Conference Paper

Development of Smelting Technology of Complex Ferroalloy with the Use of High-ash Coals

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Abstract

The article presents the results of studies that contribute to solving the problem of extraction of aluminum from the ash part of high-ash coals and its further application in ferrous metallurgy. Technologies of obtaining multicomponent complex alloys, including ferrosilicon aluminum, aluminosilicate manganese, and aluminum-silicon-chrome were described in detail. These complex alloys are designed for deoxidation and partial alloying of steel, as well as for the metal-thermal production of various ferroalloys. The main charge material for their production is high-ash coals, which are not used in the national economy and belong to man-made waste. The content of solid carbon in high-ash coals is sufficient for the passage of all reduction reactions, which eliminates the use of expensive coke from the process chain. The use of cheap materials and the refusal to use metallurgical coke allows smelting complex alloys at a relatively low cost. The article also presents the results of a series of large-scale laboratory and pilot tests on the smelting of the above complex alloys using high-ash coals from various coal basins of Kazakhstan. A detailed analysis was made to identify the advantages and disadvantages of the developed technologies in comparison with their analogues.

Keywords: complex alloy, high-ash coal, ferrosilicon aluminum, aluminum-silicon-chrome, aluminum-silicon-manganese, slag-free process

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1. Introduction

High-ash coals are of little use in the fuel and energy complex, the national economy and refers to man-made waste. Thousands of tons of high-ash coals can serve as cheap raw materials for the smelting of complex alloys based on Si, Al, Fe, Cr, Mn, Ca, Ba, having in its composition a number of useful components.

For ferrous metallurgy, a major consumer of primary aluminum, it is possible to significantly expand the raw material base for aluminum, as more than half of the world's coal reserves are high-ash. One ton of high-ash coal contains more than 140 kg of alumina (Al_2O_3). Due to the developed technologies, alumina can be extracted from the ash

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part of the coal into the composition of complex alloys, which are further used in the production of steel and metal-thermal production of various ferroalloys.

Promising and deeply studied among all methods for producing complex alloys from waste coal industry is the technology of smelting ferrosilicon aluminum (FSA) containing Si, Al and Fe. Production of FSA is based on carbothermal reduction of the mineral part of high-ash (48–65%) carbonaceous rocks and quartzite without the use of coke in open furnaces of ore-thermal type. FSA smelting is characterized by a slag-free, continuous process with periodic release of the alloy for every 2–2.5 hours. The amount of oxy-carbide with inclusions of metal slag beads does not exceed 3–5% of the mass of the reduced metal.

Depending on the requirements of the consumer, the composition of ferrosilicon aluminum varies between: 45–60% Si; 8–25% Al; the rest – iron. Its vintage and chemical composition of the regulated TU 14-5-233-99. It is used as a deoxidizer in the production of calm and low-alloy steel grades in converters and electric furnaces, as well as a metal reducing agent in metallothermy.

In ferrous metallurgy, steelmaking is the main consumer of silicon and aluminum. With an annual volume of steel production in the world of about 1.6 billion tons, the use of silicon and aluminum in the global metallurgical industry can be estimated at more than 5 million tons and 1.5 million tons, respectively, in terms of pure metal. To obtain the specified amount of silicon and aluminum, a significant amount of pure natural raw materials is spent: kaolinite, quartz, bauxite and coke, as well as more than 110 billion kWh of electricity.

Traditionally, when producing calm and alloyed steel grades in the steelmaking process, ferrosilicon grades FS65, FS75 and primary aluminum or secondary aluminum containing 80–85% aluminum are used for processing.

At the same time, their production technologies are energy-intensive, requiring high costs in the preparation of raw materials for melting. For example, only the cost of electricity for the smelting of ferrosilicon FS75 and aluminum is 8–10 thousand and 15–20 thousand kWh per 1 ton of products, respectively. Since the deoxidation of a significant part of the steel is carried out by a mechanical mixture of ferrosilicon and aluminum, it is possible to observe the oxidation of silicon and aluminum on the surface of the liquid steel with air oxygen, while their use in the form of an alloy would reduce their losses. The transition to the deoxidation of steel ferrosilicon aluminum involves a significant expansion of the raw material base of production of silicon and aluminum, because their source in this case is unlimited reserves of coal in the world.

It is this problem that led to the search for effective and cheap ways to obtain ferrosilicon alloys with aluminum from technogenic waste (coal ash, coal preparation waste, etc.), which would correspond to their mechanical mixture used in the deoxidation of steel. The presence of such an alloy, along with its cheapness, would provide a low carbon dioxide of aluminum and silicon, a deeper cleaning of steel from non-metallic inclusions, since the interaction of fused ferrosilicon and aluminum with oxygen in the volume of steel are born easily floating liquid aluminosilicates. Whereas when using pure ferrosilicon and aluminum, refractory and hard-to-remove oxide inclusions (silica and corundum) are formed in the volume of liquid steel.

At high temperature reduction of the charge consisting of carbonaceous rock and quartzite necessary for neutralization of excess carbon, numerous competing reactions of reduction, oxidation, removal of gaseous products, carbide formation, etc. occur simultaneously in the furnace.

Depending on the physical condition of the charge materials, their temperature and the degree of recoverability, the furnace bath can be divided into a number of zones:

- zone of solid charge materials (500–1400°C);
- zone of softened materials (1400–1800°C);
- zone of slag melt (1800–2200°C);
- zone of the molten metal.

Due to the full thermodynamic analysis of the processes at high-temperature coal melting with the help of special software systems, data were obtained, which allowed to radically revise all technological approaches and develop methods for the process of obtaining ferrosilicoaluminium in ore-thermal furnaces. Almost all industrial tests at Aksu (electric furnace with capacity of 1,2 MBA), Aktobe (furnace 4,5 MBA) ferroalloy and Ural aluminum (furnace 7 MBA) plants, as well as furnaces 9 and 23 MVA of LLP "KSP Steel" (Pavlodar), were carried out taking into account these data and were aimed at finding ways to manage the above phenomena. As a result, established the main technological parameters and methods of implementation of the process, getting almost the entire range ferrosilicoaluminum from brands FS45A10 to ФС65А20 from carbonaceous rocks of the coal basins of Kazakhstan, providing easy to manage the smooth running of furnaces with high technical and economic indicators. The extraction of silicon and aluminum amounted to 93.8 and 82.8%, respectively, and the power consumption within 11.2–11.4 MV per ton of metal. Table 1 presents the technological parameters of FSA smelting from various high-ash coals in electric furnaces with the power of transformers 1,2–5,0 MV·A.

TABLE 1: Technological parameters of FSA smelting.

N°.	Indicators	Furnaces			
		1,2 MV·A		5,0 MV·A	
		Borly CR	Ekibastuz CR	Borly CR	Ekibastuz CR
1.	Useful power, kW	592	542	1590-1815	1370
2.	Secondary voltage, V	74,5	68,2	110-137	110
3.	Productivity, t/day	1,26	1,0	3,37	2,7
4.	Specific consumption of materials:				
	carbonaceous rock, t	2,86	2,3	2,9	2,54
	quartzite, t	0,61	0,66	0,63	0,78
	iron shavings, t	0,115	0,23	0,12	0,153
5.	Alloy obtained, t	3,77	3,0	10,1	8,1
6.	The chemical composition of the alloy, %				
	Si	58-60	49-52	57-58	54-56
	Al	20-22	15-16	18-20	17-19
	Fe	14-16	31-33	18-20	25-28
7.	Specific energy consumption, MWh/t	10,4	11,2	10,8	11,2
8.	Extraction Si, %	81	79	80	76
9.	Extraction Al, %	74	73	73	72

At the same time, to determine the market, as well as to facilitate the introduction of the alloy in steelmaking, almost the entire volume of the alloys was tested in various metallurgical and foundry industries, with the deoxidization of steels of grades 10SP, 3SP and casting grades with complete replacement of ferrosilicon, and with a decrease (in some cases with the exception) of secondary aluminum consumption with improved steel quality for the content of harmful impurities, the distribution of non-metallic inclusions and reducing of their sizes.

For the first time serial production of FSA was started in 1998 in the conditions of Ekibastuz mini-plant in three ore-thermal electric furnaces with a capacity of transformers 1,2 MVA (1 furnace) and 5 MBA (2 furnace). The products of the mini-plant were supplied to Kazakhstan and Russian metallurgical plants for processing of calm and low-alloy steel grades.

To confirm the previously obtained results, in 2010 additional tests of FSA grades FS45A15 and FS65A20 were carried out at various steel plants in Kazakhstan, Russia, Turkey and China.

On the basis of the FSA production technology, the Institute developed a technology for the production of aluminosilicate manganese using high-ash coals and substandard manganese content of high-silicon manganese ores of Central Kazakhstan. These manganese ores contain up to 45% silica, even when melting on silica manganese process is characterized by an increased slag ratio, which dramatically reduces the technical and economic indicators. Repeated tests carried out in large – scale laboratory conditions allowed to establish the principal possibility of obtaining a wide range of aluminosilicate manganese containing in its composition: Si – 28–45%; Al – 8.2–16%; Mn – 28–30%; Fe – 10–25%; P – 0.03–0.032% depending on the scope of application. This alloy composition meets the requirements for its further use in the production of steel and refined grades of ferromanganese.

It should be noted that work on the development of technology for the smelting of AMS using a variety of carbon - and where the manganese containing materials have been carried out earlier [1, 2]. The AMS alloy smelted according to previous technologies, after release during cooling, crumbled to a powdery state due to a small amount of aluminum and an increased (up to 1.25%) phosphorus content in the alloy. Such a powdered alloy had to be briquetted, that is, there was a need for additional costs. Further studies have shown that the phenomenon of spillage of the molten metal can be avoided by using low-phosphorous and high-alumina coals.

In the ChMI also developed the technology of producing aluminum-silicon-chrome (FASCh), which is intended for production of steel and medium-carbon grades of ferrochromium. The flowchart of FASCh is very simple and is almost indistinguishable from the technology of standard silicon-chrome. Technology of silicon-chrome as the charge materials used: coke, quartzite and high-carbon FCh (or metal concentrate), and during the smelting of FASCh, instead of coke, high-ash coal. The composition of FASCh for silicon and chromium is the same as that of silicon-chrome, but additionally contains up to 12–15% Al. In the future, this aluminum, when using FAS in the process of obtaining refined ferrochrome, goes into slag and radically changes its phase composition. In the CaO–MgO–Al2O3–SiO2 system, the phase composition of the slag moves from the region of bicalcium silicate to the region of helenite, which makes it possible to obtain non-crumbling slags. In addition, due to the high activity of FASCh (where $\sum$ = Si + Al $\geq$ 60%), the slag basicity can be maintained at Cao/SiO2 = 1.5–1.6, against to 2.

From literature data of the known analog aluminum-silicon-chrome – alloys AChS [1, 2], resulting from poor chrome ores and uncindery and befuraline one-stage method using as a reducing agent of Ekibastuz coal.

In the smelting of aluminum-silicon-chrome as the charge materials used: high-ash coals of the Karaganda basin, related to anthropogenic wastes and are unsuitable as fuel in the national economy; quartzite of deposit ”Tekturmas”; substandard screenings from crushing high-carbon ferrochrome.

The ash of high-ash coal contains a sufficient amount of silica and alumina, which are the main source of silicon and aluminum, and the carbon content in the coals is sufficient to ensure all the reduction reactions in the furnace bath. Thus, in this process chain expensive coke is excluded, and quartzite is used to neutralize excess carbon.

The charge of the complex AChS alloy consists of two components: poor chromium ores of the Don mining and processing plant and Ekibastuz coal. Along with the importance of their involvement in metallurgical redistribution, a number of shortcomings should be taken into account. More than 20% of MgO is present in Kazakhstan chrome ore. As is known, the magnesium reduction reaction takes place at high (about 2000°C) temperatures. Naturally, a significant amount of electricity and reducing agent is spent on its restoration. The reduced magnesium does not dissolve in the metal, but rises from the reaction zone of the furnace. According to the calculation of the heat balance of the melting AChS alloy, heat consumption for the reduction of MgO and the sublimation of magnesium is 12–16% of total arrival of the heat. To exclude this problem, instead of chromium ore in the process of obtaining aluminum-silicon-chrome, it is necessary to use screenings of high-carbon ferrochrome (HFCh), as in the traditional technology of melting ferrosilicochrome FChS48. Table 2 shows the indicators of the processes of obtaining aluminum-silicon- manganese and aluminum-silicon-chrome in a variety of ways and from the same raw materials.

Smelting technology of both alloys is produced practically in the so-called slag-free mode. The high extraction of silicon and aluminum during the smelting of aluminosilicochrome is explained, firstly, by the fact that the charge materials have a high melting point; secondly, the volatile suboxides of silicon and aluminum are captured by the filter layer of the cold charge and returned to the reaction zone. Therefore, in real conditions, much attention is paid to the processing of the charge on the furnace top.

Thus, under the conditions of the Chemical and metallurgical Institute, high-ash varieties of coal and carbonaceous rocks of various coal mines were studied from the point of view of their use for smelting complex ferroalloys. The most interesting physico-chemical properties and industrial power from the point of view of their use for the production of complex ferro-alloys are high-ash coals of deposits ”Borly” and ”Saryadyr” Karaganda and Teniz–Corioconsole coal basins, respectively. Table 3 presents charge materials to produce alloys of ferrosilicoaluminum (FSA), aluminum-silicon-manganese (FASM) and aluminum-silicon-chrome (FASCh).

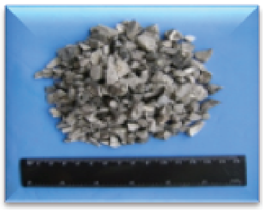
Thus, on the basis of the results of laboratory, large-laboratory and pilot tests conducted by scientists of the Institute, technologies for producing complex ferroalloys were

Table 2: Technical and economic indicators of smelting of aluminum-silicon-manganese and aluminum-silicon-chrome.

Indicators	Melting options			
	Aluminum-silicon-manganese		Aluminum-silicon-chrome	
	FASM	AMS [1]	FASCh	AChS [3]
Number of issues	7	216	12	109
Set charge, kg				
- high-ash coal (Saryadyr/Ekibastuz/Borly)	116,5		240	25500
- manganese ore	49,6		-	-
- chrome ore	-	-	-	22867
- screenings of high-carbon ferrochrome	-	-	51,5	-
- quartzite	-	-	74	-
Alloy obtained, kg	42,0	15600	142,1	11655
Average output weight, kg	6,0	72,2	11,8	106,9
Average alloy composition (wt. %)				
Si	33,8	26,9	51,8	21,4
Al	12,6	2,8	13,8	7,8
Mn	25,4	50,2	-	-
Cr	-	-	17,7	42,6
Fe	22,7	18,6	13,6	-
Mg	-	-	-	0,23
P	0,02	0,06	0,03	-
Ca	1,10		0,2	-
C	0,10		0,5	-
S	0,003		0,004	-
Material consumption per 1 t of alloy, t:				
- high-ash coal	2,80		1,69	1,7
- manganese ore	1,20		-	-
- chrome ore	-	-	-	2,0
- screenings of high-carbon ferrochrome	-	-	0,37	-
- quartzite	-	-	0,52	-
Electricity, MWh/t	7,81	10,5	5,52	9,9
Extraction in an alloy, %:				
Si	80,2	77,8	82,7	66,7
Al	76,0	14,6	72,2	45,6
Mn	85,0	75,0	-	-
Cr	-	-	81,8	88,4
Fe	97,5		97,7	-
P	48,7		43,2	-
Ca	13,0		5,4	-

developed, which will be used in the production of steel and metal-thermal melting of refined grades of ferroalloys.

Table 3: Charge materials for FSA, FASM, and FASCh alloys.

The type of alloy	**Charge components**		
FSA	 High-ash coal		 *Quartzite*
FASM	 High-ash coal		 *Manganese ore*
FASCh	 High-ash coal	 Quartzite	 *Screenings of high-carbon ferrochrome (h/c FCh)*

References

[1] Druinski M.I. and Zhuchkov V.I. (1988). Formation of complex ferroalloys from mineral raw material of Kazakhstan. Alma-Ata: Nauka.

[2] Medvedev, G.V. and Takenov T.D. (1979). Alloy AMS. Alma-Ata: Nauka.

[3] Medvedev, G.V., Sadkovskaya Ye.F., Lappo S.I., Gruzinov V.K. and others. (1969). Semi-skilled melting of AChS alloy (aluminum-chromium-silicon) from a poor chrome ore and Ekibastuz coal//Complex processing of iron, manganese and chromite ores of Kazakhstan, 139–143. Alma-Ata.