

ABSTRACT

The dissertation for the degree of Doctor of Philosophy (PhD) in the educational program 8D07201 – Metallurgy

KAMENOV ALMAT AITASOVICH

RESEARCH OF THE PROPERTIES OF CAST IRON USED FOR POURING ANODES IN ALUMINUM ELECTROLYSIS PRODUCTION

Relevance of the research topic. The development of the aluminum industry in Kazakhstan is leading to increased attention not only to the main but also to the auxiliary production processes. The process of electrolytic production of primary aluminum remains one of the most energy-intensive industries in the world. Significant electricity consumption by aluminum production plants makes improving energy efficiency important from both economic and environmental perspectives, especially in the context of the global transition to ESG principles.

A significant source of unproductive electricity losses in an aluminum electrolyzer is the voltage drop, a considerable share of which, from 8% to 12%, occurs in the anode assembly. The main cause of these losses is the high contact electrical resistance in the "steel nipple - cast iron pour - carbon anode" structural unit, which is determined by the physicochemical and operational properties of the sealing cast iron.

In this situation, to improve overall production efficiency, it becomes necessary to analyze the properties and optimize the chemical composition of the sealing cast iron used in the technological process at JSC «Kazakhstan Aluminium Smelter».

The aim of the dissertation work is to optimize the chemical composition of the sealing cast iron to reduce electrical losses in the anode assembly of aluminum electrolyzers and improve operational characteristics.

To achieve this aim, the following **objectives** were defined:

- Conduct a comprehensive study of the physicochemical and operational properties of the sealing cast iron used at JSC «Kazakhstan Aluminium Smelter»;
- Establish the patterns of influence of chemical composition and technological factors on the structure, casting, mechanical, and electrical properties of the sealing cast iron;
- Develop an optimal chemical composition for the sealing cast iron with a reduced phosphorus content;
- Develop an anode assembly design to change the geometry of the cast iron pour;
- Conduct tests of the developed solutions and confirm their technical and economic effectiveness.

The object of the research is the cast iron used in the pouring of anodes for the aluminum electrolyzer.

Scientific novelty of the obtained results. The scientific novelty of the dissertation work lies in solving a problem important to the metallurgical industry and is based on the following results obtained for the first time:

- The relationships between the chemical composition, microstructure, casting, mechanical, and electrical properties of the industrial cast iron used at JSC «KAS» were studied and established, which allowed identifying the factors determining the voltage drop in the anode assembly by an average of 85 mV;

- The effectiveness of refining cast iron for anode pouring using ladle furnace slag and lime was theoretically substantiated and experimentally confirmed, making it possible to obtain cast iron with a phosphorus content of <0.18%;

- A quantitative relationship was established between the reduction of phosphorus content (from 0.94% to <0.18%) in the sealing cast iron, the morphological transition of the phosphide eutectic from a continuous intergranular network to isolated inclusions, and the reduction in the alloy's specific electrical resistance.

- A new nipple socket design with trapezoidal protrusions was developed, ensuring a simultaneous reduction in voltage drop and facilitating the dismantling of the cast iron pour by changing the geometry of the cast iron.

Main provisions submitted for defense The following main scientific and practical results are submitted for defense:

- The results of the study of physicochemical, mechanical, and electrical properties of the industrial sealing cast iron from JSC «KAS» and the established patterns of their influence on the voltage drop in the anode assembly;

- The results of thermodynamic modeling of cast iron refining processes using ladle furnace slag, lime, and ferroalloys;

- The developed technology for refining industrial cast iron, ensuring the production of metal with an optimized chemical composition, wt. %: carbon: 3.3-3.5; silicon: 2.4-2.5; manganese: 0.7-0.72; phosphorus: 0.15-0.18; sulfur: 0.05-0.06; iron - remainder;

- A developed new design of the nipple socket with stress concentrators, which ensured a 36% reduction in the dismantling force;

- Test results confirming a reduction in the voltage drop in the anode assembly from 85 mV to 41 mV when using cast iron of a new composition and the proposed baked anode nipple socket design.

Practical significance of the work. The practical significance of the work lies in the development of a comprehensive solution aimed at improving the economic and energy efficiency of primary aluminum production. The developed technology for refining cast iron using available secondary industrial products (ladle furnace slag from LLP «KSP Steel») and the new anode assembly design were successfully tested at LLP «Incom Company», a company specialized in energy expertise, energy conservation, and energy audits, which is confirmed by the relevant test reports.

An optimized composition for sealing cast iron was proposed, and a new design for the aluminum electrolyzer anode was developed and patented. The implementation of the proposed solutions allows for a reduction in the voltage drop in the anode assembly, providing a direct economic effect.

The results of the dissertation work have been implemented into the educational process at NJSC «Toraighyrov University» for the discipline «Ferrous Metallurgy and Recycling» for 3rd-year students of the educational program 6B07205 «Metallurgy».

Publications and approbation of the work. The results of the dissertation work are published in four articles:

- one article in a journal indexed in the Scopus database (35th percentile):

1. Kamenov A. A., Bogomolov A. V., Bykov P.O., Zhunusov A. K., Suyundikov M. M. Determination the properties of cast iron used in the installation of anodes // *Metalurgija* 62 (1) (2023) 1, P. 107-110.

- three publications in journals from the list 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 for publishing the main results of scientific activity:

2. Kamenov A.A., Bogomolov A.V., Bykov P.O., Suyundikov M.M., Zhunusov A.K. Sovremennyye sostavy chuguna, primenyayemogo dlya zalivki anodov alyuminiyevykh elektrolizerov // *Trudy universiteta*, 2023, No. 1. - P. 37-42.

3. Kamenov A.A., Bogomolov A.V., Bykov P.O., Suyundikov M.M., Zhunusov A.K. Test of an baked anode of an aluminum electrolyzer with a new nipple socked design // *Nauka i tekhnika Kazakhstana*, 2023, No. 4. - P. 154 - 162.

4. Kamenov A.A., Bogomolov A.V., Zhakupov A.N., Ryspaev T.A., Kulumbaev N.K. Optimizatsiya khimicheskogo sostava zalivochnogo chuguna // *Nauka i tekhnika Kazakhstana*, 2025. - No. 2. - P. 276-294.

- patent of the Republic of Kazakhstan for invention obtained:

5. Kamenov A.A., Bogomolov A.V., Suyundikov M.M., Zhunusov A.K., Bykov P.O., Abdrakhmanov E.S., Kulumbaev N.K. Baked anode of an aluminum electrolyzer : pat. for invention No. 36204 Rep. Kazakhstan - publ.: 05.05.2023 Bul. No. 18.

- patents of the Republic of Kazakhstan for utility model obtained:

6. Kamenov A. A., Bogomolov A. V., Bykov P. O., Zhunusov A. K., Suyundikov M.M. Baked anode of an aluminum electrolyzer: pat. for util. model No. 8475 Rep. Kazakhstan - publ.: 29.09.2023. Bul. No. 39.

7. Kamenov, A. A., Bogomolov, A. V., Zhakupov, A. N., Suyundikov, M. M., Zhunusov, A. K., Bykov, P. O. Cast iron: pat. for util. model No. 10455 U Rep. Kazakhstan: IPC C22C 37/10 (2006.01) - No. 2025/0371.2 ; appl. 07.03.2025 ; publ. 25.04.2025, Bul. No. 17.

The main provisions and results of the work were tested and reported at an international conference in the form of oral presentations:

8. Kamenov, A. A., Bogomolov, A. V. Matematicheskoye modelirovaniye optimizatsii khimicheskogo sostava zalivochnogo chuguna dlya alyuminiyevykh elektrolizerov // *Materialy Mezhdunarodnoy nauchnoy konferentsii «XXV Satbayev okulary» atty, posvyashchennoy 65-letiyu Toraygyrov universiteta*. - Pavlodar: Toraygyrov universiteti. T. 15 «Zhas galymdar». - 2025. - P. 262-266.

Structure and volume of the dissertation. The dissertation work consists of an introduction, four chapters, a conclusion, a list of references, and appendices. The work is presented on 131 pages of printed text, contains 68 figures and 26 tables. The list of references includes 127 items.