

## ANNOTATION

of dissertation for the degree of Doctor of Philosophy PhD  
in the specialty 6D070900 - "Metallurgy"

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### **Research and development of technology for smelting of ferrosilicoaluminum from raw materials of the Kuu-Chekinsky coal field**

**The relevance of the study** is due to the fact that at the moment the smelting of a complex ferrosilicoaluminum (FSA) alloy in the conditions of the Republic of Kazakhstan is not performed.

In connection with the construction of a ferroalloy plant («Karaganda Complex Alloys Plant» LLP) on the industrial site of the Sary-Arka free economic zone (Karaganda city), the use of coal raw materials from the Kuu-Chekinsky coal field closest to the plant will be economically justified. Commercial coals of this section are mined for use in energy purposes, but their use in ferroalloy processing has not been carried out. Therefore, one of the promising areas is the smelting of high-silicium grades of FSA containing 60-65% silicium and 9-15% aluminum from coal with an ash content of 40-45%. These grades of alloys (FS65A10 and FS65A15) were not produced and the technology of their smelting has not been developed.

Despite the industrial development of the technology for smelting ferrosilicoaluminum, the mechanism and areas of alloy compositions that tend to disintegrate have not yet been established. This significantly reduces the technical and economic indicators of production. To solve this problem, it is necessary to carry out a set of theoretical and experimental studies using thermodynamic-diagrammatic analysis of the Fe-Al-Si system.

FSA alloy was mainly used for processing ordinary and low-alloy steel grades. To establish the fundamental possibility of using FSA for processing alloy steel grades, it is necessary to conduct pilot tests with the study of the mechanical properties of the final steel product.

The implementation of the tasks set in the dissertation will allow us to assess the applicability of a coal from the Kuu-Chekinsky coal field and develop a technology for smelting high-silicium grades of FSA. Determine the mechanism and areas of alloy compositions that are susceptible to spillage, and in addition, establish the possibility of using FSA for processing alloyed steel grades.

**Objective.** Investigation of coals from the Kuu-Chekinsky coal field and development of technology for smelting high-silicium FSA grades, as well as determination of stable alloy compositions based on thermodynamic-diagram analysis of the Fe-Al-Si system.

**Research objectives.** In accordance with this goal, the following complementary tasks were solved in the dissertation:

- to investigate the comparative physicochemical and electrophysical properties of high-ash varieties of coal from the Kuu-Chekinsky coal field and the compositions of the phases formed in the bulk of coal in the temperature range 750-1650 °C;
- to clarify the possible mechanism and the beginning of the reduction reactions of silicium and aluminum oxides during the smelting of the FSA alloy;
- to determine the possible mechanism of disintegration of the FSA alloy of individual compositions on the basis of thermodynamic diagrammatic analysis of the Fe-Al-Si system;
- conducting laboratory research and industrial tests to establish the possibility of using FSA alloy for processing alloyed steel grades Cr40 and 30CrNi2Mo;
- to work out the technological modes of smelting high-silicium grades of FSA (FS65A10 and FS65A15) based on large-scale laboratory tests in an electric furnace which has a capacity of 200 kVA

**Scientific novelty.** In this dissertation work for the first time:

- physicochemical studies of high-ash varieties of coal from the Kuu-Chekinsky coal field were carried out and an assessment was made of the applicability for smelting a ferrosilico-aluminum alloy in comparison with previously used coal raw materials from other coal fields;
- on the basis of studies under high-temperature heating conditions, the mechanism of phase transformations in the volume of high-ash coal has been determined for the first time, and the temperature of the beginning of silicium dioxide gasification and the formation of silicium carbide and mullite has been established. It was determined that all free silicium dioxide in the coal is converted into silicium carbide and the residual condensed phases are silicium carbide, mullite and solid carbon;
- for the first time, based on the triangulation of the Fe-Al-Si system, the critical region of the FSA alloy composition was established, where the joint crystallization of the metastable high-temperature phase of leboite ( $\text{FeSi}_2\text{B}$ ) and the ternary compound  $\text{FeAl}_3\text{Si}_2$  occurs. It has been established that the destruction of alloys in composition in this region is a consequence of the segregation of the ( $\text{FeSi}_2\text{B}$ ) phase and its further recrystallization with an increase in volume;
- were worked out technological modes for smelting high-silicium FSA grades from coals of the Kuu-Chekinsky coal field with the help of large-scale laboratory tests in an electric furnace with a capacity of 200 kVA. During smelting FS65A10 and FS65A15 alloys, it is established that the excess carbon should be 10-15% relative to the stoichiometric flow rate;
- in the conditions of a metallurgical plant of special steels (Xinin, China), for the first time, tests were carried out on the processing of 40Cr alloy steel with an FSA alloy instead of ferrosilicium and metallic aluminum. A comparative increase in the useful use of silicium and aluminum from FSA and a high economic efficiency of the alloy have been established. The fundamental possibility of using the FSA alloy for the processing of alloyed steels was established using the example of Cr40 and 30CrNi2Mo grades.

### **The practical value of the work.**

- as a result of the studies carried out, the correspondence of the coal raw materials of the Kuu-Chekinsky coal field for the smelting of ferrosilicoaluminium alloy was established, the proximity of which to the «KZKS» LLP plant will help to reduce the costs of transportation costs;

- by carrying out isothermal holdings, it was determined that in relation to coal from the Kuu-Chekinsky coal field, the beginning of the reduction of silicium dioxide occurs in the temperature range of 1450-1500 °C, and the reduction of aluminum oxide occurs only from mullite;

- on the basis of the triangulation of the Fe-Al-Si system, the critical regions of the compositions of the FSA alloy subject to crumbling are determined. Stable FSA alloy compositions are recommended;

- through large-scale laboratory tests, the possibility of using coals from the Kuu-Chekinsky coal field for FSA smelting was established. The technological modes for the smelting of high-silicium FSA grades are determined;

- laboratory research and industrial tests have established the possibility of using FSA for processing alloy steel, in particular for grades 40Cr and 30CrNi2Mo.

### **Statements for Defense:**

- results of studies of comparative physical and chemical properties of high-ash coal from the Kuu-Chekinskoye coal field;

- the results of changes in the phase composition of coal when heated to a temperature of 1650 °C;

- results of thermodynamic-diagrammatic analysis of the Fe-Al-Si system and determination of the main phase compositions of the FSA alloy during crystallization;

- results of large-scale laboratory tests of FSA smelting in a 200 kVA electric furnace;

- results of laboratory research and industrial tests on the use of FSA alloy in processing alloyed steel grades Cr40 and 30CrNi2Mo.

**The work was carried out** at the Department of "Nanotechnology and Metallurgy" of the Karaganda Technical University and at the Chemistry and Metallurgy Institute named Zh.Abishev within the framework of the contractual topic "Metallographic and petrographic studies of samples of high-ash coal from the Kuu-Chekinsky open-pit mine, various grades of ferrosilicoaluminium and steels treated with a ferrosilicoaluminium alloy" (responsible executive).

**Approbation of work, publication.** The main scientific results of the discerning work are presented in 9 publications, including:

- 3 articles were published at editions recommended by KOKSON MES of Republic of Kazakhstan (1 article - "Vestnik KazNITU", Almaty city, Republic of Kazakhstan; 1 article - "Bulletin of EKSTU named after D. Serikbayev in Vestnika"; Oskemen city, Republic of Kazakhstan; 1 article in the Russian journal - "Bulletin of IrSTU", Irkutsk city);

- 2 articles in the international scientific journal "Metalurgija" (Zagreb, Croatia), which is included in the Scopus database (percentile 57).

The main results were reported at 4 international scientific and practical conferences:

- 2 theses of reports at the international scientific-practical conference "Integration of science, education and production - the basis for the implementation of the Plan of the nation" (Saginov readings No. 10 and No. 11), Karaganda city, Republic of Kazakhstan;

- 1 report at the international scientific and practical conference "Innovations in the field of natural sciences as the basis for export-oriented industrialization of Kazakhstan", Almaty, Republic of Kazakhstan;

- 1 report at the XV International Scientific and Practical Conference "Conduct of modern science 2019", Sheffield, England.

**The structure and scope of the disclosure:** the disclosure consists of the introduction, the main part of 6 chapters, the conclusion, 3 application. The scope of the distribution is 135 pages of text, the work contains 23 figures, 40 tables, a list of used sources, including 94 names.