ABSTRACT

of the dissertation submitted for the degree of Doctor of Philosophy (PhD) in the educational program 8D07203 – "Metallurgy"

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«Research and Development of the Technology of High-Dispersed Dust of Ferroalloy Production for the Purpose of its Utilization»

The dissertation focuses on the development of a scientifically substantiated technology for agglomerating highly dispersed dust (HDD) generated during ferrosilicon production in order to obtain a conditioned product suitable for reuse in ferroalloy production. The study addresses the pressing challenge of incorporating technogenic waste from ferroalloy production into the secondary production cycle, improving the efficiency of raw material utilization, and reducing the environmental impact.

Ferroalloy production is accompanied by the generation of significant amounts of technogenic waste, including dust, sludge, and slag. Dust collected by gas-cleaning systems consists of fine particles containing valuable components; however, its physicochemical properties do not allow it to be efficiently used directly in metallurgical processes. The accumulation of such waste results in economic losses and adversely affects the environment.

Modern metallurgy relies heavily on the use of fine-grained raw materials, which require preliminary agglomeration to ensure the necessary gas permeability of the charge and the stability of technological processes. Fine particles tend to compact, impair gas flow, and may be carried out of the furnace in the form of dust, thereby reducing production efficiency. Therefore, agglomeration is an essential stage in preparing raw materials and waste for metallurgical processing.

Since industry consumes large amounts of energy and is one of the major consumers of natural resources, it contributes significantly to environmental pollution and resource depletion. It also generates substantial amounts of waste and contributes to adverse environmental phenomena, including acid rain. Thus, industry is one of the major factors contributing to global environmental degradation.

Relationship of the Research to Other Research Projects.

The dissertation was carried out within the framework of a grant-funded project supporting young scientists conducting scientific and/or scientific-technical research for 2023–2025, funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (IRN AP19576811, Contract No. 114-KMU4 dated May 17, 2023). The applicant served as the principal responsible researcher for the project.

Relevance of the Research. To date, a significant amount of various industrial waste has accumulated in the Republic of Kazakhstan, and its volume continues to increase. This waste occupies extensive areas and adversely affects the

atmosphere, water resources, and soil, thereby deteriorating the environmental conditions and reducing the quality of life of the population. Waste storage facilities, which are often not equipped with adequate protective systems, become sources of secondary pollution: harmful substances are released into the atmosphere and, during rainfall and floods, enter water bodies such as rivers, lakes, and ponds.

The production of ferroalloys inevitably generates highly dispersed dust (HDD), along with other technogenic waste. This dust has two main sources. First, it is generated directly during the technological process when the ferroalloy product is discharged. Second, it is produced by gas-cleaning systems.

Regardless of its origin, highly dispersed dust has a composition similar to that of the ferroalloy being produced and can be used as a raw material to obtain a conditioned product.

Particular attention should be paid to the problem of processing metallurgical waste, especially highly dispersed dust from ferroalloy production. Effective utilization of this waste requires preliminary agglomeration.

The problem of utilizing highly dispersed dust from ferroalloy production is not new; nevertheless, it remains largely unresolved in the Republic of Kazakhstan.

Currently, the utilization of HDD in Kazakhstan remains largely unresolved: significant quantities of dust are exported to foreign countries, including the Russian Federation, China, and Uzbekistan, as raw material, and subsequently re-imported into Kazakhstan as briquetted products with high added value. Developing domestic agglomeration technologies is therefore a strategically important task for ensuring the technological and economic efficiency of the country's metallurgical industry.

Highly dispersed dust itself poses an environmental hazard because it requires extensive storage areas, contributes to air pollution, and exhibits significant pyrophoricity due to its large specific surface area and the resulting high reactivity.

At present, a sufficient number of technologies for utilizing highly dispersed dust have been implemented worldwide; however, such technologies are not widely used in Kazakhstan. This is due to the fact that dust generated at each individual enterprise has unique physicochemical properties, particle-size distribution, and impurity composition. Consequently, it is necessary to investigate established agglomeration methods and develop new charge compositions, including the selection of binders and the calculation of particle-size distributions, to meet the requirements for the resulting raw material.

Thus, research aimed at developing effective agglomeration regimes for highly dispersed dust to produce high-quality briquetted products is both relevant and timely from environmental, scientific, and practical perspectives.

Object of the Research: Briquettes produced from highly dispersed dust (HDD) generated during ferrosilicon production.

Aim of the Research: To develop a technology for agglomerating highly dispersed dust (HDD) generated during ferrosilicon production in order to obtain a conditioned product.

Research Objectives:

– To analyze the composition and properties of highly dispersed dust (HDD) generated during ferrosilicon production;

– To investigate the physicochemical properties of the initial dust (chemical and phase compositions and particle-size distribution) as factors determining the agglomeration technology;

– To conduct experimental studies to select the optimal binder for the briquetting process;

– To determine the optimal technological parameters of the briquetting process;

– To evaluate the quality of the resulting briquettes using a set of indicators, including compressive strength, the yield of undersize material, and silicon and carbon contents;

– To conduct pilot-scale industrial trials at a steelmaking production site using experimental briquettes.

Scientific Novelty:

– The relationship between the iron ore concentrate content in the charge and the compressive strength of the finished briquettes was established. The maximum strength of 25 MPa was achieved at an iron ore concentrate content of 15%;

– The dependence of briquette strength on the type and amount of binder was established. Bentonite clay at a content of 3–5% provides a compressive strength of up to 25 MPa, which is 1.4–1.7 times higher than that achieved using liquid glass or caustic soda;

– The influence of briquetting process parameters, including pressing pressure, drying temperature, and drying time, on the properties of briquettes produced from a charge containing iron ore concentrate and bentonite clay was determined;

– The possibility of completely replacing standard-grade FS50 ferrosilicon with briquettes made from HDD during the deoxidation and alloying of 30KhGS steel, without deterioration in its mechanical properties or chemical composition, was experimentally demonstrated.

Practical Significance:

- A new charge composition for briquetting has been developed and experimentally validated. It includes the following components (wt.%): highly dispersed dust (HDD) — 50–55%, iron ore concentrate — 15%, fine off-grade ferrosilicon — 25–30%, bentonite — 3%, and water — 2%. This composition increases briquette density to 4.8–4.9 g/cm³, comparable to that of lump ferroalloys, preventing the briquettes from floating in the melt and accelerating their dissolution. The compressive strength reaches at least 25 MPa, while the proportion of undersize material (particles smaller than 10 mm) does not exceed 10%. These parameters meet the requirements of GOST 1415-93 regarding the mechanical strength of ferrosilicon during transportation and furnace charging. The chemical composition of the briquettes fully complies with the FS70 grade specifications for silicon (68–74%), carbon (≤0.1%), sulfur, and phosphorus.

- The optimal technological parameters for briquetting have been determined: a pressing load of 50 kN, a drying temperature of 40–60°C, a drying time of 90

minutes, and a charge moisture content of 2% before pressing. These parameters can be directly applied when equipping industrial briquetting lines at ferroalloy plants.

- Pilot-scale industrial trials conducted at Parkhomenko Mechanical Engineering Plant LLP (TOO “KMZ im. Parkhomenko”) confirmed the possibility of completely replacing standard-grade FS50 ferrosilicon with the developed briquettes during the production of 30KhGS steel in accordance with GOST 4543-2016. The chemical composition of the resulting steel (0.32% C, 1.2% Si, 0.8% Mn, 1.1% Cr, and S and P ≤0.035%) fully complies with the applicable standard requirements.

- A process flow sheet for converting HDD into briquettes has been developed and implemented (Appendix D). An implementation certificate confirming the industrial applicability of the proposed solution has been obtained.

Provisions Submitted for Defense:

- The feasibility of using iron ore concentrate as a component of the charge in the briquetting process;
- The relationship between the iron ore concentrate and bentonite contents in the briquetting charge and the compressive strength of the briquettes;
- The composition of briquettes produced from highly dispersed dust (HDD) generated during ferrosilicon production;
- The technological parameters for producing briquettes from HDD using iron ore concentrate and bentonite clay.

Applicant’s Contribution. The applicant’s contribution consists of defining the research aim and objectives, analyzing scientific and technical literature on the utilization of highly dispersed dust from ferrosilicon production, investigating the chemical properties of the initial raw material, and planning and conducting experimental studies to develop a briquetting technology. The applicant selected and justified the charge composition and binding materials, determined the optimal technological parameters of the briquetting process, investigated the physicomechanical properties of the resulting briquettes, and evaluated their quality.

The applicant also participated directly in pilot-scale industrial trials involving the use of briquettes in steelmaking, processed and analyzed the experimental results, and formulated scientific conclusions and practical recommendations. In addition, the applicant prepared scientific publications on the dissertation topic, developed a process flow sheet for converting highly dispersed dust into briquettes, and prepared documents confirming the practical significance of the research results and the feasibility of their implementation.

Approbation of the Research. Based on the research results, 14 scientific papers have been published, including:

– Two articles in the journal Metallurgija (Croatia), indexed in Scopus (Scopus percentile — 32);

– One article in the international journal Acta Metallurgica Slovaca (Slovakia), indexed in Scopus (Scopus percentile — 52);

– Three articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan: Trudy Universiteta, No. 3, 2023; Trudy Universiteta, No. 4, 2024; and Science and Technology of Kazakhstan, No. 3, 2025 (second list);

– Two utility model patents: No. 9155, dated February 12, 2024, “Method for Briquetting Dusty Waste Generated during Ferrosilicon Production”; No. 10925, dated July 25, 2025, “Method for Briquetting Highly Dispersed Dust from Ferroalloy Production Using Iron Ore Concentrate”;

– One monograph, Study of the Process of Obtaining a Conditioned Product from Ferrosilicon Production Waste, ISBN 978-601-12-3322-4;

Five presentations at national and international scientific and practical conferences:

1. The 15th International Scientific and Practical Conference “Integration of Science, Education and Production — the Basis for Implementing the Nation’s Plan” (Saginov Readings No. 15), dedicated to the 70th anniversary of the university, June 17–19, 2023.
2. The 16th International Scientific and Practical Conference “Integration of Science, Education and Production — the Basis for Implementing the Nation’s Plan” (Saginov Readings No. 16), June 13–14, 2024.
3. The 23rd International Scientific and Technical Ural School-Seminar for Young Metallurgists, Yekaterinburg, February 3–7, 2025.
4. The 17th International Scientific and Practical Conference “Integration of Science, Education and Production — the Basis for Implementing the Nation’s Plan” (Saginov Readings No. 17), June 26–27, 2025.
5. An international scientific conference, with the paper published in Mechanical Engineering: An International Journal (MEIJ), 2025, No. 1/2, Vol. 12, pp. 9–17. DOI: 10.5121/meij.2024.12201.

The following implementation and testing certificates were obtained:

- A certificate confirming the implementation of the technology at Parkhomenko Mechanical Engineering Plant LLP (TOO “KMZ im. Parkhomenko”);
- A certificate confirming the industrial trials conducted at Parkhomenko Mechanical Engineering Plant LLP;
- A certificate confirming the testing conducted at the branch of the National Center for Complex Processing of Mineral Raw Materials, “Khloristyi Metallurgicheskii Institut named after Zh. Abishev” (NC KPMS “KhMI named after Zh. Abishev”);
- A certificate confirming the testing conducted at Manganets Research and Production Association LLP (TOO “NPO Manganets”).

Structure and Length of the Dissertation. The dissertation consists of an introduction, a main body comprising five sections, a conclusion, and appendices. The dissertation comprises 106 pages of typescript and contains 35 figures, 31 tables, and a list of references comprising 109 sources.