l/min</td></tr>
<tr><td>2 zone</td><td>18 l/min</td><td>40 l/min</td><td>58 l/min</td><td>77 l/min</td><td>98 l/min</td></tr>
<tr><td>3 zone</td><td>14 l/min</td><td>28 l/min</td><td>41 l/min</td><td>77 l/min</td><td>68 l/min</td></tr>
<tr><td colspan="4">Application of the SFM</td><td colspan="2">SFM BF18AT</td></tr>
<tr><td colspan="4">The pouring speed is set depending on the temperature of the metal in the tundish within the range:</td><td>Temp. in s/c, ºC</td><td>Casting speed, m/min</td></tr>
<tr><td colspan="4">automatic mode of adjustment of the casting speed, the casting speed is set according to the results of discrete temperature measurements

- section ∅300 mm</td><td>1534-1540</td><td>0,4-0,55</td></tr>
</table>

Further in the work the data on the content of non-metallic inclusions and HIC indices in seamless pipes obtained from steel grade 13HFA of experimental melts were analyzed. The analysis of the macrostructure is given in Table 10. The main characteristics of the pipes are given in Table 11.

Table 10 – Analysis of the macrostructure of the CCB

Melt number	Macrostructure, score				
	CP	OHN	CCT		KTZ
			by section	axial	
5160162	0	1	0	0	0
5160163	0	1	0	0,5	0
5160164	0	0,5	0	0,5	0
5160165	1	1	0,5	0,5	0,5
5160166	1	1	0,5	0,5	0,5
5160167	0	1,5	1	1	0,5
5160168	0	1	0	0,5	0
6160154	0	1	0	0,5	0
6160155	0	1	0	0,5	0,5
6160156	0	1	0	0,5	0
6160157	0	1	0	1	0,5
6160158	1	1,5	0	0,5	0,5

Table 11 – Pipe characteristics

Melt number	Metallographic examination of pipes (non-metallic inclusions according to GOST 1778)									Corrosion testing		
	SO	PO	BS	PS	NDS	S	SN	PN	AlN	CSR, %	CLR, %	CTR, %
5160162	2,5	2,5	2,5	2,5	2,5	2,25	1,5	1,5	1,5	0	0	0
5160163	2,5	2,5	2,5	2,5	2,5	2,25	1,5	1,5	1,5	0	0	0
5160164	2,5	2,5	2,5	2,5	2,5	2,25	1,5	1,5	1,5	0	0	0
5160165	2,5	2,5	2,5	2,5	2,5	2,25	1,5	1,5	1,5	0	0	0
5160166	2,5	2,5	2,5	2,5	2,5	2,25	1,5	1,5	1,5	0	0	0
5160167	2,5	2,5	2,5	2,5	2,5	2,25	1,5	1,5	1,5	0	0	0
5160168	2,5	2,5	2,5	2,5	2,5	2,5	1,5	1,5	1,5	0	0	0
6160154	2,5	2,5	2,5	2,5	2,5	2,5	1,5	1,5	1,5	0	0	0
6160155	2,5	2,5	2,5	2,5	2,5	2,5	1,5	1,5	1,5	0	0	0
6160156	2,5	2,5	2,5	2,5	2,5	2,5	1,5	1,5	1,5	0	0	0
6160157	2,5	2,5	2,5	2,5	2,5	2,5	1,5	1,5	1,5	0	0	0
6160158	2,5	2,5	2,5	2,5	2,5	2,5	1,5	1,5	1,5	0	0	0
String oxides SO, Point oxides PO, Brittle silicates BS, Plastic silicates PS, Non-deformable silicates NDS, Sulfides S, String nitrides and carbonitrides SN, Point nitrides and carbonitrides PN, Aluminum nitrides AlN												

Conclusions

Thus, in the course of the work performed, a set of technological measures for smelting, extra-furnace treatment and casting of 13HFA steel was developed, ensuring a high level of resistance to hydrogen cracking.

A series of smelts carried out according to the developed technological indicators ensured the achievement of the main HIC indicators at the level of CLR and CTR = 0%.

The recommended parameters for smelting steel in the EAF are:

– reducing the oxygen content in steel before tapping from the EAF to 1300 ppm;

– feeding lime and fluorspar when tapping metal from the EAF.

These measures made it possible to reduce the content of non-metallic inclusions in steel, reduce the consumption of lime and fluorspar during extra-furnace treatment, and, as a result, improve the results in resistance to hydrogen cracking.

The recommended parameters for extra-furnace treatment are:

– reducing the duration of metal residence in the ladle to 160 minutes (from the tapping of steel from the EAF to feeding to the continuous caster).

– the calcium content in steel before feeding to the continuous casting machine should be at least 0.0020 % (with a recommended ratio of Ca/S = 1.5 - 2.0).

These measures made it possible to reduce the contact time of the metal with the ladle lining, which led to a decrease in the content of magnesium oxide inclusions.

It should be noted that when smelting steel, the ratio of Ca/S = 1.5 - 2.0 was not always maintained.

The recommended parameters for continuous casting are:

– changing the parameters of the secondary cooling of the continuous casting machine, in order to uniformly cool the billet and reduce the temperature heterogeneity of the billet surface to 40 ºC.

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ТӨМЕН ЛЕГИРЛЕНГЕН БОЛАТТЫ БАЛҚЫТУ КЕЗІНДЕГІ ТЕХНОЛОГИЯЛЫҚ ФАКТОРЛАРДЫҢ СУТЕГІ КРЕКИНГІНЕ ТӨЗІМДІЛІГІНЕ ӘСЕРІН ЗЕРТТЕУ

Соңғы онжылдықта мұнай-газ саласы коррозияға төзімді болат жіксіз құбырларға өте мұқтаж, бұл құрамында күкіртсутек пен басқа да агрессивті қоспалардың көп мөлшері бар мұнай өндірудің дамуына байланысты.

Сутегі крекингіне төзімділіктің жоғары көрсеткіштеріне қол жеткізудегі шешуші рөл металл емес қоспалардың түрін, санын, мөлшерін және морфологиясын, қоспалардың болу формаларын, металл емес артық фазалардың бөлінуін немесе құрылымдық компоненттерді ығайту әдістерін әзірлеу және қолдану болып табылады.

Авторлар «KSP Steel» ЖШС ҚФ кәсіпорнында 13хфа болатты балқыту және құюдың қолданыстағы технологиясына талдау жүргізді және сутегі крекингіне төзімділік көрсеткіштерінің жоғары деңгейін қамтамасыз ететін 13хфа маркалы болатты балқыту, пештен тыс өңдеу және құю бойынша технологиялық іс-шаралар кешенін әзірледі.

Әзірленген технологиялық көрсеткіштер бойынша жүргізілген жүзу сериясы CLR және CTR = 0 % деңгейінде HIC негізгі көрсеткіштеріне қол жеткізуді қамтамасыз етті.

Республикасы Ғылым және жоғары білім министрлігі Ғылым комитетінің 2024–2026 жылдарға арналған ғылыми және (немесе) ғылыми-техникалық

жобалар бойынша гранттық қаржыландыруға арналған конкурс бойынша гранттық қаржыландыру шеңберінде «Төмен көміртекті даму стратегиясын іске асыру кезінде баламалы тотықсыздандырғыштармен Темірді толық ала отырып, Қазақстан бокситтерін кешенді қайта өңдеу» АР23487674 жобасы бойынша жүргізілді.

Кілтті сөздер: төмен легирленген болат, сутегі крекингі, балқыту, пештен тыс өңдеу, үздіксіз құю.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ ТЕХНОЛОГИЧЕСКИХ ФАКТОРОВ ПРИ ВЫПЛАВКЕ НИЗКООЛЕГИРОВАННОЙ СТАЛИ НА СТОЙКОСТЬ К ВОДОРОДНОМУ РАСТРЕСКИВАНИЮ

В последние десятилетие нефтегазовая отрасль остро нуждается в стальных бесшовных трубах стойких к корррозионному разрушению, что связано с развитием добычи нефти содержащей большое количество сероводорода и других агресивных примесей.

Ключевая роль в достижении высоких показателей по стойкости к водородному растрескиванию отводится разработке и использованию методов управления типом, количеством, размером и морфологией неметаллических включений, форм присутствия примесей, выделений неметаллических избыточных фаз или упрочняющих структурных составляющих.

Авторами проведен анализ действующей технологии выплавки и разливки стали 13ХФА на предприятии ПФ ТОО «KSP Steel» и разработан комплекс технологических мероприятий по выплавке, внепечной обработке и разливке стали марки 13ХФА, обеспечивающих высокий уровень показателей по стойкости к водородному растрескиванию.

Проведенная серия плавок по разработанным технологическим показателям обеспечила достижение основных показателей HIC на уровне CLR и CTR = 0 %.

Исследования проводились в рамках грантового финансирования Комитета науки Министерства науки и высшего образования Республики Казахстан по конкурсу на грантовое финансирование по научным и (или) научно-техническим проектам на 2024–2026 годы по проекту АР23487674 «Комплексная переработка бокситов Казахстана с доизвлечением железа альтернативными восстановителями при реализации стратегии низкоуглеродистого развития».

Ключевые слова: низколегированная сталь, водородное растрескивание, плавка, внепечная обработка, непрерывная разливка.

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