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ISSN 0543-5846
METABK 60(3-4) 415-418 (2021)
UDC – UDK 549.73:338.987.4:621.92:536.5.002.61=111

INFLUENCE OF TEMPERATURE ON THE STRENGTH OF ALUMINA-CONTAINING RAW MATERIALS

Received – Primljeno: 2021-02-12
Accepted – Prihvaćeno: 2021-04-15
Preliminary Note – Prethodno priopćenje

The work is devoted to the study of the effect of temperatures on the physical and mechanical properties of an alumina-containing product in order to select crushing and grinding equipment for subsequent enrichment operations. In the course of the study, three series of experiments were carried out: at room temperature 23 °C, with heating the material in a drying chamber to 200 °C, and also under cryogenic exposure – 195,75 °C using liquid nitrogen. As a result, the substantiation of the change in the physical and mechanical properties of raw materials when changing is presented. Recommendations for the selection of crushing equipment have been developed.

Key words: alumina-containing material, raw materials, crushing, temperature.

INTRODUCTION

In the process of electrolysis production of aluminum in factories, dusting and spilling of alumina and fluoride salts occur through leaks in the structural elements of equipment, mechanisms and motorized equipment. The main reason for the formation of a large number of such products is the use of the cryolite-alumina melt electrolysis technology with the installation of baths with a self-baking anode [1]. As a result, a large amount of alumina-containing waste is generated at the plants of the aluminum industry, unsuitable for reuse in the electrolysis process due to significant contamination of alumina by oxides of iron, silicon and other impurities (sand particles, pieces of asphalt, concrete, frozen metal, etc.), which significantly reduces the technical and economic indicators of production [2].

The need to process such material is due to the fact that it contains a significant amount of valuable components (Na_3AlF_6, Al_2O_3, AlF), the extraction and reuse of which in the production of aluminum can help to increase the profitability of production [3-4]. It should be noted that it is not always possible to subject this raw material to enrichment operations in its primary form without preliminary preparation, since the material has a wide distribution by size classes. In this regard, for its efficient processing into the technological chain, it is necessary to introduce crushing operations.

The aim of the study was to study the effect of temperatures on the physical and mechanical characteristics of an alumina-containing estimate of aluminum production for preparation for subsequent processing operations.

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Research part

The object of the study was the estimate - waste located at the ± 0 m mark of the electrolysis shop of an aluminum production enterprise. The estimate is a heterogeneous material of a wide range of sizes, containing particles of alumina, electrolyte, silicon products, etc. A sample of the product, the particle size distribution of which is shown in Figure 1, was analyzed for the content of components (Table 1). The analyzes were performed on a VARIAN 730-ES optical emission spectrometer.

The largest content in the sample has the size classes – 0,315 + 0,16 mm in the volume of 29,85 % and the largest class + 2,5 mm – 37,22 %. The content of the material of the class - 70 + 40 mm, used for further studies to determine the crushing index, was 20,26 % of the total mass.

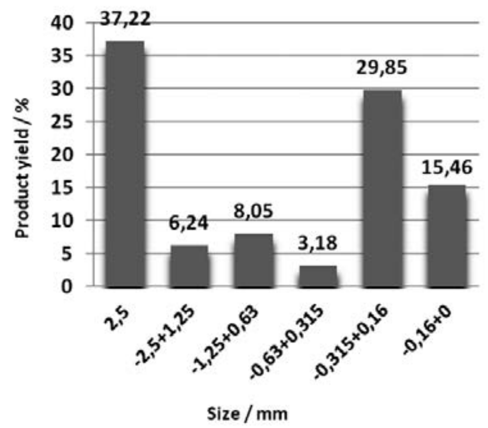

Figure 1 Granulometric composition

In the process of further research, part of the metallic aluminum was isolated in the form of unbreakable pieces of fractions + 20 mm and + 5 mm. The total yield of this product was about 2 %.

Table 1 **Chemical composition of the combined sample estimate**

	Mass fraction of an element / %							
Element	Al	Ca	Fe / Fe_2O_3	Mg	Mn	K	Na	Si / SiO_2
Content	30,18	2,59	0,22 / 0,847	0,177	0,0044	0,254	13,3	0,69 / 1,48

* The table shows the contents of the main elements. Data on the complete chemical analysis are presented in [5].

According to the results of the study of the phase composition of the samples, it was found that the estimate mainly consists of cryolite, chiolite, corundum, quartz, feldspar, carbonaceous matter and the technogenic phase of the composition (NaF) · $1{,}5CaF_2 \cdot AlF_3$. Samples differ only in the ratio of minerals. Optical and macroscopic studies have established that emission of metallic aluminum is associated with light particles, which is also found in the form of free individuals. A detailed study of the structure of the particles revealed that they are aggregates of various types (Fig. 2): massive, homogeneous in texture and structural parameters; lumpy porous formations, represented by an aggregate of smaller particles; man-made conglomerates - mixed aggregates of the above types.

Optical studies of the average fraction of the estimate found that the composition of the bulk material contains morphological types of particles, which correlate with the phase composition of the aggregates. Aggregates of white and light gray color are represented by compounds of fluorine, sodium, aluminum and calcium among themselves and in combination with a hydroxyl group, in which silica is present in the form of inclusions, as well as micro- and macro-inclusions of metallic aluminum. Dark particles are represented by compounds of iron and silicon.

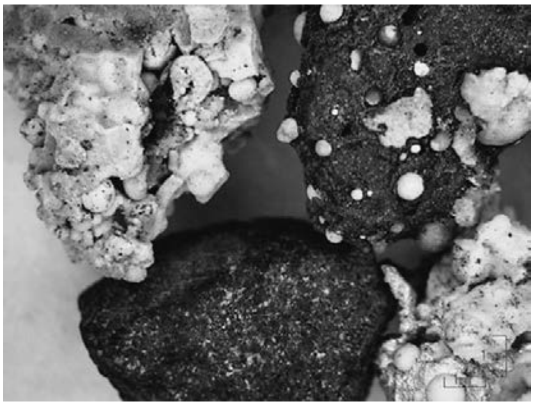

Figure 2 Lumpy aggregates of mineral phases of various compositions in a coarse fraction estimate of alumina

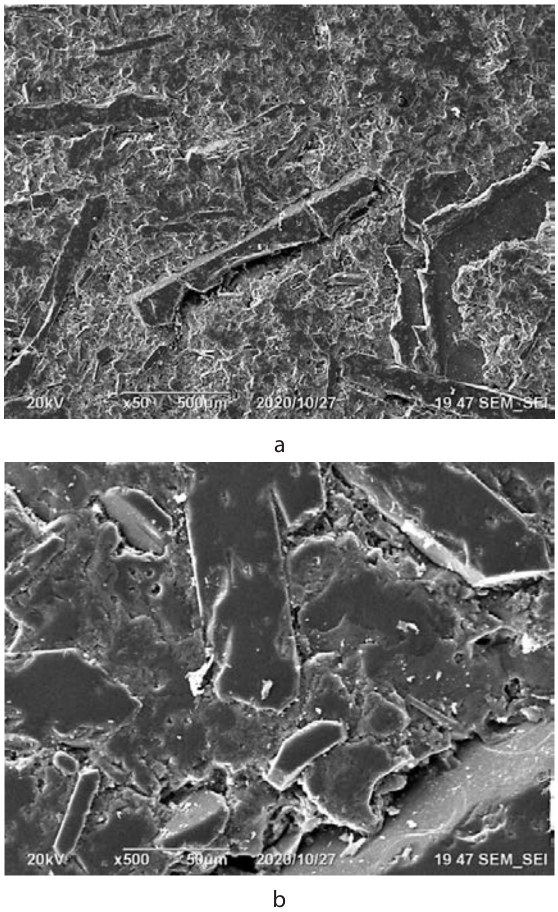

Figure 3 Photographs of the material surface: a - 50 times magnification, b - 500 times magnification

Additionally, on samples of material to determine the presence of impurities, studies were carried out using a JIB-4500 double-beam scanning microscope (multi-beam system) equipped with a LaB6 electron gun and an ion gun. Images of the material surface are shown in Figure 3,a,b.

The results of the images of the material surface showed the heterogeneity of the structure with a large number of inclusions of irregular shape and different sizes. A scanning microscope using the obtained characteristic X-ray radiation determined the qualitative and quantitative composition of the sample at the indicated points.

This made it possible to determine the elemental composition of aluminum-containing structures and contaminants on the surface of the material (Figures 4,5). The results in the tables 2,3 indicate the percentage of a particular element in the specified scan area.

Based on the microscopic studies carried out on the surface of the material, the presence of iron and silicon-containing minerals most likely contained in the technogenic phase was established. To determine the quality indicators, the material surface was mapped (Figure 6).

As a result of the analysis of the data obtained, the dissemination of minerals Si and Fe was recorded. In addition, the emulsion impregnation of iron can be present in metallic aluminum, which will require additional technological operations to isolate these compounds.

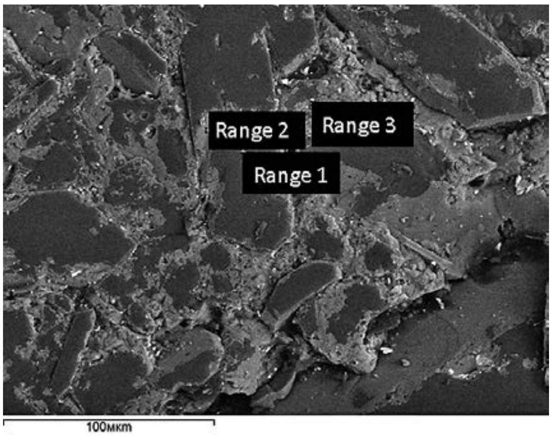

Figure 4 Photographs of the material surface with indication of the points of taking the spectrum.

Table 2 **Results of spectra at various points of the surface (sample a)**

Spectrum	Spectrum 1 / %	Spectrum 2 / %	Spectrum 3 / %
C	19,89	31,63	58,61
O	47,78	30,61	
F			29,55
Na			7,01
Al	28,62	37,76	3,41
Ca			1,42
Fe	1,29		
Si	2,42		

The choice of equipment for the disintegration of mineral and technogenic raw materials is an important stage in the development of materials processing technology. As a rule, the choice of grinding equipment is based on the Bond indices. The authors in work [6] on the destruction of alumina-containing estimates were studied: the working index of impact crushing (CWi), the working index of ball grinding (BWi) and the working index of abrasiveness (Ai). In [6], studies were carried out according to the classical method, which does not take into account the temperature characteristics of the material, as well as the fact that a large number of enterprises of the aluminum industry are located in the northern territories, where negative temperatures influence the process of destruction for subsequent processing. Often this fact is not

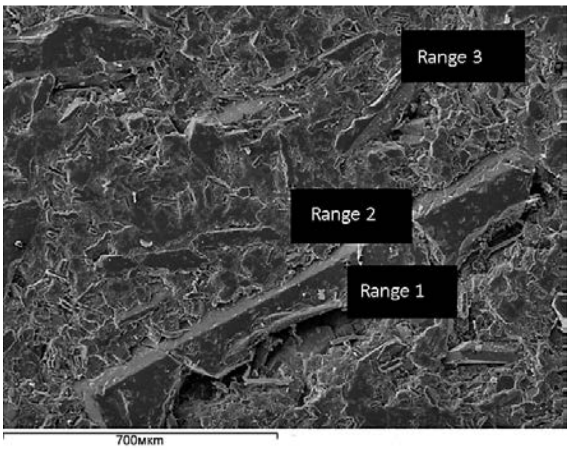

Figure 5 Photographs of the material surface with indication of the points of the spectrum.

Table 3 **Results of spectra at various points of the surface (sample b)**

Spectrum	Spectrum 1 / %	Spectrum 2 / %	Spectrum 3 / %
C	10,61	15,93	18,66
O	51,41	46,50	49,24
F			7,42
Na			1,12
Al	37,98	38,10	17,50
Ca			0,44
Fe			2,14
Si			1,75

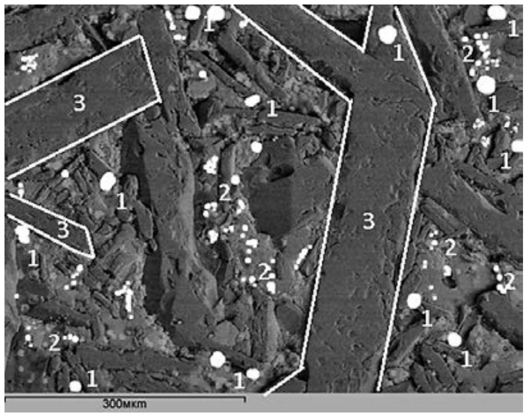

Figure 6 Results of mapping the material surface. Al- 1, Si-2, Fe-3

included in the calculation, which quite often leads to ultra-fast wear of both the destructive surface of the equipment and the kinematic units. In this regard, we initiated studies on the effect of temperatures on the strength of the alumina-containing estimate.

Experimental technique

The purpose of the experiment was to determine the strength of the material at different temperatures and the subsequent substantiation of the operating parameters of the crushing process, taking into account the structural features of the material. In the course of the study, three series of experiments were carried out: at room temperature 23 ° C, with heating the material in a drying chamber to 200 ° C, and also under cryogenic exposure – 195,75 ° C using liquid nitrogen. In four experiments, 20 samples of material were investigated with a piece size of 20 - 40 mm, 40 - 60 g each. After crushing, 5 weights are combined, sieved on a sieve with a hole size of 0,5 mm, the undersize product of the sieve is poured into a volumetric meter, the height of the column of fines is measured with a plunger.

The measurement results of each experiment are entered into the formula for determining the rock hardness coefficient δ:

$$\delta = \frac{20 \cdot n}{h},$$

where 20 is an empirical numerical coefficient that provides generally accepted values of the strength coefficient and takes into account the work spent on crushing;

n - the number of weight dropping when testing one sample;

h - the height of the column of the fine fraction in the volumetric meter after testing five portions, mm. The arithmetic mean of the results of four determinations is taken as the final test result.

RESULTS AND DISCUSSION

As a result of the study, 480 samples of material were analyzed and the following values of the strength of the samples tested at various temperatures were obtained (Figure 7).

Alumina-containing raw materials tested at temperatures of + 23, + 200 and –195.75 ° C according to the Protodyakonov fortress scale belong, respectively, to categories VII (soft), VIIa (rather soft) and VI (rather soft).

Fortress is a conditional concept that determines the total physical and mechanical properties of rocks (minerals). It increases with an increase in the strength of bonds between particles and separate (blocks) of rocks and the content of strong minerals in the rock and decreases, mainly, with moisture. In this connection, the moisture content of the material (W) was additionally studied, the average value of which was 2,314 %.

The increase in the strength index of the investigated alumina-containing raw materials with a change in temperature in the negative and positive sides can be explained by the heterogeneous phase composition of the alumina-containing raw materials, humidity and other factors. With an increase in temperature, an increase in the strength index is most likely associated with the removal of moisture and, as a result, strengthening of structural bonds between material particles. This effect is observed, for example, when comparing the curves of differential thermal analysis and measuring the compressive strength in the manufacture of ceramics, one of the main components of which is also alumina.

The influence of negative temperatures on an increase in the strength of alumina-containing raw materials is determined by an increase in strength characteristics arising from the phase transition of capillary and adsorption water into ice, which has a cementing effect. In addition, with a decrease in temperature, the compressive strength is influenced not only by the ice content and the presence of unfrozen water, but also by the change in the ice strength, the intensity of which increases according to a complex law. Also, the compressive strength depends on time (application of a load, instantaneous or long-term, since ice under the influence of instantaneous loads considered in this study has a high strength characteristic.

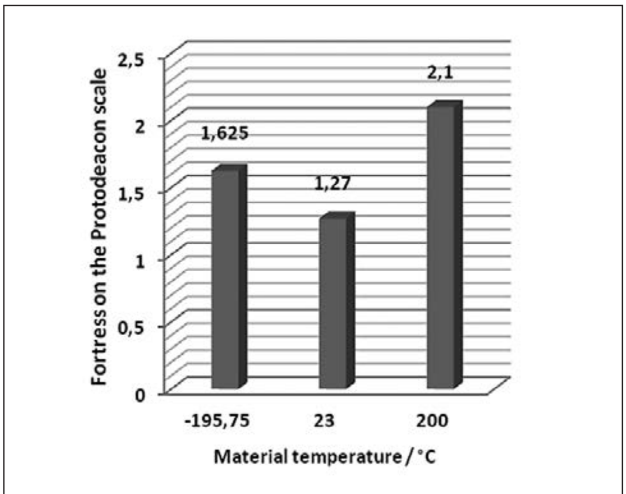

Figure 7 Values of the strength index of alumina-containing raw materials.

Along with this, an increase in the strength index can also be associated with an increase in the elastic properties of the material under study, the elastic modulus in some cases increases at sharply negative and positive temperatures.

In this regard, it can be argued that for the correct choice of crushing equipment when processing alumina-containing estimates, additional tests are required.

CONCLUSION

On the basis of the studies carried out, a significant effect of temperature on the change in the fortress of the alumina-containing estimate has been established, which is an important factor for optimizing the crushing processes in the schemes for preparing technogenic raw materials for secondary use. It is especially important to take this factor into account when choosing crushing and grinding equipment when enterprises operate in conditions of low air temperatures in the northern territories, which will reduce energy costs for unproductive work to destroy material with increased strength characteristics, reduce downtime due to accidents and breakdowns of equipment, and generally improve the efficiency of its work.

REFERENCES

[1] Dou, Y.-H., Liu, Y., Liu, Y.-B., Xia, Q.-B.,. Effect of Si content on friction-wear properties of high-silicon aluminum alloys fabricated by mechanical alloying and hot pressing. Fenmo Yejin Cailiao Kexue yu Gongcheng 18 (2013), 669–674.

[2] Mehdi, H., Effect of Silicon content on the Mechanical Properties of Aluminum Alloy. International Research Journal of Engineering and Technology 2 (2015), 1326–1330.

[3] Mann, V., Buzunov, V., Pingin, V., Zherdev, A., Grigoriev, V., Environmental aspects of uc rusal's aluminum smelters sustainable development. Minerals, Metals and Materials Series (2019), 553–563.

[4] Shabanov, Y., Baisanov, S., Grigorovich, K., Baisanova, A., Toleukadyr, R., Saulebek, Z., 2020. Recovery of low-carbon ferrochrome with multi-component aluminum-silicon-chrome (Al-Si-Cr) alloy. Metalurgija 59 (2020) 4, 514–516.

[5] Burdonov, A.E., Zelinskaya, E.V., Gavrilenko, L.V., Gavrilenko, A.A., Investigation of substantial composition of alumina-bearing material of aluminium electrolysers for usage in primary aluminium technology. Tsvetnye Metally 3 (2018), 32–38.

[6] Burdonov, A.E., Barakhtenko, V.V.,Prokhorov, K.V., Gavrilenko, A.A., Results of studies of disintegration working indices for alumina-containing wastes. Obogashchenie Rud 4 (2018), 11–16.

Note: The responsible translator for the English language is Alexander Garashchenko – English-speaking translator in Irkutsk, Russia