

EXPERIMENTAL MELTING OF HIGH-SILICON FERROMANGANESE WITH THE USE OF FERROMANGANESIAN ORE AND MANGANESE SLAG

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Preliminary Note – Prethodono priopćenje

This work presents the results of smelting ferromanganese from high-silica iron-manganese ores with 36 % manganese content by the flux method. The Shubarkol deposit coal and metallurgical coke as reducing agents were used. The fluxing material was solid slag from the smelting of medium-carbon ferromanganese. The technological modes of the smelting process are established. The optimal composition of the charge was determined. As a result of the theoretical and experimental studies, the tasks have been solved completely - the smelting technology of high-silicon ferromanganese was developed and tested using a substandard raw materials, such as iron-manganese ores and flux.

Keywords: ferroalloys, high-silicon ferromanganese, ore-thermal smelting, substandard raw materials, chemical composition

INTRODUCTION

The steady growth of world steel production observed in recent decades is associated with the inherently growing demand of the metallurgical industry for ferroalloys. The most used today are manganese-containing ferroalloys (high- and low-carbon ferromanganese, ferrosilicon manganese, metallic manganese, etc) [1].

Today, it is interesting and relevant to obtain high-silicon ferromanganese using non-traditional ferromanganese ores and manganese slag for this process. Interest arose in connection with the steady depletion of reserves and the high cost of manganese-containing raw materials.

It is known that for the carbon ferromanganese FeMn75 and FeMn78 grade production requires high-quality concentrates with at least 43 and 50 % manganese content, respectively. The Mn/Fe ratio must be at least 8 [2-4].

Standard carbon ferromanganese, according to GOST 4755-91 must contain no more than 2 % of silicon. Therefore, the ratio of SiO_2/Mn in manganese-ore raw materials should be equal to 0,3 and 0,2 for the smelting of carbon ferromanganese, respectively, grades FeMn75 and FeMn78. Manganese ores with SiO_2/Mn ratio greater than 0,4 are not applicable [5-6].

The study of the process of obtaining ferromanganese with a high silicon content (6-8 %) is particularly relevant today. This alloy can be used for deoxidation of

quiet steel, where the presence of silicon facilitates the deoxidation process. The production of ferromanganese from iron-manganese ores with a ratio of silicon to manganese greater than 0,4 is appropriate due to its cost-effectiveness due to the use of cheap substandard raw materials. Thus, the purpose of this work is to research using of iron-manganese ores and slag from the medium-carbon iron-manganese smelting of instead of standard expensive raw materials for ferromanganese smelting.

RESEARCH METHODOLOGY

In real industrial conditions, refined ferromanganese is obtained from manganese ore, low-phosphorous manganese slag or silicomanganese withlime, where lime binds silica to calcium silicates [7]. In this paper, tests for ferromanganese smelting were carried out using iron-manganese ores with a high content of silicon from the Bogach and Yessymzhal deposits.

Chemical composition of Bogach and Yessymzhal ore deposits, which were used for experimental tests are presented in Table 1 and Table 2, respectively.

Metallurgical coke and long – flame gas coal of the Shubarkol deposit as a reducing agent were used. Technical analysis of Shubarkol deposit coal and metallurgical coke is shown in Table 3. Chemical composition of coal ash / %: SiO_2 – 60 - 64, Al_2O_3 – 30 - 35. Specific heat of coal burning is 7 500 – 8 000 thousand kcal/kg. Specific consumption of high-ash coal per 1 ton of ferroalloy was 2,72 t.

The fluxing material was solid slag from of the medium-carbon ferromanganese smelting with 22 – 24 %

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Table 1 **Chemical composition iron-manganese ore with a high content of silicon from the Bogach deposit**

№	Name of the sample	Content / %				
		Mn _{total}	Fe _{total}	SiO ₂	Mn/Fe	SiO ₂ /Mn
1	Sample of Mn ore 1	30,11	8,35	18,72	3,61	0,62
2	Sample of Mn ore 2	33,8	4,97	23,0	6,80	0,68
3	Sample of Mn ore 3	26,53	6,87	17,52	3,86	0,66
4	Sample of Mn ore 4	35,51	5,98	14,13	5,94	0,40

Table 2 **Chemical composition iron-manganese ore with a high content of silicon from the Yessymzhal deposit**

№	Name of the sample	Content / %				
		Mn _{total}	Fe _{total}	SiO ₂	Mn/Fe	SiO ₂ /Mn
1	Sample of Mn ore 5	39,30	6,52	18,53	6,03	0,47
2	Sample of Mn ore 6	28,17	19,32	16,87	1,46	0,60
3	Sample of Mn ore 7	34,11	7,64	15,64	4,46	0,46
4	Sample of Mn ore 8	29,23	4,50	19,61	6,50	0,67

Table 3 **Technical analysis of the Shubarkol deposit coal and metallurgical coke**

Material	Technical analysis / %			
	W (moisture)	A (ash)	V (volatile matter yield)	Cs (solid carbon)
Shubarkol deposit coal	1,78	29	12	46
Metallurgical coke	1,28	12,18	2,0	84,92

MnO content and a basicity of 1,3 – 1,5. Additional charging by other materials was not done.

Tests on the smelting of high-silicon ferromanganese were carried out at the experimental site of the Chemical and metallurgical Institute named after J. Abishev on an ore-thermal furnace, which is equipped with a two-phase step-down furnace with 0,2 MVA transformer capacity. The secondary voltage varies between 18 - 50 V (six steps), the current on the high side reaches 789 A. Lining the inner surface of the furnace with fireclay and magnesite refractory bricks, with filling the seams with fireclay powder, coking the pilot block, preparing the electrode holder, graphite electrodes and nipples was part of the preparation of the ore-thermal furnace for melting.

Prepared a flying hole at the bottom at the level of the bottom for the release of metal. The filling of the furnace bottom is carried out at a slight angle in the direction of the pilot hole, which provides an easier exit of the melt from the recovery zone. The temperature in the reaction zone reaches 2 500 – 4 500 °C is provided by



Figure 1 Release of ferromanganese from the 0,3 MVA furnace

the discharge of an arc of a graphite electrode with 200 mm diameter.

The furnace was heated for 8 hours using a coke pillow as an electric current conductor. At the end of the heating period, the bath was completely cleared of the remains of the coke pillow. Electric mode of the heating period: voltage 49 V, load on the electrodes 100 - 200 A.

After the initial heating period and the formation of a garnissage on the walls of the furnace, the formation of the crucible shifted slightly towards the right electrode because the main arc burning occurred under it. The current load was stable at 380 - 430 A. The charge collapsed by self-propelled, which indicates the presence of a gas cavity under the grate, which also contributed to the easy cutting of the pilot hole.

The melting process was periodic with an average duration of 1 - 1,5 hours, i.e. the charge is loaded after the release and set of current load. The charge settled by itself as it was melted, forming a slag bath in the center of the furnace. During melting, the current load was kept evenly ($I = 150 - 250$ A), and no emissions were observed on the grate. The slag was liquid and active. After melting the charge, the slag and metal were released from the pilot hole (Figure 1). The metal and slag were separated well after cooling.

During operation, no serious deviations from the normal course were observed. The landing of the electrode was quite deep and stable, no sintering of the grate was observed. Metal and slag came out actively, which confirmed the hot course of the process as a whole.

The alloy was produced in cast-iron mills, the average weight of the alloy piece is 11-15 kg, the alloy does not crumble. To average the alloy, grinding was performed on a jaw crusher, where the formation of fines (fractions less than 10 mm) is no more than 10 % of the total mass.

After cooling, the molten metal was subjected to rapid analysis using a portable Niton X-ray-fluorescence analyzer to monitor the melting process and charge composition.

RESULTS RESEARCH

Selectively, individual samples were submitted for a full chemical analysis of the main elements. The results of chemical analysis of experimental samples of slag and metal are presented in Table 4 and Table 5, respectively.

According to the results of experimental work on the smelting of high-silicon ferromanganese, the following was established:

- the multiplicity of slag is 2,1 - 2,3;
- manganese extraction rate 79 - 81 %
- the degree of silicon recovery is 18 - 22 %.

In the process of smelting high-silicon ferromanganese using iron-manganese ore and manganese slag, the furnace operation was characterized by a stable current load. The landing of the electrode was sufficiently deep and stable, and the top was not sintered. Metal and slag came out actively, which confirmed the hot course of the process as a whole.

Thus, as a result of experimental melting, an experimental batch of ferromanganese alloy with a high con-

tent of silicon was developed. The alloy which was obtained by the experimental melting in ore-thermal furnace is characterized by the following chemical composition / %: Mn - 73 - 76, Si - 5,7 - 9,09, P - 0,07-0,131; S - 0,0026 - 0,0039; C - 2,2.

Also, possibility of achieving the minimum content of 3,3 - 3,4 % MnO in waste slags was shown.

CONCLUSION

Thus, as a result of experimental melting, an experimental batch of ferromanganese alloy with a high content of silicon was developed. The experimental alloy was obtained using substandard materials as the charge. Such materials as iron-manganese ores of Bogach and Yesymzhal deposits were used. The slag from the smelting of medium-carbon ferromanganese as fluxing materials was used. Metallurgical coke and long-flame gas coal from the Shubarkol deposit were used as reducing agents.

The tests have shown that for the smelting of high-silicon ferromanganese corresponding to the FeMn75 grade for manganese, it is possible to use manganese ores with a Mn/Fe ratio of less than 8 and SiO₂/Mn ratio of more than 0,4, which significantly reduces the requirements for the quality of the initial manganese raw materials.

Experiments on smelting were carried out in an ore-thermal furnace with a transformer capacity of 0,3 MVA. This study has shown the possibility of smelting carbon ferromanganese, standard for the main element, from high-silica ferromanganese ores with a content of less than 36% of manganese by the flux method. At the same time, as a fluxing and low-iron manganese additive, it is possible to use a solid slag from the smelting of medium-carbon ferromanganese with a content of 22 - 24 % MnO and a basicity of 1,3 - 1,5.

Engaging for ferromanganese smelting substandard raw materials allows to exclude traditionally used silicomanganese brand SiMn17 and SiMn26. In this rough comparative economic evaluation of traditional and developed technology shows that the cost of 1 t of ferromanganese in the studied technology will be significantly lower than traditional.

The data obtained by us give grounds to make a tentative conclusion about the possible economic and technological feasibility of obtaining ferromanganese with a high content of silicon from high-silica ferromanganese ores and manganese slags.

To establish the economic and technological efficiency of this alloy, it is necessary to conduct further research and implement it in real production conditions as a deoxidizer and modifier of steel.

The obtained data will further allow us to develop a comprehensive and resource-saving technology for smelting a new type of manganese-containing Ferroalloy, which can be used in the steel industry, in particular for deoxidizing steel and other types of steel.

Table 4 **Chemical composition of metal samples obtained from experimental smelting of high-silicon ferromanganese**

№	Content / %				
	Mn	Fe	Si	S	P
1	75,1	11,71	5,91	0,0039	0,131
2	76,0	11,77	4,57	0,0032	0,100
3	75,0	10,37	4,88	0,0039	0,096
4	74,8	11,04	5,60	0,0032	0,092
5	75,1	10,76	5,98	0,0039	0,081
6	74,3	10,71	9,09	0,0039	0,073
7	72,8	12,32	7,34	0,0038	0,092
8	74,1	10,48	9,02	0,0032	0,081
9	74,3	10,04	8,98	0,0038	0,092
10	75,0	10,48	5,71	0,0026	0,112

Table 5 **Chemical composition of slag obtained as a result of experimental smelting of high-silicon ferromanganese**

№	Content / %							
	MnO	Fe _{total}	SiO ₂	Al ₂ O ₃	CaO	MgO	S	C
1	7,9	0,38	36,47	7,32	42,26	0,15	0,095	0,078
2	16,3	-	35,36	5,19	43,82	-	0,115	0,230
3	3,7	0,27	27,90	4,45	57,91	-	0,217	5,317
4	7,0	1,26	21,55	4,17	54,78	0,08	0,231	4,283
5	3,4	0,44	27,21	6,35	54,78	0,01	0,134	3,150
6	3,8	0,27	29,00	6,01	52,43	0,06	0,117	3,308
7	3,3	0,055	29,97	7,31	56,34	0,01	0,141	1,776
8	3,7	0,27	27,90	4,45	57,91	-	0,217	5,317
9	4,0	1,26	21,55	4,17	54,78	0,08	0,231	4,283
10	5,4	0,49	25,14	5,95	54,65	-	0,186	4,311

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Note:The responsible translator for English language is Nataliya Drag, Karaganda, Kazakhstan