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MELTING OF FERROSILICON MANGANESE WITH THE USE OF HIGH ASH ROCK COAL AS A REDUCING AGENT

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A study of the process of smelting ferrosilicon manganese with the use of high ash rock coals as a reducer instead of traditional coke was carried out. The physicochemical properties of coke from high-ash coals of the Kuu-chek deposit have been studied. The fundamental possibility of its application for the production of standard ferrosilicon manganese in large-scale laboratory conditions has been shown.

Keywords: melting, ferrosilicon manganese, ore thermal furnace, coke, reducing

INTRODUCTION

Currently, ways of using of various carbonaceous reducing agents for the electrothermy of ferroalloys is known [1 - 5]. However, the reducing agents that are used in the production of ferroalloys are either unstable in their physicochemical properties and therefore do not satisfy the specifics of the process, or are limited in terms of production. Typically, ferroalloy factories cover their needs for reducing agents at the expense of scarce blast furnace coke and the waste generated during its sorting. One of these wastes is coke nut, which is the main type of carbonaceous reducing agent used in the production of ferroalloys.

Nevertheless, the one and the other, possessing high mechanical strength, have low reactivity and electrical resistivity. The results of numerous studies and factory practice indicate that when smelting ferroalloys in electric furnaces, especially silicon ferroalloys, the course of the technological process differs significantly when using different carbon-reducing agents, even with the same carbon content in them.

This is due to the variety of properties of carbon materials, on the one hand, and the complexity and specificity of the reduction process in the production of various alloys, on the other. Kazakhstan has large reserves of mineral raw materials, in particular, manganese ores and coal, as well as the necessary production capacities [6,7] Thus, the purpose of this work was to research on the use of high-ash coke from coal from the Kuu-chek deposit instead of coke nut for ferrosilicon manganese smelting.

RESEARCH METHODOLOGY

The high-ash coals of the Kuu-Chek deposit are poorly sintered. Coal coking was carried out in a laboratory shaft furnace with a volume of 0,04 m^3 by the thermal-oxidative pyrolysis method [2,8]. The process of obtaining coke proceeded in the autothermal mode, in which high-speed thermal-oxidative treatment of the coal charge was provided, due to selective combustion in a layer of volatile substances. The duration of coking depended on the height of the coal charge, this in a laboratory installation reached 400 - 600 mm. In this case, in contrast to layer coking, a charge consisting of fractionated coal with a particle size of 40 - 60 mm is subjected to thermal-oxidative pyrolysis, and the initial coal size is practically preserved in the resulting coke, which, as a rule, has a higher reactivity with sufficiently high lump strength indicators. Switch over to coking mode in the laboratory installation is consisted in a gradual rise in temperature in the coal bed to 900 - 1 000 °C due to the heat from the combustion of volatile substances. An experimental 600 kg of coke batch was produced.

To assess the behavior of high-ash coke under conditions of ferrosilicon manganese electric smelting, large-scale laboratory tests were carried out in an “RKO-0,2 MVA” ore-thermal furnace. This is a single-phase ore thermal furnace with a transformer capacity of 0,2 MVA. The furnace is designed to simulate the processes of ore electrothermia. Two transformers in the furnace with 100 kVA capacity are connected in parallel, provide a power of 200 kVA at a maximum voltage of 49,0 V and a current load of up to 4 000 A. The electric furnace is equipped with four stages of secondary voltage regulation - from 18, 24, 36 and 49 V. Arc discharge temperature 2 500 - 4 500 °C. The furnace has two electrodes with a diameter of 150 mm, and the lower electrode is rigidly coked in a hearth made of a conductive packing. The upper electrode is fixed in a copper contact jaw placed on a current-insulated suspension. Moving the electrode in the vertical plane is done manually. The electrical mode is monitored through an ammeter connected to the high side of the furnace transformer. The furnace bath is stationary and has one taphole equipped with a graphite taphole block. The furnace is of the open type and is equipped with an exhaust

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hood located at a height of 700 mm from the upper cut of the furnace body. The process gas removal system is equipped with a cyclone and a bag filter for dust collection. The surface of the hearth is inclined at an angle of 5 - 7 ° in the direction of the tap hole, which facilitates the exit of metal from the recovery zone. For opening and piercing the taphole, a piercing system with a graphite electrode 30 mm of diameter was installed. The lining of the furnace is made of refractory bricks. Clay plugs are used to close the tap hole. Melting in the furnace is carried out continuously, with periodic loading of charge materials as they are melted. The release of smelting products is periodic, every 2 hours.

RESULTS RESEARCH

To determine the physicochemical properties and strength characteristics of Kuu-chek coke, a general representative sample weighing 40 kg was taken from the batch produced in accordance with GOST 23083-78. The granulometric composition of the finished coke was determined by sieving into four fractions. They are 0 - 5, 5 - 10, 10 - 25 and 25 - 40 mm. The results of the granulometric analysis of coke are presented in Table 1. Technical analysis of coke ash by fractions (25 - 40, 10 - 25, 5 - 10 and 5 - 40 mm) are shown in Table 2

Chemical analysis of the average fraction ash 5 - 40 mm coke / %: SiO_2 - 62,01; Al_2O_3 - 22,32; CaO - 6,12; MgO - 0,62; Fe_{total} - 6,18; S - 0,23; P - 0,02. The reactivity of coke and its strength after the reaction is determined according to GOST P 54250-2010 (ISO 18894:2006). The coke reactivity index CRI / % by weight is 26 %. The coke strength after the CSR reaction is 43 %. The strength of the coke body (structural) was assessed by the yield of + 1 mm class, formed in a steel cylinder with a volume of 50 cm^3 from coke of 3 - 6 mm class according to GOST 9521-74. The strength of the coke body is high, 86 %. The porosity of the coke was established according to GOST 10220-82. The porosity is amounted 33 %. The proportion of fine pores (iodine number) is 16 %. For the pilot campaign, representative samples of manganese ores from the Yesymzhal, Bogach, Arman deposits and fluxes were prepared. The chemical composition of samples is shown in Table 3. The waste of the reducing agent on the top of the furnace was 10 %. The calculated slag ratio was 1,025.

Table 1 **Granulometric composition of Kuu-Chek coke**

Fractions / mm	25 - 40	10 - 25	5 - 10	0 - 5
Output / %	23,06	69,64	5,24	2,06

Table 2 **Technical analysis of coke by fractions**

Fractions / mm	Technical analysis / %			
	W (moisture)	A (ash)	V (volatile matter yield)	Cs (solid carbon)
25 - 40	1,27	32,23	1,28	65,11
10 - 25	1,41	32,16	1,05	65,38
5 - 10	1,34	45,35	2,26	41,05
5 - 40	1,35	33,90	1,32	63,42

The electric furnace was heated for 12 hours on a coke bed. Electric mode of the heating-up period: secondary voltage 18,4 V, current on the high side of the transformer 100 A. At the end of the heating-up period, the furnace bath was cleared of the remains of the coke bed and the charge began to be loaded. Taking into account the energy intensity of the ferrosilicon manganese smelting process, the optimal secondary voltage for this furnace is 24 V. After the end of the heating period, the furnace was switched to the indicated stage until the end of the trial campaign. Smelting was carried out continuously, with charging the charge in small portions as the top shrinks, with a periodic release of metal every 2 hours. The tap hole was pierced with a metal rod. The metal of each release was weighed, after which a sample was taken for analysis. Based on the results of the chemical analysis of the smelting products, the composition of the charge was adjusted and the degree of extraction of silicon and manganese was calculated.

The composition of the charge was / kg: Esymzhal ore – 10,0; Bogach ore – 8,0; Arman ore – 2,0; coke Kuu-check – 5,4; lime – 1,8; quartzite – 1,2. This composition of the charge was subject to correction based on analyzes of the slag and metal to achieve the optimal basicity of the slag in (CaO + MgO) / SiO_2 at the level of 0,6. According to the known practical data [9], this basicity creates favorable conditions for the reduction of manganese and provides sufficient fluidity of the slag to exit the furnace. It should be noted that the high ash content of Kuu-chek coke is more than 30 % and the ash content of over 60 % of silica can significantly reduce the specific consumption of quartzite, which can be up to 400 kg / t of metal [9]. During a stable period, all indicators (current load, electrode fit, top temperature and condition, charge descent, metal and slag temperature, etc.) of the furnace were within the normal range for this process. The oven was running stably, with no signs of deviations from normal operation.

The furnace productivity in this period was close to the calculated one and averaged 4,8 kg / hour or 9,6 kg per outlet. Slag multiplicity slightly exceeded the calculated value and averaged 1,05. If at the initial stage the average content of manganese and silicon was 53 % and 11 %, respectively, then within the stable period these indicators reached 69 % and 18 %, respectively, which fully meets the requirements of GOST 4756-91 for grade MnSi17.

The main indicators of the pilot campaign are shown in Table 4. The productivity of the furnace, the specific consumption of raw materials, the quality of the metal, achieved using Kuu-chek coke as a reducing agent, are not inferior to the parameters of industrial furnaces. The extraction rates of manganese and silicon were 87,2 % and 38,9 %, respectively. This exceeds the known practical data.

CONCLUSION

Coke Kuu-chek has a satisfactory technical and chemical composition. In terms of particle size distribu-

Table 3 **Chemical composition of charge materials / %**

Material	V^c / ignition losses	W	S	Mn_{total}	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5
Yesymzhal ore	11,55	0,77	0,023	30,18	29,71	3,22	5,18	2,00	1,23	0,33
Bogach ore	10,52	1,50	0,034	30,59	26,54	3,00	8,50	1,50	1,72	0,08
Arman ore	9,56	1,54	0,019	34,01	23,91	1,94	7,13	2,50	1,48	0,10
Quartzite	-	0,50	0,03	-	96,52	1,69	0,50	0,42	0,34	0,02
Lime	32,20	0,74	0,002	-	0,64	0,16	0,14	65,71	0,38	0,025

Table 4 **Technical indicators of the smelting process of ferrosilicon manganese MnSi17 with Kuu-chek coke**

Indicators	Units /	Value
Voltage step	V	24
Transformer power	kV·A	200
Total running time	day	5
amount of metal produced	kg	345,8
amount of slag produced	kg	413,2
Slag multiplicity	–	1,05
Extraction of Mn	%	87,2
Extraction of Si	%	38,9
Aurnace output	kg / hour	4,8
Raw materials consumed / kg		
Yesymzhal ore	522,5	
Bogach ore	416,6	
Arman ore	104,3	
Kuu-Chek coke	296,4	
Lime	147,0	
Quartzite	25,2	
Average chemical composition of metal / %		
Si	18,09	
Mn	69,59	
C	2,2	
P	0,11	
S	0,018	
Average chemical composition of slag / %		
MnO	12,55	
SiO_2	36,24	
CaO	23,43	
Al_2O_3	12,44	
Fe_2O_3	1,02	

tion and mechanical strength indicators, coke is a high-quality carbonaceous material for smelting ferrosilicon manganese and fully meets the requirements for reducing agents in ferroalloy production. High-ash coke Kuu-chek has a high electrical resistivity and contributes to the improvement of the furnace stroke, deep electrode fit, and high extraction of leading elements. Ash of Kuu-chek coke contains more than 60 % silicon dioxide, which is a positive sign of this material, as it allows to reduce the consumption of quartzite used in industrial smelting of ferrosilicon manganese. The alumina content of more than 20 % in coke ash leads to increasing in the temperature of the slag formation onset and the formation of relatively refractory alumina slags. This will lead to an increase in the temperature of the process. This favors the intensification of the electrothermal process of smelting ferrosilicon manganese.

As a result of large-scale laboratory tests a pilot batch of ferrosilicon manganese was obtained. The 385,8 kg of alloy was produced. The slag ratio was 1,05. The chemical composition of the metal / %: Mn - 69,59; Si - 18,09; P - 0,11; S - 0,018; C - 2,2. This composition corresponds to ferrosilicon manganese grade MnSi17 in accordance with GOST 4756-91. The extraction rates of manganese and silicon were 87,2 % and 38,9 %, respectively.

Thus, according to the results of the provided studies, the fundamental possibility of using Kuu-chek high-ash coke for smelting ferrosilicon manganese was shown.

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