

## **ABSTRACT**

of the PhD dissertation thesis

### **«DEVELOPMENT OF THEORETICAL FOUNDATIONS AND IMPROVEMENT OF THE TECHNOLOGY OF PRODUCTION OF COMPLEX ALLOY OF THE Fe-Si-Mn-Al GROUP USING HIGH-ASH COAL AND MANGANESE ORES OF KAZAKHSTAN»**

submitted for the degree of Doctor of Philosophy (PhD)

specialty 6D070900 – «Metallurgy»

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**The purpose of the dissertation thesis** is to develop a technology for obtaining complex ligatures based on Fe-Si-Mn-Al from substandard manganese-containing charge materials and high-ash coals of the Republic of Kazakhstan. Investigation of the physico-chemical characteristics of the initial charge materials and the resulting products. Determination of rational technological parameters of the complex ligature smelting process.

#### **Research objectives**

- carrying out thermodynamic-diagram analysis of Fe-Si-Mn-Al metal system in order to study the phase-structural structure of the system;
- carrying out thermodynamic modeling in order to predict and obtain new data in the smelting of complex master alloys;
- study of temperature characteristics of softening of manganese ores of various deposits depending on temperature;
- determination of electrical resistivity of high-ash coals of various deposits depending on temperature;
- carrying out laboratory tests to obtain alloy samples using manganese ores, briquettes and high-ash coals;
- setting up and testing the technology for obtaining complex ligatures from manganese ores, briquettes and high-ash coals;
- study of the physicochemical and metallurgical properties of a new Fe-Si-Mn-Al containing complex ligature.

#### **Research methods**

The main methods of research and analysis used in the performance of the dissertation thesis include:

- thermodynamic diagrammatic analysis of the system under study was carried out on the basis of geometric tetrahedra by closing a triangle on a tetrahedron;
- thermodynamic modeling of the smelting process of Fe-Si-Mn-Al containing complex ligature with the direct application of the «Equilibrium Compositions» module of the HSC Chemistry software package (Outokumpu, Finland), based on the minimization of the Gibbs energy and variational principles of thermodynamics;
- determination of an adequate regression equation and construction of a geometric representation of parameters based on rotatable plans of the second order;

- determination of softening start temperature and softening temperature range of manganese ores in accordance with GOST 26517-85;
- determination of the electrical resistance of various types of carbonaceous raw materials using the Institute of Metallurgy method of the Ural Branch of the Russian Academy of Sciences;
- smelting complex ligatures in ore-thermal electric furnaces with a capacity of 150 and 200 kVA.

To study and analyze the phase compositions and structure of the initial charge materials and final products, the following were used:

- X-ray diffractometer XRD7000C (Shimadza, Japan) with a set of high- and low-temperature chambers, a polycapillary optics system (Institute of Metallurgy Ural Branch of the Russian Academy of Sciences, Yekaterinburg, RF);
- scanning electron microscope FEG SEM (TESCAN MIRA3) with a field emission cathode (Karaganda University named after Academician E.A. Buketov);
- multifunctional X-ray diffractometer Rigaku SmartLab (Nazarbayev University JSC).

### **Main provisions (proven scientific hypotheses and other conclusions that are new knowledge) submitted for defense**

- results of thermodynamic-diagrammatic analysis of the Fe-Si-Mn-Al system to study the friability through the phase-structural structure of the alloy;
- results of thermodynamic modeling of the process of obtaining a complex ligature using a thermochemical software package with universal modules for modeling technological schemes;
- results of new experimental data obtained on the characteristics of manganese-containing materials from various deposits and high-ash coals for obtaining complex ligatures: on initial and final temperatures and softening temperature range, and on the electrical resistivity of high-ash coals;
- results of a study to determine the optimal composition of a briquette from screenings of manganese-containing ore and coke, as well as their study of the microstructure at high temperatures;
- results of laboratory and large-scale laboratory tests of a new complex ligature in ore-thermal electric furnaces with a capacity of 150 kVA and 200 kVA, with the production of alloy samples using manganese ores, briquettes and high-ash coals;
- the results of studying the physicochemical and metallurgical properties of a new complex ligature containing Fe-Si-Mn-Al.

### **Description of the main results of the study**

As a result of theoretical and experimental studies the following results can be described:

- for the first time, a diagram of the four-component Fe-Si-Mn-Al metal system was constructed using Fe-Al-Si and Si-Mn-Al ternary compounds and, based on the results of the studies, the predicted area leading to the alloy crumbling was determined;
- complete thermodynamic modeling of the process of melting complex master alloys using manganese-containing briquettes was carried out. It has been established

that the metal-forming phases consist of: FeSi, Fe<sub>3</sub>Si, FeSi<sub>2</sub>, FeSi<sub>2.43</sub>, FeSi<sub>2.33</sub>, Mn<sub>11</sub>Si<sub>19</sub>, MnSi, Mn<sub>5</sub>Si<sub>3</sub>, Mn<sub>3</sub>Si and aluminum in the form of CaAl<sub>2</sub>, CaAl<sub>4</sub>;

- adequate regression equations were obtained and optimal conditions were determined for the transition of the main elements of a complex ligature into an alloy using theoretical research methods based on second-order rotatable plans with the construction of a geometric image of optimization parameters that have practical value;

- new experimental data were obtained on the characteristics of manganese ore and high-ash coals from various deposits to obtain a complex master alloy in terms of softening temperature range and electrical resistivity;

- a technology was developed and tested for melting Fe-Si-Mn-Al containing complex ligature from manganese ores, manganese-containing briquettes and high-ash coals in ore-thermal electric furnaces with a capacity of 150 and 200 kVA by carbothermal and slag-free methods.

### **Substantiation of the novelty and importance of the results obtained**

Development of a technology for the production of complex master alloys used as deoxidizers in the production of calm and semi-quiescent steel grades that are not subject to self-disintegration and obtained from substandard manganese ores, briquettes made from waste manganese ores and coke, as well as from high-ash coal, unsuitable from an energy point of view .

The development of technology for obtaining complex ligatures, in the aggregate, will allow organizing the production of obtaining and developing the extraction of substandard manganese deposits, as well as an increase in the production of coal deposits, previously used only in the national economic sector of the Republic of Kazakhstan. The development of the technology for the production of complex ligatures using high-ash coals will determine the role of coal deposits in Kazakhstan as a long-term (for centuries) raw material base for the ferroalloy production of Kazakhstan.

### **Compliance with the directions of scientific development or state programs**

The topic of the dissertation thesis corresponds to the specialized scientific direction «New multi-purpose materials based on natural raw materials and industrial waste» and the priority «Geology, mining and processing of mineral and hydrocarbon raw materials, new materials, technologies, safe products and designs» of the National Scientific Council under the Government Republic of Kazakhstan.

When performing the dissertation thesis, part of the research work was carried out as part of grant funding for young scientists on scientific and (or) scientific and technical projects for 2020-2022: AP08052301 – «Development of a technology for the production of high-quality steel castings by processing and refining from non-metallic inclusions with an alloy of highly active elements Al-Mn-Ca-Si», in which the doctoral student is the executor of this project. Applicant: Branch of RSE on REM «National Center for Complex Processing of Mineral Raw Materials of the Republic of Kazakhstan» of the Committee for Industrial Development and Industrial Safety of the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan "Chemical and Metallurgical Institute named after Zh. Abisheva».

## **Description of the contribution of the doctoral student to the preparation of each publication**

The personal contribution of the author is to carry out the bulk of the theoretical and experimental research outlined in the dissertation work, including the development of theoretical models, experimental research methods, research, analysis and presentation of the results in the form of publications and scientific reports.

Total 8 scientific papers have been published on the topic of the dissertation work, including: 2 (two) articles in peer-reviewed scientific publications on the scientific direction of the dissertation topic, indexed in the Science Citation Index Expanded of the Web of Science database (Clarivate Analytics) and according to CiteScore in the Scopus database (Elsevier), 1 (one) article in a domestic publication in the field of metallurgy recommended by COXON, 1 (one) article in a domestic scientific journal and 4 (four) articles in collections of International and Republican scientific and practical conferences.

Information about the main publications indexed in the Science Citation Index Expanded database Web of Science (Clarivate Analytics), in a peer-reviewed scientific publication that has a CiteScore percentile in the Scopus database (Elsevier) on the topic of the dissertation:

1. Zhuniskaliyev, T., Nurumgaliyev, A., Zayakin, O., Mukhambetgaliyev, Y., Kuatbay, Y., Mukhambetkaliyev, A. / Investigation and comparison of the softening temperature of manganese ores used for the production of complex ligatures based on Fe-Si-Mn-Al // Metalurgija. – 2020. Vol 59, Iss. 4. – P. 521-524;

2. Mukhambetgaliyev, Y., Zhuniskaliyev, T., Baisanov, S. / Research of electrical resistance and beginning softening temperature of high-ash coals for melting of complex Alloy // Metalurgija. – 2021. Vol 60, Iss. 3-4. – P. 332-334.

Information about publications in domestic publications in the field of metallurgy scientific journals on the topic of the dissertation:

1. Жунискалиев Т., Мухамбетгалиев Е., Нурумгалиев А., Жумагалиев Е. Применение комплексных сплавов для раскисления спокойных марок сталей // Промышленность Казахстана №3 (107) 2019, стр. 80-82;

2. Мухамбетгалиев Е.К., Байсанов С.О., Рошин В.Е., Ахметов К.Т., Жунискалиев Т.Т. Перспективы производства алюмосиликомарганца из сырья Казахстана // Вестник Карагандинского государственного индустриального университета, №1 (28) 2020, стр. 20-27.

Information about the reports reported and discussed based on the results of the dissertation thesis at the International and Republican scientific and practical conferences:

1. Жунискалиев Т.Т., Нурумгалиев А.Х., Мухамбетгалиев Е.К., Куатбай Е.Қ. Перспективы производства комплексной лигатуры группы Fe-Si-Mn-Al из казахстанского сырья // Труды X Международной научно-практической конференции «Конкурентоспособность нации - основное условие повышения благосостояния народа», посвященной 55-летию юбилею Карагандинского государственного индустриального университета, Ч.1. 29-30 ноябрь 2018. РК. г. Темиртау: КГИУ. 2018, стр. 278-282;

2. Zhuniskaliyev T.T., Yersainova A.A., Zhumagaliyev Ye.U. Development of technology for processing of manganese - containing ores with small reserves // Сборник статей по итогам Международной научно-практической конференции «Наука и инновации в современных условиях». 13 март 2019. РФ. г. Стерлитамак: Агентство международных исследований. 2019, стр. 62-65;

3. Нурумғалиев А.Х., Байсанов А.С., Қуатбай Е.Қ., Жүнісқалиев Т.Т. Дифференциально-термический анализ шихтовых материалов для выплавки комплексных ферросплавов // Материалы Международной научно-практической конференции «Инновации в области естественных наук как основа экспорт ориентированной индустриализации Казахстана», посвященной 10-летию Казахстанской национальной академии естественных наук и 25-летию Национального центра по комплексной переработке минерального сырья Республики Казахстан. 4-5 апрель 2019. РК. г. Алматы: РГП «НЦ КПМС РК». 2019, стр. 315-319;

4. Мухамбетғалиев Е.К., Жүнісқалиев Т.Т., Шаркаев С.Н. Перспективы производства комплексного ферросплава Fe-Si-Al-Mn-Ca Қазақстан Республикасы тәуелсіздігінің 30 жылдығына арналған «Инновациялық технологиялар және инженерия» ХІ халықаралық ғылыми-практикалық конференциясының жинағы, - Теміртау. ҚР: ҚарИУ. 2021, стр. 84-87.