A. A. KAMENOV, A. V. BOGOMOLOV, P. O. BYKOV,
A. K. ZHUNUSOV, M. M. SUYUNDIKOV

ISSN 0543-5846
METABK 62(1) 107-110 (2023)
UDC – UDK 621.741:621.35/661.13:66.014:620.18:621-498=111

DETERMINATION PROPERTIES OF CAST IRON USED IN THE INSTALLATION OF ANODES

Received – Primljeno: 2022-06-09
Accepted – Prihvaćeno: 2022-08-20
Preliminary Note – Prethodno priopćenje

This paper presents the results of determining the cast iron's properties, which is used in the installation of anodes in the electrolytic production of aluminum. The research methods and applied instruments used for metallographic analysis and chemical composition analysis are described. The results of metallographic analysis of cast iron microstructure "before" and "after" electrolysis are presented. The cast iron's chemical composition was analyzed by using an X-ray fluorescence spectrometer. The results of experimental melting for testing the casting properties of cast iron for fluidity in a spiral sample are presented.

Keywords: cast iron, installation of anodes, chemical composition, metallographic analysis, fluidity

INTRODUCTION

One of the largest aluminum production facilities in the region encountered a problem with the incomplete removal of cast iron casting from the anode holder's steel nipple and high voltage fluctuations in the nipple-anode contact [1, 2].

In this regard, the purpose of this work is to investigate the properties of cast iron which is used in the installation of anodes at the aluminum electrolysis plant.

Modern electrode production at aluminum smelters is an independent production facility with a branched transport and technological scheme and an automated process control system.

Three production processes are performed at the same time in the anode mounting department [3]:

- cleaning and removing cinders;
- cleaning and preparation of nipples and current-carrying rods, preparation of cast iron;
- pouring of new fired anodes with pre-prepared current-carrying anode holders.

The fixing of the carbon blocks to the steel anode holder is due to the cast iron. The cast iron is poured into the nipple socket, where the steel nipple of the anode holder is installed [4, 5] (Figure 1).

Cast irons have the natural brittleness necessary to remove the casting from the spent anode nipple. The following requirements are placed on the quality of cast iron:

- minimum linear shrinkage during curing (0,7 – 1,3 %);
- high wetting ability, which is achieved due to the presence of graphite in cast iron in the form of thin-platy (laminate) structure, increased fluidity;
- increased mechanical compressive strength (500 – 1 000 MPa);
- melting at a lower temperature than steel with similar properties.

Minimum shrinkage and increased fluidity are prevalent because these properties determine the reliable filling of the nipple socket with cast iron, including contact with all elements of the nipple and nipple socket structure, and the prevention of shrinkage and detachment of the cast iron casting from the walls of the nipple socket.

Cast iron for nipple casting, as a rule, has in its composition 3,0 – 3,7 carbon and 2,0 – 3,6 % silicon. If the

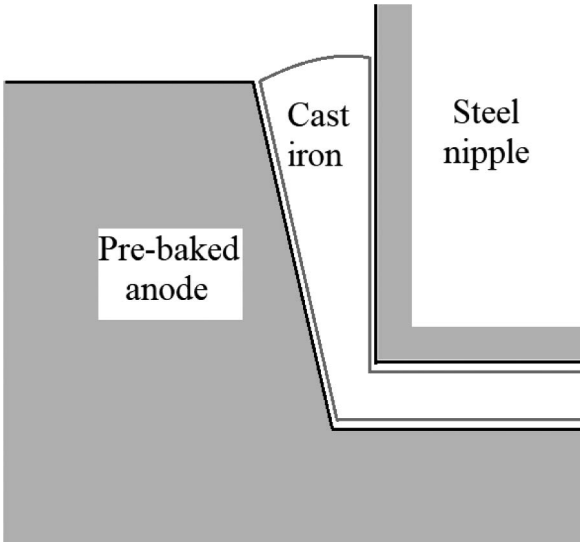

Figure 1 Attaching the steel nipple to the pre-baked anode with cast iron

A. A. Kamenov,
A. V. Bogomolov (bogomolov71@mail.ru),
P. O. Bykov, A. K. Zhunusov, M. M. Suyundikov,
Toraighyrov University, Pavlodar, Kazakhstan

silicon content in cast iron is low, there is an increased risk of formation of metastable eutectics (austenite + iron carbide), which is unstable and already in the solid-state is transformed into a more stable crystalline form. Such compositions are highly undesirable. Restructuring in solid form occurs with the ingress of volumetric changes into the material.

The value of volumetric shrinkage of an iron casting at the maximum content of 4 % C and 3,6 % Si is ≈ 0,018, and at the minimum concentrations of C and Si (3 and 2,8 %) – 0,024 %. Consequently, carbon and silicon contribute to a decrease in the volumetric shrinkage of cast iron.

The cast iron's properties and microstructure can also be determined by the casting conditions and the cooling rate of the casting. The latter depends on the nipple anode gap thickness, nipple mass, cast iron temperature, etc. In this case, the actually obtained structure may differ significantly from the assumptions that follow from the composition.

It should be noted the danger of the presence of non-metallic impurities in cast iron (slag, dross), which can cause the formation of defects in the structure of the casting, as well as cracks and shells after the crystallization of cast iron.

METHODS AND MATERIALS

As is known, the properties of cast iron depend on its chemical composition and structure. To research the structure and chemical composition of cast iron used at the plant, provided samples of cast iron "before" and "after" electrolysis, samples of recycled and foundry cast iron, steel nipple, and ferroalloys. The cast iron samples are shown in Figure 2.

The structure of cast iron was researched by metallographic analysis. During the metallographic analysis, we used metallographic optical microscopes LOMO LV-34, OLYMPUS GX53 - to research the microstructure of the metal, macroscope MPB-2, USB-micro CS02-500 Digital Microscope with Coolingtech Software Digital Engineering - to determine the macrostructure of the metal [6].

Analysis of the chemical composition was carried out by an express analyzer AN-7529M, spectrometer Supermini X VE62-500.

Preparation of cast iron samples for metallographic analysis was carried out according to ISO 945-1:2019 and recommendations. Grinding and polishing of samples were realized on the grinding and polishing machine MR-2B of Grinder Polisher (Germany).

To determine the casting properties of cast iron, melting in a laboratory induction furnace was realized. The calculation of the charge for experimental melts was performed [7]. Melting has been realized with the crucible open, the temperature of the melt was 1 430 – 1 450 °C, the mass in the ladle was 5,2 kg, melting time from the beginning was 15 minutes. To test the fluidity a spiral sample was used, with a trapezoidal cross-section of 0,56 cm^2, the molding height of the funnel was 90 mm, diameter was 40 mm.

RESULTS AND DISCUSSION

The results of metallographic analysis of the microstructure of cast iron are shown in Figures 3 - 5 and Table 1.

Metallographic analysis showed that the microstructure of cast iron did not change significantly during electrolysis. Cast iron «before» and «after» the electrol-

Figure 2 Example of a steel nipple with cast-iron casting

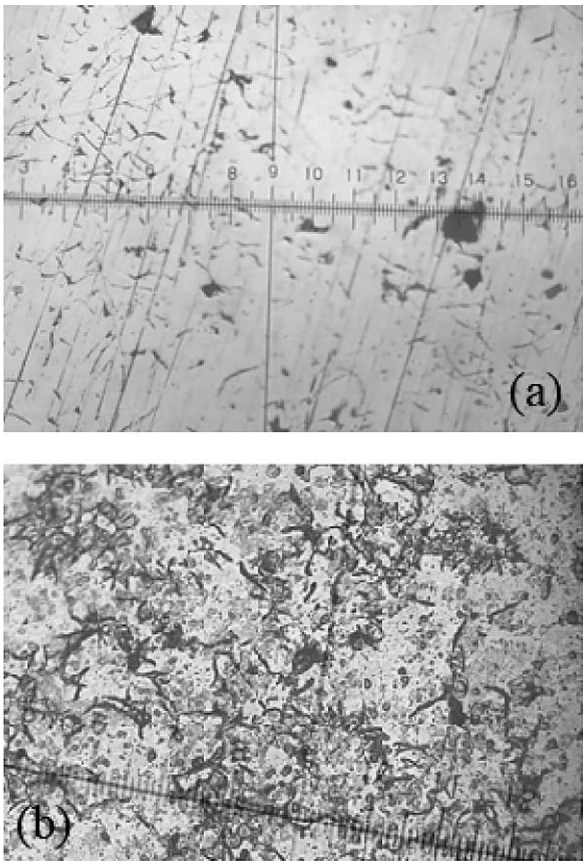

Figure 3 Microstructure of cast iron: lamellar graphite, ferrite, cementite, phosphide eutectics, magnification 200 x: (a) not etched; (b) after etching 4 % HNO_3

Figure 4 Distribution of inclusions in cast iron, magnification 200 x. Etched 10 g ammonium sulfate, 90 cm^3 of water, distribution of inclusions: FER2 - torn mesh

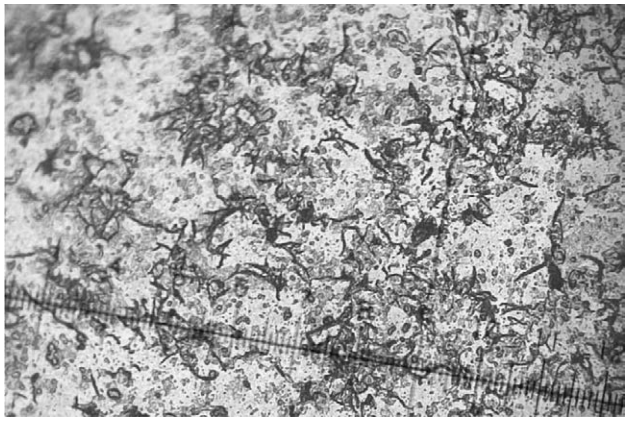

Figure 5 Metallic base of cast iron: Magnification 200 x. Etched with 2,5% HNO_3

Table 1 **Results of metallographic analysis of cast iron samples ("before" and "after" aluminum electrolysis)**

The name of the determinable Indicator	Regulatory document	Unit of measure	Value
Determination of graphite content	ISO 945-1:2019		I
Shape of graphite inclusions	ISO 945-1:2019		Plate
Length of graphite inclusions, μm	ISO 945-1:2019	μm	4
Distribution of graphite inclusions	ISO 945-1:2019		A, uniform
Determining the metal base (Type of structure):	ISO 945-1:2019		Ferrite Cementite Phosphide eutectics

ysis has a structure on a ferrite-cementite basis with inclusions of rectilinear lamellar graphite of I type according to ISO 945-1:2019. There is also phosphide eutectics in the cast iron. The distribution of graphite inclusions of PGr1 is uniform. The length of graphite inclusions is up to ~ 15 microns (size 4).

The results of the analysis of the chemical composition of cast iron «before» and «after» electrolysis are presented in Table 2.

Table 2 **Chemical composition of the initial cast iron and after electrolysis**

The name of the determinable parameter	Unit	Normalized value according to the plant's technological instructions	Actual value based on «before» electrolysis tests	Actual value according to the results of the «after» electrolysis tests
Mass fraction of C	%	3,00 - 3,50	3,23	3,19
Mass fraction of Mn	%	not more than 0,90	0,69	0,61
Mass fraction of Si	%	2,50 - 3,00	2,9	2,8
Mass fraction of Cr	%	not more than 0,30	0,06	0,05
Mass fraction of S	%	not more than 0,20	0,15	0,09
Mass fraction of P	%	0,50 - 1,60	0,94	0,91

The research of the chemical composition of cast iron samples showed no significant changes in the composition during electrolysis and compliance with the normalized values according to the technological instructions of the plant.

The length of the spiral sample poured to check the fluidity was 86,5 cm. Taking into account the amount of cast iron poured, pouring the spiral sample for the fluidity test (Figure 6) showed that the basic composition of cast iron used at the plant has high fluidity.

Figure 6 Fluidity test of the base cast iron composition

CONCLUSION

Based on the research conducted on the properties of cast iron samples used in aluminum production, the following was established:

1) The microstructure of cast iron does not change significantly during electrolysis. Cast iron "before" and "after" the electrolysis has a structure on a ferrite-cementite basis with inclusions of rectilinear lamellar graphite of I type according to ISO 945-1:2019. Phosphide eutectics is present in the cast iron. The distribution of graphite inclusions of A is uniform. The length of graphite inclusions is up to ~ 15 microns;

2) The length of the poured spiral sample for the fluidity test was 86,5 cm. This confirms that the cast iron provided for the study has a high fluidity, sufficient to fill the cavity of the anode socket.

3) Chemical composition of cast iron after the study is as follows ("before" - "after" electrolysis): C - 3,19 - 3,23 %, Mn - 0,69 - 0,61 %, Si - 2,9 - 2,8 %, Cr - 0,06 - 0,05 %, P - 0,94 - 0,9 %.

Carbon and silicon are the predominant elements in cast iron. Carbon has a greater influence on fluidity than silicon, but the influence of phosphorus is also taken into account. The regularity describing the minimum eutectic melting point of cast iron is described by the formula defining the carbon equivalent of CE [8]:

$$CE = C\ \% + (0{,}3\ Si\ \% + P\ \%)$$

It is believed that high phosphorus (P) content increases the fluidity of cast iron, and allows for reducing the gap between the steel nipple and the carbon anode, thereby providing a decrease in voltage drop. For this reason, cast iron with high phosphorus content is still used at a number of foreign plants. On the other hand, the negative effect of phosphorus on the properties of cast iron is known. Phosphorus increases the specific electrical resistance of cast iron itself. A number of sources [9, 10] recommend reducing the content of phosphorus and silicon in cast iron, compensating this with a higher carbon content to maintain sufficient fluidity. At the content of 0,5 – 1,5 % P in the structure of cast iron, there is a significant amount of phosphide eutectics, which increases the specific electrical resistivity.

It should also be noted that the properties and microstructure of the cast iron may also be determined by the casting conditions and the cooling rate of the casting. The latter depends on the thickness of the gap between the nipple and the anode, the mass of the nipple, the temperature of the cast iron, etc.

REFERENCES

[1] O.E. Lysenko, G.V. Galevsky, V.V. Rudnev. The current state of the world and domestic production of baked anodes for aluminum electrolyzers / Non-ferrous metals (2019), 16-26.

[2] Bykov P., Kuandykov A., Zhunusov, A. Refining of Primary Aluminum from Vanadium / Defect and Diffusion Forum 410 (2021), 405-410.

[3] E.A. Yanko. Anodes of aluminum electrolyzers. Ores and metals (2001), 510-511 and 513

[4] Mohamed M. Ali et al. Int. Characterization of New Cast Iron Alloys for the Stub-Anode Connection in the Aluminium Reduction Cells / Journal of Engineering Research and Application 5 (2013), 414-419.

[5] V. G. Babkin, V. A. Kukartsev, A. I. Cherepanov, G. V. Arkhipov, A. N. Savina. Effect of cast iron structure and properties on contact quality with an aluminum electrolyzer carbon anode, Metallurgist 61 (2017) 3–4, 318-324

[6] A. Zhakupov, A. Bogomolov, A. Zhakupova, S. Abdulina, V. Salina. Determination of technological parameters for continiuous casting of a hollow pipe billet, Metalurgija, 60 (2021), 3-4, 329–331

[7] A. Kanaev, A. Gulyarenko, A. Bogomolov, T. Sarsembaeva, Analysis of mechanisms for hardening constructional steels by structure parameters, Metalurgija 61 (2022), 1, 241–243.

[8] A.N. Savina, A.V. Lanshin, V.G. Babkin, A.I. Cherepanov, V.A. Kukartsev. Cast iron for casting anodes with an optimized composition without the addition of phosphorus / Materials int. Congress "Non-ferrous metals and minerals", Krasnoyarsk 2017, 496-503.

[9] Kondratiev V.V., Balanovsky A.E., Ivanov N.A., Ershov V.A., Kornyakov M.V. Evaluation of the influence of the composition of the modifier with nanostructured additives on the properties of gray cast iron / Metallurgist, 5 (2014), 48-56.

[10] R. Gavrilova, M. Manchev, V. Manolov, A. Cherepanov Investigation of the effect of modifiers with nanosizes on the crystallization process in iron-based alloys / Nauchnyye izvestiya [Scientific News] (2013), 313–315.

Note: The responsible for English translate is Anar Shabakbayeva, Nur-Sultan, Kazakhstan.