

Conference Paper

Metallothermic Production of Boron-containing Silicon Barium

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Abstract

Silicon barium is an effective modifier for ferrous and non-ferrous metals. In Kazakhstan, it is produced at the Aksu Ferroalloy Plant, but its smelting volumes are significantly lower than those of traditional ferroalloys, moreover, it is melted only to order. To improve the consumer properties of silicon barium, we proposed to introduce boron to it, possessing a high effect of a positive impact on the quality of metals at low (0.001–0.003%) concentrations. The core of the proposed technology is reduced to pouring out silicon barium from the ore-smelting furnace into a ladle with boron-containing oxide material. Silicon and barium of the molten metal were assumed to reduce boron from B_2O_3 in accordance with such reactions, for instance: $4Si + 2B_2O_3 = B_4Si + 3SiO_2$ and $10Ba + 3B_2O_3 = BaB_6 + 9BaO$. We have carried out a complete thermodynamic analysis of the proposed technology using the TERRA software package, having enriched its database with the compounds anticipated in the products of smelting. A possibility of fulfilling the technology in principle has been established. It has been found that a share of barium participation in the recovery processes increases with increasing its concentration in the metal being poured off from the furnace. The experiments using an industrial sample of ferrosilicobarium have been carried out in a high-temperature laboratory furnace. The recovery of boron was within the limits of 48–71%, showing its progressive fall while attempting to obtain a metal with a higher boron content. Judging by the weight loss of reducing agents in the metal being poured off, barium is the main participant in the process. Based on thermodynamic and physical simulation, we have made a conclusion on the possibility to obtain a boron-containing silicobarium by the metallothermic method in a ladle and necessity to carry out industrial testing.

Keywords: modification, silicon barium, boron, ladle

1. Introduction

Modification and microalloying are an effective means of enhancing the performance characteristics of ferrous and non-ferrous metals. As a modifier, barium is widely used. It

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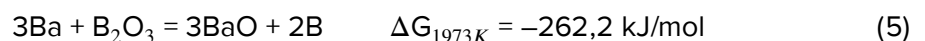
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has a low solubility in iron (0.0003%) and to overcome this threshold it is produced in the form of alloys with silicon or aluminum. In the first case, well-soluble silicide (BaSi , BaSi_2) are formed in iron and therefore such alloys are called silicon barium or ferrosilicon with barium. Due to the joint efforts of the Russian and Kazakh specialists, the production of such alloys was established at the Yermakovskiy (now Aksu) ferroalloy plant [1–5]. But the production volumes of silicon barium are much lower than those of traditional ferroalloys and melt it in the presence of orders. To increase the consumer properties of silicon barium, exploratory studies have been conducted on the introduction of boron into it, given the high effect of its positive influence on the quality of ferrous metals at low (0.001-0.003%) concentrations [6, 7]. The essence of the technology is merging from the ore-smelting furnace of silicon barium into the ladle with boron-containing oxide material. This method of production of boron-containing ferrosilicon under the guidance of professor Zhuchkova V.I. was developed and successfully used at the Serov Ferroalloy Plant [8, 9].

2. Modeling Silicon Barium with Boron using the TERRA Software Package

In the present work, it was assumed that silicon and barium of molten metal will reduce boron from B_2O_3 borate ore:



In the expectation of obtaining 1 mole of boron, the average value of the Gibbs energy change in silicon reduction reactions (1) - (6) is 11.9 kJ/mol, and barium (5), (6) - 150.3 kJ/mol. It can be concluded that silicon, especially barium, will vigorously reduce boron. But in conditions of real smelting, besides those indicated above, other reactions may occur that can change the process.

For this reason, we performed a complete thermodynamic analysis of the proposed technology at a temperature of 1973K using the TERRA software [10], replenishing its database with the compounds expected in the smelting products [11, 12]. The composition adopted for the calculation of the initial metals merging from the furnace is shown in Table 1.

TABLE 1: The chemical composition of the initial alloys.

N°.	Element content, g		
	Fe	Si	Ba
1	34	65	1
2	33	65	2
3	30	65	5

The composition of the planned to obtain metals is shown in Table 2.

TABLE 2: The chemical composition of the planned alloys production.

N°.	Element content, g			
	Fe	Si	Ba	B
1	33	65	1	1
2	32	65	1	2
3	31	65	1	3
4	32	65	2	1
5	31	65	2	2
6	30	65	2	3
7	29	65	5	1
8	28	65	5	2
9	27	65	5	3

Pure B_2O_3 was used as a boron source. The calculations on the software package TERRA give the phase composition of the smelting products. Then it was counter on element. The composition of the obtained metal for all nine variants of the calculation is shown in Table 3.

It can be seen that with the bucket method, high boron extraction is achieved. Both silicon and barium are involved in this, which can be seen from the loss of their weight at the end of the process. Moreover, at low levels of barium in the starting metal (1-2%), its participation in recovery processes is significantly inferior to silicon, increasing at high (alloys 7–9, Table 3).

TABLE 3: Chemical composition of metal.

N°.	Element content, g				Weig., г	Relative decline, %		Boron extraction, %
	Fe	Si	Ba	B		Si	Ba	
1	34	63,05	0,99	0,98	99,02	3	1	98,0
2	34	61,10	0,99	1,98	98,07	6	1	99,0
3	34	59,15	0,99	2,99	97,13	9	1	99,7
4	32,9	63,05	1,99	0,99	98,93	3	0,5	99,0
5	33	61,11	1,99	1,99	98,08	6	0,5	99,5
6	33	59,14	1,99	2,99	97,12	9	0,5	99,7
7	30	63,34	4,11	0,99	98,44	3	17,8	99,0
8	29,9	61,18	4,23	1,98	97,29	6	15,4	99,0
9	29,9	59,15	4,26	2,97	96,28	9	14,8	99,0

3. The Experiments in a Laboratory Resistance Furnace

When using the initial metal with 10, 20 and 30% barium to obtain 2% boron in the final metal, the barium weight loss is 57.7; 38.1 and 25.7%. The observed can be explained by an increase in the proportion of barium in the reduction process in the merging metal, despite its connection to disilicide ($BaSi_2$) (Table 4) [11]. It has been carried out experiments in a laboratory resistance furnace. An industrial sample of ferrosilicobarium of the Aksu Ferroalloy Plant containing (mass%): 15 Fe, 63 Si, 22 Ba was used. There have been obtained three samples of metal of different composition (Table 5), with the addition of pure iron (Fe) and crystalline silicon (Si) into alloy.

TABLE 4: The composition of the initial ferroalloys.

N°.	Alloy	The composition of the alloy, the mass, %					
		Chemical			Phase		
		Fe	Si	Ba	$BaSi_2$	Si	FeSi
1	ΦC65	35	65	-	-	47,4	52,6
2	ΦC65Ba1	34	65	1	1,4	47,5	51,1
3	ΦC65Ba2	33	65	2	2,8	47,6	49,6
4	ΦC65Ba5	30	65	5	7,0	47,9	45,1
5	ΦC65Ba10	25	65	10	14,1	48,3	37,6
6	ΦC65Ba20	15	65	20	28,2	49,3	22,5
7	ΦC65Ba30	5	65	30	42,3	50,2	7,5

Planned to get shown in Table 6 alloys.

TABLE 5: The chemical composition of the initial alloys.

N°.	Element content, mass.%		
	Fe	Si	Ba
1	34	65	1
2	33	65	2
3	30	65	5

TABLE 6: Chemical composition of alloys planning for production.

N°.	Element content, mass.%			
	Fe	Si	Ba	B
1	33	65	1	1
2	31	65	2	2
3	27	65	5	3

Reactive B_2O_3 was used as a boron source. Attempts to carry out experiments by pouring the molten metal from the furnace into a graphite crucible with boron oxide were not successful. The stock of heat of the hot metal was not enough to pass recovery processes. A porous slag-metal mixture was obtained. The reason for this is a large heat sink due to the high ratio of the cooled surface of a thin-walled crucible to its volume. Therefore, the mixture of silicobarium and B_2O_3 was briquetted and melted in the furnace at 1973K. The results of the experiments are shown in Table 7.

TABLE 7: The chemical composition of the experimental metal.

N°.	Content in the alloy, the masses, %				Relative decline, %		Boron extraction, %
	Fe	Si	Ba	B	Si	Ba	
1	31,6	64,02	0,69	0,71	1,5	31	71
2	30,6	60,4	1,5	1,2	7,1	25	60
3	24	63,1	2,4	1,8	2,9	52	48

Boron extraction was in the range of 48-71%, showing its progressive fall when trying to produce metal with a high boron content. Viewing by the weight loss of reducing agents in the merging metal, barium takes the main part in the process.

4. Conclusion

Thus, thermodynamic and physical modeling shows the possibility of obtaining boron-containing silicon barium by the ladle metallurgical method. The final conclusion can be made after the planned industrial tests.

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