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EXPERIENCE WITH FERROSILICOALUMINUM ALLOY DURING DEOXIDATION OF STEEL

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The article describes the process of deoxidation quiet and low-alloyed steel alloy ferrosilicoaluminum complex in comparison the existing, and with steel deoxidation technology with conventional alloys - ferrosilicon and secondary aluminum. A comparative analysis of quality steel, non-metallic inclusions metallographic studies and studies of the mechanical properties of the resulting steel was done. On a large array of experimental steel proved cost-effectiveness and feasibility of ferrosilicoaluminum during deoxidation quiet and low-alloyed steel.

Key words: steel, deoxidation, ferrosilicoaluminum, microstructure, mechanical properties

INTRODUCTION

At present time tasks of improving the quality of the metal and reducing its cost, using raw materials of regional origin, quality and efficacy of usage of non-inferior to foreign analogues are set before the metallurgical industry of Kazakhstan (JSC "ArcelorMittal Temirtau").

One of the ways in achieving the objectives is improving the quality of steel due to its complex deoxidation by alloys. It allows deoxidizing steel more deeply and by modifying non-metallic inclusions to get more favorable structure and consequently higher mechanical properties.

Such complex alloy among the others was developed by a group of Kazakh scientists [1].

Economic feasibility of smelting ferrosilicoaluminum is that high-cheap carbonaceous rocks of Ekibastuz coal and exclude the use of expensive coke are used as a raw material.

EXPERIMENTAL PART

Equipment and tools

Scavengers that have universal effect on the properties of steel, where the greatest application is received by ferromanganese, silicon manganese, ferrosilicoaluminum ingots are mainly used at steel plants as it is shown by industrial practice of steel deoxidation. During deoxidation of calm and alloyed steel the main role is played by ferrosilicon, aluminum and titanium. However, high burn rates of leading elements in these processes (aluminum - 85 %, silicon till 35 %, titanium till 50 %) make necessary the development of other methods of steel deoxidation. Such method is the application of reductants in complex, in one alloy. Process of efficiency is achieved by increasing the reactivity of the elements due to more favorable energy environment in which the reaction of components by dissolved oxygen in the molten steel is flown more completely. Amplification of complex deoxidizing action of alloy while using two or more reductants is called fuller form of complex deoxidation products [2].

The presence of the second metal oxide deoxidizer facilitates nucleation phase. So the positive effect of the second deoxidizer should manifest the greater degree the higher the difference in the interfacial tension of the molten oxides.

Taking into account the correlation between the value of the interfacial tension with molten iron oxide and forming them deoxidizing ability of reductants, the conclude that a significant reduction in the energy barrier for nucleation of oxides strong deoxidizer in the case when the second element has a substantially lower capacity deoxidizing can be done [3].

By selecting the composition of complex alloys the challenges of deep steel deoxidation, removal of deoxidation products from it and management of the composition of formed n/i can be met. Fulfilment of the given tasks will allow limiting the formation conditions of n/i such as corundum, sulfides, and mixtures of low-melting eutectics in the following stages of the movement after deoxidation of metal - casting and crystallization, as well as to influence their structure and properties.

Materials and methods

Pilot tests were carried out in several large series during deoxidation of steel produced in the 300 - ton converters. In this case present technology of steel deoxidation by traditional alloys was investigated - ferrosilicon (brand FS65) and secondary aluminum (brand AB87). A comparative analysis of the quality of steel

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deoxidizing by existing technology with metallographic studies of nonmetallic inclusions and research of mechanical properties of the resulting steel was conducted.

According to information received in relation to the conditions of steelmaking in BOF shop the technology was developed, according to which balance out experimental melting quiet and low-alloy steels with the definition of the optimal flow rate and composition of complex alloy grades ferrosilicoaluminum FS45A15, FS55A15 and FS60A20. The chemical composition of deoxidants is shown in Table 1.

Table 1 **Composition of deoxidants/ wt %**

Brand	Silicon, not less	Aluminum	Sulfur, max	Phosphorus, max
AB87	4,0	87,0	-	-
FS65	65,0	1, 0	0,004	0,003
FS60A20	60,0	17,5-22,5	0,020	0,070
FS55A15	50,0	12,5-17,5	0,020	0,070
FS45A15	40,0	12,5-17,5	0,020	0,070

Skillful alloys are used in the smelting of dead-melted brand steel 3sp and low-alloy brand 09G2S prevailing in the melting of these groups and subjected to deep deoxidation by silicon and aluminum-containing alloys. The chemical compositions of steels according to the standards are shown in Table 2.

Table 2 **Chemical composition of steels/ wt %**

Steel	C	Mn	Si	Al	Ti	S	P
3 sp	0,14-0,22	0,40-0,65	0,15-0,30	0,02-0,05	-	0,035	0,035
09 G2S	0,09-0,12	1,41-1,70	0,50-0,80	0,02-0,05	0,01-0,03	0,030	0,035

Deoxidation of dead-melted and low-alloy steels were carried out in the ladle during its release from the furnace by feeding of feed bins required to qualify for the specified amount of the composition of ferro-alloys in the form of a lump in the following sequence. At the beginning of discharge till the filling the bucket on ¼ the secondary aluminum of brand AB87 in the form of ingots was served by hands in the amount of 150 - 200 kg (33 % of the total number of 450 - 600 kg / fusion). Filling ¼ bucket supply of ferrosilicon and silicon-manganese (SiMn) with the remaining aluminum was done. The temperature of the steel production, depending on the steel grade and duration of melting is within 1 600 - 1 630^0 C, with the requirements of the instructions for dead-melted brands is 1 605 - 1 615^0 C and low-alloyed - 1 610 - 1 625^0 C.

Scavengers and alloying ferroalloys were introduced according to the norms in an amount determined by the rate of penetration into the desired chemical composition:

$$F = \frac{(C^i_{fin} - C^i_{de}) \times V \times 100}{C^i_f (100 - I^i)},$$

where F – supply amount of ferroalloy/ t; C^i_{fin} - average content of a given i-element in the finished steel/ %; C^i_{de} - element content in the steel before the deoxidation/ %; *V* – mass of metal produced in the bucket/ t; C^i_f - element content of ferroalloy/ %, I^i – intoxication element in reducing and doping/ %.

During the development of the technologies about 150 thousand tons of steel and the same amount of experienced steel produced by the current technology with the study of qualitative experimental metal in comparison with indicators of rolled steel deoxidized by the underlying technology were studied.

Particular attention was paid to the study of the influence of complex alloys on the nature of non-metallic inclusions in the metal structure and comparative analysis of the results of mechanical tests rolled out experimental and comparative steel. The cost-effectiveness of the technology of deoxidation of converter steel by complex alloys FSA rather than the traditional version - FS65 and aluminum brand AB87 is made.

RESULTS AND DISCUSSION

FS55A15 was used in the first series of industrial tests for deoxidation of brand steel 3sp and 09G2S, in the second series ferrosilicoaluminum FS60A20 was tested.

On the investigated The effect of replacement of ferrosilicon FS65 and parts of aluminum ingots alloys FSA on the degree of assimilation of silicon and aluminum was studied on the example of steel 3sp. Figure 1 shows the dependence of intoxication of silicon while deoxidation of the amount of injected silicon with the silicon from SiMn17.

Silicon intoxication at alloys with is higher than silicon, dispensed by ferrosilicon that the most likely associated with an increase in the deoxidizing ability of silicon introduced into the alloy composition of the complex in conjunction with aluminum. This is confirmed by dependencies in Figure 2, derived from the equations of the concentration of aluminum in the finished metal from the total deposited silicon.

As it is seen from the graphs, the residual aluminum content in the steel deoxidized by alloys with FSA is

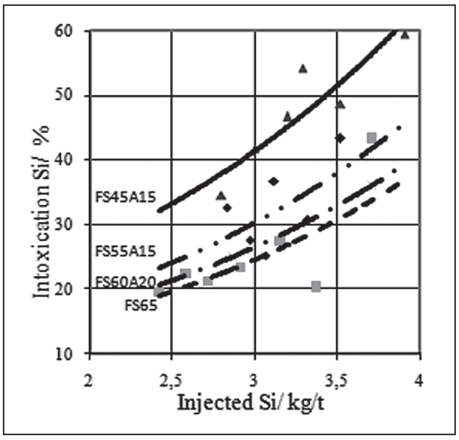

Figure 1 Dependence of silicon intoxication from dispensed silicon

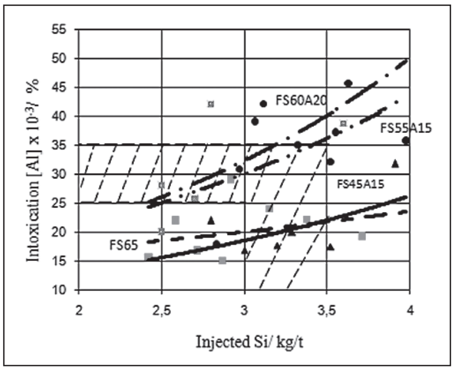

Figure 2 Dependence of $[Al]_{fin}$ from dispensed Si

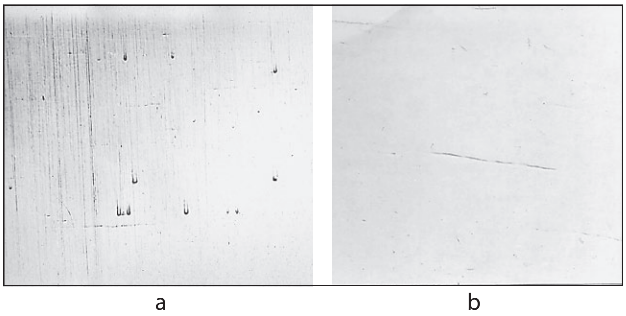

Figure 4 Non-metallic inclusions in steel deoxidized by FSA: *a*- corundum disoriented; *b* - sulfides, x100

higher than the aluminum content in the steel, deoxidized by the same amount of aluminum with ferrosilicon. Aluminum intoxication on experimental batches using FSA alloys fell to 70 % in comparison to 85 % for deoxidation of ferrosilicon.

Metallographic analysis of steels 09G2S and 3sp, deoxidized by FS65 showed the presence of non-metallic inclusions in the metal of several types: titanium nitride crystals in the form of a regular crystal form, orange color, located disoriented on thin section area reaching up to 1,5 points; thin rolled manganese sulfides (MnS) and iron (FeS) reaches up to 4 points, oriented along the direction of deformation in the form of broken lines, which under mechanical stress cracks, Figure 3 *a*. Small amounts of manganese sulfides, which are located in the form of films and membranes on nitride and point oxides forming oxysulfides are found, Figure 3 *b*. The most common (4,5 points) oxide is alumina oxides (Al_2O_3 - corundum), which are arranged in the form of individual, small groups (clusters), often in the form of long lines extending along the rolling direction, leading to a defect “bundle” on stage rolling and reduces the mechanical properties of steel, Figure 3 *c*.

In the studied samples of experimental metal out of steel 3sp and 09G2S, deoxidized by ferrosilicoaluminum FS55A15 brand it has been a sharp decline in concentration of corundum - from 4,5 to 2,0 points. Reducing the amount of corundum in steel has led to its more favorable distribution in theaters - single grains of corundum were located disoriented, not stitch, eliminating the occurrence of the defect “bundle”, Figure 4 *a*. It should be noted a significant decrease in points of sulfides (from 4 to 2,5 points), Figure 4 *b*.

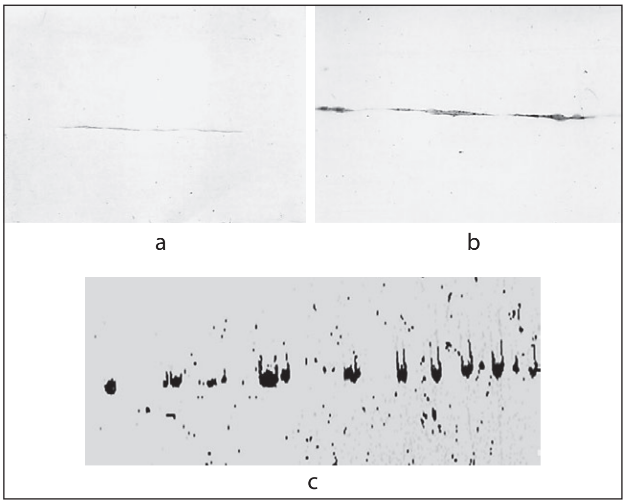

Figure 3 Non-metallic inclusions in steel deoxidized by FS: *a* – thin rolled sulfides; *b* – thin rolled oxysulfides; *c* - corundum stringers, x100

Thus the metallographic investigations of nonmetallic inclusions confirmed that the use of alloys integrated with active elements of FSA greatly reduces the amount of oxide inclusions and their size through formation of a fusible particles of oxides and sulfides readily assimilable by slag from the metal.

Table 3 shows the results of the assessment of pollution steel by points and types of non-metallic inclusions.

Table 3 **Metallographic analysis and microstructure of the steel 09G2S and 3sp, deoxidized by FS and FSA**

Type of deoxidation	Brand of steel	Number of experiments	Oxydes	Sulfides	Nitrides	Point of grain	Point of grain vidmanshtaten
FS	09G2S	11	3a	3,5a	16	9-10	2
FS	3 sp	11	3,5	4	1,5	8-9-10	1,5
FSA	09G2S	15	2	3	0,5	9-10	1
FSA	3 sp	18	2	2,5	0,5	9-10-11	2

Results of mechanical testing of samples of hot-rolled steel sheet of 3sp and 09G2S are shown in Tables 4 and 5. It shows that the majority of the heats alloys using FS55A15 FS60A20 in comparison to using FS65 is higher in indices of the mechanical properties characterized by the metal complex alloys deoxidized by FSA.

Thus the analysis of the mechanical properties shows that using the alloy FSA during deoxidation of the metal for processing of steels 3 sp and 09G2S is more efficient than using FS65 alloy; and the strength and plastic properties are improved by modifying oxysulfide inclusions in globular form more favorable by the formation of low-melting eutectic.

Table 4 **Mechanical properties of experimental and comparative heats of dead-melted steel 3 sp**

Type	Thick-ness/ mm	KCV/ J / m^2		
		temperature/ ^{0}C		After mechanical aging
		+20	-20	
FSA	> 4mm	95,6÷180 128,12	47,67÷95 64,95	41,7÷84 51,98
FS65	> 4 mm	97,6÷125,3 111,88	40÷80,67 64,52	40÷62,5 51,85
Type	Thick-ness, mm	*R*m/ MPa	*R*p$_{0,2}$/ MPa	*A*/ %
FSA	> 4mm	425,0÷635 494,76	265÷450 393,03	21÷37 29,38
FS65	> 4 mm	320,0÷595 490,5	240÷480 372,50	24,0÷43 29,18

Table 5 **Mechanical properties of experimental and comparative heats of low alloy steel 09G2S**

Type	Brand of steel/ mm	KCV/ J / m^2		
		temperature/ ^{0}C		
		+20	-40	-70
FSA	6	59,27 40÷83	74,64 54÷90	61,07 36÷74
	> 6	61,32 51,9÷90	68,92 48÷101	66,39 49÷86
	> 10	79,38 74÷85	80,50 79÷84	51,75 34÷76
FS65	6	58,85 38÷77	72,70 49÷97	61,18 10÷82
	> 6-10	67,17 45÷74	67,0 46÷83	58,90 41÷72
	> 10	59,50 40÷74	67,5 54÷80	42,25 34÷64
Type	Brand of steel/ mm	*R*m/ MPa	*R*p$_{0,2}$/ MPa	*A*/ %
FSA	6	529 500÷620	422 360÷515	32,5 25÷40
	> 6	492 440÷560	385 315÷440	30,7 27÷37
	> 10	464 435÷490	366 335÷390	30,3 26÷36
FS65	6	522 455÷570	413 370÷455	29,2 14÷38
	> 6-10	480 450÷530	367 335÷410	30,6 24÷35
	> 10	453 440÷475	348 325÷370	30,0 28÷30

CONCLUSIONS

Decrease of intoxication and increase of the digestibility of silicon and aluminum associated with an increased ability of deoxidizing silicon dispensed in complex composition with an aluminum alloy FSA.

Consumption of expensive aluminum ingots at experienced batches with FSA that decreased on average by 50 %, from 1,4 to 0,7 kg / t of steel.

Metallographic studies of non-metallic inclusions confirmed that the use of complex alloys lead to a significant reduction in the amount of oxide inclusions and their size through formation of a fusible particles of oxides and sulfides, deteriorating the quality of steel.

Increase of mechanical properties is due to the modification of oxysulfide inclusions in a more favorable globular shape through the formation of low-melting eutectic. Metal deoxidized by complex FSA alloy FS55A15 and FS60A20 in most trunks showed better mechanical properties in comparison with steel, traditionally deoxidized by ferrosilicon.

Thus cost-effectiveness and feasibility of ferrosilicoaluminum during deoxidation of dead-melted and low-alloy steels were proved on large array of experimental steel.

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