INFLUENCE OF THE BORON-CONTAINING FERROALLOYS COMPOSITION ON THE CHARACTERISTICS OF THE PROCESSED STEEL

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Abstract

The influence of the composition of boron-containing alloys: ferroboron and complex modifier (ferrosilicomanganese with boron) on the microstructure and mechanical properties of the processed steel is studied. High-temperature laboratory experiments on steel alloying with boron-containing ferroalloys have been carried out to obtain samples of the 26CrMoVN tube of steel. The degree of boron absorption by steel was studied using various boron-containing ferroalloys. The microstructure, mechanical characteristics and contamination with nonmetallic inclusions of the processed steel were determined. It is shown that the use of ferrosilicomanganese with boron allows to achieve a higher (82%) degree of boron absorption by metal in comparison with the use of standard ferroboron (44-52%). Also noted higher mechanical properties (tensile strength, yield strength, elasticity) of the resulting metal, greater purity of nonmetallic inclusions and stable results on the grain size of steel are noted, which is a good characteristic of the complex modifier influence on the structure of the processed metal.

Keywords: *Metallurgy, boron, steel, structure, properties, ferroalloys, microalloying*

1. INTRODUCTION

Microalloying of steel with boron is one of the most promising areas of improving the quality of rolled metal. In modern metallurgy there has been a tendency to expand the range and increase the production of boron-containing steels. This growth is observed both in the smelting of high-strength and wear-resistant steels and in the production of relatively new high-strength pipe steels, low-carbon steels for deep drawing and high-strength martensitic steels for the manufacture of responsible units for vehicle [1-4].

The influence of boron as an alloying element is associated with the formation of nitrides and iron borides in steel [5-11]. With an elevated (more than 0.01%) content of boron in steel, its quality deteriorates due to precipitation of iron borides along the grain boundaries. In the literature there are different views on the meaning of the optimal boron content in steel. The amount of boron, introduced into the metal, depends on the steel grade, its deoxidation level and the composition of the boron-containing ferroalloy [1, 5, 12, 13]. Limits of boron content in steel are usually indicated from 0.0005 to 0.01%, but the majority of researchers consider the optimal concentration to be 0.001-0.003% V.

Boron is introduced into the steel mainly in the form of ferroboron with 17-20% of boron, as well as various complex alloys. The best results on the microalloying of boron steel are achieved when it is introduced into the metal simultaneously with other alloying elements (Nb, V, Mn, Si) [7, 14, 15].

It is reasonable to have 1-3% content of boron in complex ferroalloys, which makes it possible to increase the amount of the introduced alloy, increasing the reliability and stability of boron absorption. In addition, the technology of obtaining such alloys is simplifying.

Previously, we studied main physicochemical characteristics (melting temperature ranges, density) of complex boron-containing ferroalloys of the Fe-Mn-Si-B system [15, 16]. It was revealed that the melting start temperature (Ts) for ferroboron grade FeB 17 ranges from 1400 to 1550°C, the density is 6700-6750 kg / m^3. The density and Ts values of ferrosilicomanganese with boron (FeSiMnB) and without boron of grade FeMnSi 17 are close and equal to ~ 6,150 kg / m^3 and 1190 ° C, respectively. This is the best performance (compared with FeB 17) in terms of alloy application for steel processing

and the absorption of ferroalloy elements by steel. Selection of new composition [17] of the complex alloy FeSiMnB is related to its optimal physicochemical characteristics, high activity of silicon and manganese, to the presence of these elements in all steel grades (which expands the field of application of this alloy), and is related to the widely developed ferrosilico-manganese production, the simplicity of bor introduction into the alloy and low cost of complex boron-containing ferroalloys.

2. MATERIALS AND METHODS

To evaluate the efficiency of steel microalloying by boron with ferroalloys of different composition (Table 1), the original samples of 26CrMoVN tube steel were used. The chemical composition of ferroalloys is shown in Table 1. The chemical composition of the original steel is shown in Table 2.

Materials	**Content, %**					
	Mn	**Si**	**Fe**	**C**	**Al**	**B**
Ferrosilicomanganese FeMnSi 17	69.15	16.0	10.07	1.5	-	-
Ferroboron FB17	-	1.09	other	-	0.23	18.12
FeSiMnB	68.70	15.74	10.94	1.6	-	0.70

Table 1. Chemical composition of ferroalloys

C	**Mn**	**Si**	**Cr**	**Ni**	**Mo**	**V**	**S**	**P**
0.25	0.55	0.55	0.89	0.06	0.15	0.04	0.006	0.012

Table 2. Chemical composition of the original steel, %

3. RESULTS AND DISCUSSION

Studies on the liquid steel treatment with boron-containing ferroalloys were carried out in a special high-temperature laboratory facility [18] using three ways of deoxidation with:

- boron-containing ferrosilicomanganese FeSiMnB (Table 3, items 1 and 2);
- ferroboron FeB 17 and ferrosilicomanganese FeMnSi 17 (Table 3, items 3 and 4);
- ferrosilicomanganese FeMnSi 17 without the introduction of boron in steel (Table 3, item 5).

№	**Ferroalloys consumption from the steel mass, %**			**Content in steel, %**			**Boron absorption, %**
	FeMnSi 17	FeSiMnB	FeB 17	B	Mn	Si	
1	-	0.613	-	0.0035	0.727	0.449	82
2	0.21	0.397	-	0.0020	0.699	0.649	72
3	0.61	-	0.0247	0.0020	0.891	0.532	44
4	0.61	-	0.0161	0.0015	0.707	0.611	52
5	0.61	-	-	-	0.687	0.610	-

Table 3. The indicators of steel microalloying with boron

Ferroalloys additives were made in accordance with the calculation of introduction of equal amount of manganese, silicon, and obtaining 0.002-0.004% boron in steel (Table 3).

From the data in Table 3, it can be seen that the introduction of boron into the metal by the complex FeSiMnB alloy increases the degree of its absorption compared to the ferroboron to 1.6 times (on average from 48 to 77%). The obtained results on the degree of boron absorption from the ferroboron FeB 17 match with the known literature data of 40-60% [2, 5].

The increased degree of boron absorption during the use of a complex FeSiMnB alloy is apparently associated with a high concentration of deoxidizing elements (Si and Mn) in the local melting zone and dissolution of the alloy, which reduces the oxidation state of boron.

The steel samples obtained after microalloying were subjected to strength and plastic properties tests. Mechanical test results of the steel test samples, depending on the way of deoxidation, are presented in Table 4.

№ *	Strength characteristics **, MPa		
	σ_B	$\sigma_{0.2}$	σ_e
1	647-665	569-588	506-556
	656	579	531
2	678-680	614-637	579-607
	679	626	593
3	614-664	614-646	557-593
	639	630	575
4	608-655	592-622	544-577
	632	607	561
5	547-571	524-547	492-525
	559	536	509

* Sample numbers correspond to the numbers given in Table 3.

** The numerator shows the range of values, the denominator - the average of values.

Table 4. Strength characteristics of steel samples

The results of the samples tests of steel, microalloyed with boron, showed that at close values of relative elongation, their indicators on the tensile strength σ_B, yield stress σ_{02} and the elastic limit σ_e are much higher than in the steel samples without boron (Table 4). Moreover, the samples of steel, microalloyed with boron with the use of the complex ferroalloy FeSiMnB (Table 4, items 1 and 2) are characterized by higher values of the strength characteristics in comparison with the way of ferroboron and ferrosilicomanganese application (Table 4, items 3 and 4)).

The contamination with nonmetallic inclusions (*I*) of deoxidized steel samples was studied. Contamination *I* was calculated by the formula:

$$I = \frac{b \Sigma a_i \cdot m_i}{l},$$

Where b - smallest grading of the ocular scale;

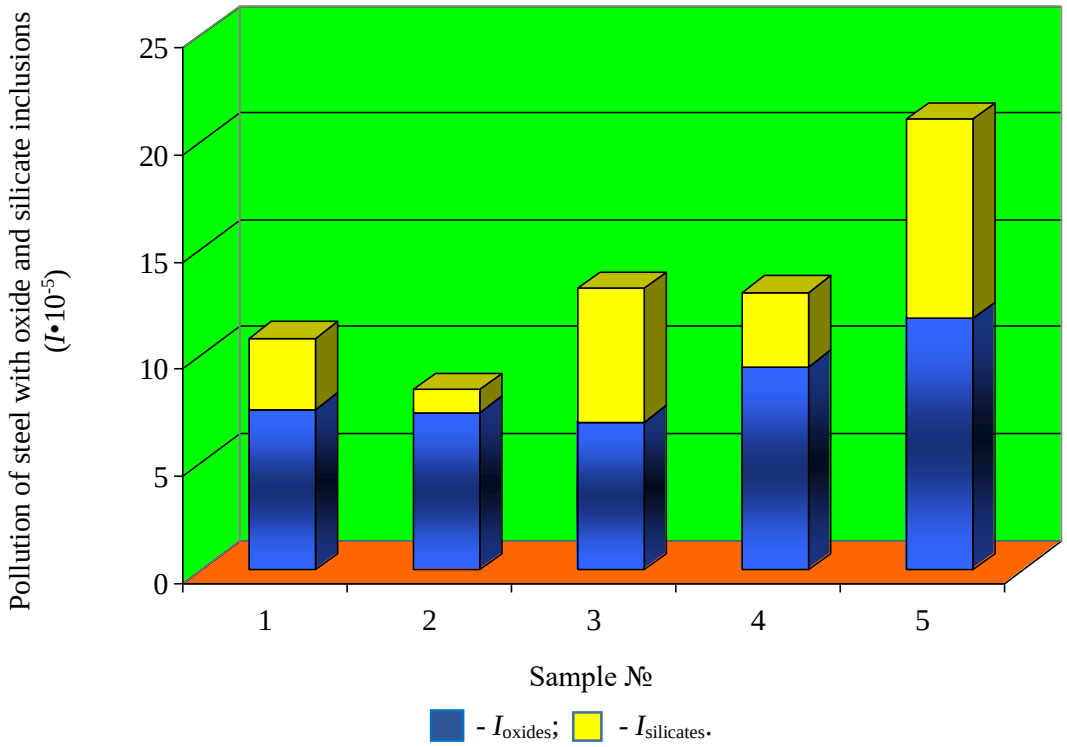
a_i - the average value of inclusions sizes in ocular scale grading;

m_i - number of inclusions of this group;

l - calculation length.

Regardless of the deoxidation way, the prototypes of steel are characterized by a low (no more than 0,001 of unit) pollution level with nonmetallic inclusions. The main distinguishing feature of metal samples without boron additives is the presence of large inclusions reaching 200 μm. In the experimental samples of steel containing boron, the majority of nonmetallic inclusions are represented by small inclusions up to 6 μm in size.

Contamination of steel samples with oxide (I_{oxides}) and silicate ($I_{silicates}$) inclusions is shown in the Figure. Steel samples that do not contain boron (Table 3, sample 5) are characterized by a high level of contamination with silicate inclusions, and have large sizes (reaching 200 μm), which have a negative effect on the mechanical properties of the steel. In the experimental samples of steel containing boron, silicate inclusions are mostly much smaller, not exceeding 2 μm.



Sample numbers correspond to those given in Table 3.

Fig. 1. Contamination of steel samples with oxide and silicate inclusions

The size of oxide inclusions in the investigated metal samples, as a rule, is not more than 6 μm. In the experimental samples of steel, deoxidized by a complex alloy FeSiMnB, the values of the I_{oxides} coefficient are stable and are 7.36-7.51, while for the samples of the metal deoxidized by ferroboron and ferrosilicomanganese this coefficient is in the range 6.94-9.49, that on average is 5.8% more than for steel, deoxidized by a complex alloy FeSiMnB.

The grain size of the deoxidized steel samples was studied. When studying the structure of samples of undeformed steel smelted without boron, there was found a large number of grains of different size. The difference between minimum and maximum grain size reaches 5 points (Table 5, sample 5).

Samples*	Grain size, μm		Grain point (GOST 5639-65)		Point divergence
	min	max	min	max	
1	28	75	4	7	3
2	34	56	6	7	1
3	31	81	4	7	3
4	20	70	5	8	3
5	16	89	4	9	5

* Sample numbers correspond to the numbers given in Table 3.

Table 5. The grain size of undeformed steel samples

Boron-containing steels (Table 5, Samples 1-4) are characterized by more stable grain size results. The divergence between the minimum and maximum size does not exceed 3 points. And the best result (the divergence between the grain sizes reaches 1 point) is obtained on steel, alloyed with a FeSiMnB alloy, which is a good characteristic of the influence of the complex modifier on the structure of the processed metal.

The hardness of deoxidized metal samples was studied. Its alteration was revealed depending on the way of deoxidation in the range from 157 to 236 HB. At the same time, the most stable results were obtained for boron-containing steels, deoxidized by the FeSiMnB alloy, reaching 210-227 and 227-236 HB, respectively, for samples 1 and 2 (Table 3). The scatter of hardness values varies from 9 to 17 units. Samples of metal, deoxidized by ferroboron, have a range of hardness values 15-25 units, and samples without boron additives have the largest difference in hardness along the fiber direction, reaching 61 units, which can be explained by the heterogeneity of the structure and the presence of large inclusions.

4. CONCLUSIONS

The results of the performed studies showed the high efficiency of the new complex FeSiMnB alloy. A significant increase in the degree of boron absorption from a complex alloy was revealed in comparison with application of the traditional ferroboron. According to the mechanical properties and structure, the prototypes of steel alloyed with the FeSiMnB alloy are equal, and in some respects exceed the characteristics of steel doped with ferroboron. In this connection, it can be concluded that it is most expedient to introduce boron into steel not by ferroboron, but by complex alloys with Si, Mn and other active elements, which agrees with the results of the other authors investigations [5]. Wide application of complex boron-containing ferroalloys will allow to expand the brand composition and production volume of boron-containing steels and, as a result, to increase the competitiveness of steel products by improving its quality at minimum costs.

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