Effect of bauxite grain size distribution on beneficiation and improvement of materials

Olga B. Kotova ▪ Institute of Geology, FRC Komi SC, UB RAS, Russian Federation ▪ kotova@geo.komisc.ru

Ilia N. Razmyslov ▪ Institute of Geology, FRC Komi SC, UB RAS, Russian Federation ▪ razmyslov-i@mail.ru

Emese Kurovics ▪ Institute of Ceramics and Polymer Engineering, University of Miskolc, Hungary ▪ fememese@uni-miskolc.hu

Aleksandr I. Lvovsky ▪ MIREA, Russia ▪ alekslvo@yandex.ru

László A. Gömze ▪ Institute of Ceramics and Polymer Engineering, University of Miskolc, Hungary ▪ femgomze@uni-miskolc.hu

Abstract

The rational use of the constituent aluminum-containing ores in the industry to create new functional materials is one of the promising trends of mineral processing and engineering. Chemical analysis was carried out by X-ray fluorescence method using Horiba MESA 500. Shimadsu XRD-6000 device was used for X-ray diffraction analysis. The particle size distribution was determined by LS 13 320 XR laser particle size analyzer (Beckman Coulter).

We compared results of X-ray phase and granulometric analyses. It was shown that the technology of deep fractionation of particles of high-iron bauxites and kaolinite clays improved the quality of raw materials and efficiency of use of minerals in enrichment processes and various industries, when creating functional materials.

Keywords: particle size distribution, high-iron bauxites, kaolinite clays, functional materials

Kulcsszavak: szemcseeloszlás, magas vastartalmú bauxitok, kaolinok, funkcionális anyagok

Olga B. Kotova
is Head of Laboratory of Technology of Mineral Raw, Institute of Geology Komi SC UB Russian Academy of Sciences. Author and co-author of 10 books, 4 patents and more than 200 scientific articles. President of ICAM-2019. The member of Science Council of Russian Mineralogical Society.

Ilia N. Razmyslov
is Junior Researcher, Laboratory of Comprehensive Assessment and Engineering of Georesources, Institute of Geology, FRC Komi SC, UB RAS. Author and co-author of 6 articles.
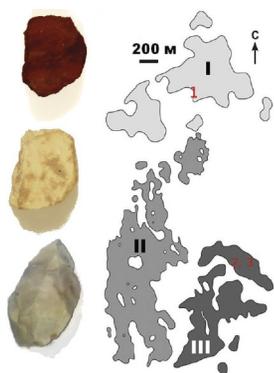
Emese Kurovics
is graduated from the University of Miskolc, Department of Ceramics and Silicate Engineering as a material engineer, where she continues her study as PhD student under supervision of Prof. L. A. Gömze

Aleksander I. Lvovsky
is Engineer of the Department of Chemistry and Technology of Rare and Scattered Elements and Nanoscale composite materials named after K.A. Bolshakov of Russian Technological University (MIREA), Moscow, Russia. He is the author of 12 scientific articles, three copyright certificates and two patents.

Laszlo A. Gomze
is establisher and professor of the Dept. of Ceramics and Silicate Engineering at Institute of Ceramics and Polymer Engineering, University of Miskolc

1. Introduction

Rising production and consumption of functional materials based on aluminum raw materials results in reducing mineral resources and formation of large volumes of wastes [1]. Environmental problems are becoming more pronounced. We need to find special ways to solve them. Information about the grain size distribution of bauxite plays a significant role in optimization of production systems in various branches of industry [2].

Middle Timan bauxites (Russia) – a valuable raw for aluminum production. Kaolinite clays and white bauxites are used to produce refractories. Middle Timan bauxites and kaolinite clays are genetically related; kaolinite clays, as a result of decomposition and removal of silica, were the basis for the formation of white bauxites. Their genetic affinity determines the similarity of their technological properties [4]. The main aluminum-containing mineral of the Middle Timan bauxites, boehmite, is also a component of kaolinite clays. For the successful development of aluminum-containing mineral raw and the development of technologies for its processing, it is necessary to know not only the chemical and mineral composition of the ores, but also their structural characteristics, including their granulometry.

The granulometric composition of the constituents of aluminum-containing ores is very important to determine the degree of grinding in technological processes. At present, grinding processes are the most energy-consuming, at the same time, under-grinding results in losses in processing of bauxite ore into alumina [5]. A significant part of the ore substance is concentrated in the finely dispersed and X-ray amorphous phases. This fraction of bauxite and clays can be used as a sorbent of heavy metals, nuclides and other pollutants, become a raw material for producing metals, and can be used in the building industry (for example, in the production of cement) [6-13].

In [5] the authors provide data on X-ray and synchrotron small-angle scattering. They note that finely dispersed particles of the order of 40 nm prevail in Middle Timan bauxites. The granulometric methods, tested earlier, have several drawbacks (the small-angle scattering method is limited to the range of 0.001-1 mcm and shows only effective particle sizes; the sieve analysis is limited for small particle sizes; the sedimentation method, based on the Stokes formula, does not take into account the real particle shape, for large particles it gives increased error, and for small particles requires a significant measurement duration), while the laser diffraction method is free from these drawbacks and gives a differential particle size distribution in a wide range of sizes (from tens nanometers to a few millimeters) with a high accuracy.

This work is devoted to identifying granulometric composition of bauxites and kaolinite clays (Vezhayu-Vorykvinskoe deposit, Russia) by laser diffraction to increase efficiency of use of minerals use in industry and to improve materials.

2. Materials ant experiments

2.1 Materials

We used samples of high-iron (VV-3) and low-iron (MZB-1) varieties of bauxites and kaolinite clays (VVK) (Vezhayu-Vorykvinskoe deposit, Russia).

1. ábra Az alumíniumtartalmú nyers (balra) vizsgált típusai és a Vezhayu-Vorykvinskoe érclelőhelyeinek elhelyezkedése, Közép-Timán, Oroszország (jobbra). Felülről lefelé: hematit-boehmite bauxit, berthierine-boehmite alacsony vastartalmú bauxit, kaolinit agyag

Fig. 1 The studied types of aluminum-containing raw (left) and map of location of ore bodies of the Vezhayu-Vorykvinskoe deposit, Middle Timan, Russia (right). Top-down: hematite-boehmite bauxite, berthierine-boehmite low-iron bauxite, kaolinite clay

2.2 Methods of investigations

We measured the particles by laser analyzer LS 13 320 XR (Beckman-Coulter, USA). This instrument structurally combines the laser diffraction method with PIDS (Polarization Intensity Differential Scattering) to increase resolution and to ensure reliable measurement of submicron particles. The analyzer allows determining distribution of particles in the range from 10 nanometers to 3.5 millimeters.

The laser diffraction method uses the angular dependence of the intensity of the scattered light on the particle size. The indicated dependence is described by mathematical models of Fraunhofer and G. Mie. The Fraunhofer model is applicable for a particle size of at least 4-6 microns. This model is incorrect for smaller particles. To measure particles smaller than the specified size, it is necessary to use the G. Mie model, while the calculations take into account the refractive index of the particle material and the dispersion medium. For large particles, both models work equally correctly.

For reliable and reliable measurement of submicron particles, LS 13 320 XR analyzer uses PIDS technology based on the phenomenon of different intensities of scattering of vertically and horizontally polarized light. The specified technology provides a lower limit 10 nanometers.

Chemical analysis was carried out by X-ray fluorescence method using Horiba MESA 500; Shimadsu XRD-6000 instrument was used for X-ray diffraction analysis.

3. Results and discussion

3.1 Chemical composition

Table 1 shows that the bauxite samples are of high quality, with a high aluminum content, high silicon module (SM). VV-3 sample is a ferruginous variety of bauxite with SM 12.7. SM of MZB-1 sample–7.75. The bauxites are suitable for processing by the Bayer method. Kaolinite SM–VVK 0.85.

3.2 Mineralogical analysis

Phase analysis (*Fig. 2*) of the initial samples shows that ferriferous brown bauxite contains boehmite (predominant), hematite, goethite,

gibbsite, rutile and possibly anatase. Low-iron bauxite contains boehmite, kaolinite, rutile, hematite as impurities. We determine kaolinite, boehmite, diaspore and rutile in kaolinite clay. *Table 2* shows approximate contents of basic minerals for each sample.

Samples	Content, %							
	Al₂O₃	Fe₂O₃	SiO₂	TiO₂	CaO	MgO	LOI	Sum
VV3	61.02	18.22	4.80	2.46	2.24	0.30	10.97	100.00
MZB-1	73.36	1.56	9.46	2.94	0.10	0.16	12.41	100.00
VVK	38.74	1.21	45.62	1.52	0.26	0.28	12.37	100.00

1. táblázat A vizsgált minták kémiai összetétele
Table 1 Chemical composition of the studied samples
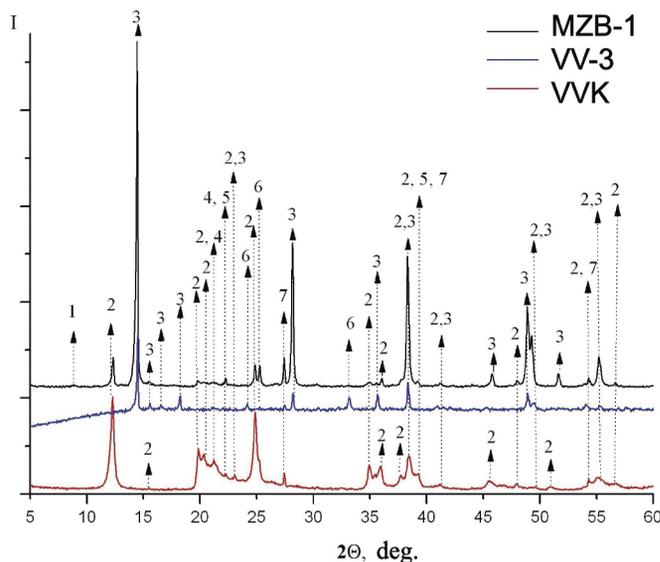
2. ábra A vizsgált minták röntgendiffraktogramjai. A számok a következő ásványoknak megfelelő csúcspozíciókat jelzik: 1 - földpát, 2 - kaolinit, 3 - boehmit, 4 - goetit, 5 - diaszpóra, 6 - hematit, 7 - rutil

Fig. 2 X-ray patterns of the studied samples. Numbers indicate peak positions corresponding to the following minerals: 1 - feldspar, 2 - kaolinite, 3 - boehmite, 4 - goethite, 5 - diaspore, 6 - hematite, 7 - rutile

Samples	Mineral phases, mass /volume fractions*, %				
	boehmite	hematite, goethite	Gibbsite	kaolinite, silica minerals	rutile, anatase
VV-3	39-40/47	36 (28+8)**/24	1-2/1.5	16/22	6/5
MZB-1	50-51/49	3-4/2	-	38/43	8/6
VVK	16-17/14	1-2/1	-	78-80/83	2/1.2

2. táblázat A vizsgált minták ásványi összetétele
*Table 2* Mineral composition of the studied samples

* Volume fraction was calculated by weight contents and by densities ρ (g/l): boehmite - 3.02; hematite - 5.26; gibbsite - 2.3; kaolinite - 2.6; rutile - 4.2
** Hematite and goethite contents are shown in parentheses, respectively, based on the comparison of Mössbauer spectroscopy data

3.3 Granulometric analysis

A significant part of bauxite substance is represented by a fine component, which complicates bauxite processing by

such traditional methods as magnetic separation. In [12, 13] the authors show that during crushing and grinding up to 90% of hematite of boehmite bauxite goes to 45 mcm class, and about 70% — to–20 mcm. The granulometric distribution and chemical composition for various size fractions of hematite-boehmite bauxite (VV-3 sample) are shown in *Fig. 3*.
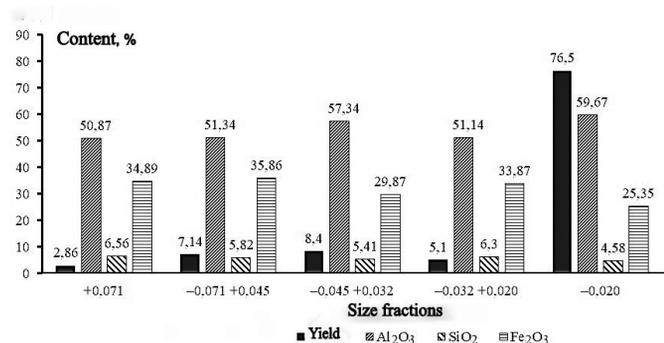
3. ábra   A VV-3 minta. Az alapvető bauxit-oxidok megoszlása méret szerint
Fig. 3   VV-3 sample. Distribution of basic bauxite oxides by size

From the data on the material composition of these fractions it follows that the information is important both for preliminary processing of bauxite ore and selection of beneficiation technologies [6, 17], and when creating functional materials in various industries (X-ray radiation-shielding materials, ceramics, etc.) [18-20].

The authors [5] note that in Middle Timan bauxites, boehmite grains are concentrated in -5 μm class, a significant part of hematite and goethite are also concentrated in thin class (–0.5 μm), a gradual increase in the content of silicon dioxide is observed as reduction of grains from 10 mcm to 1 mcm and its sharp increase in the class –1 mcm, the latter is associated with the predominance of kaolinite, chamosite (berthierine).

A similar dependence was noted in [21], where, according to the distribution of the main kaolin oxides from the Zhuravlinny Log deposit, the content of iron and aluminum oxides increased for small classes. The Al_2O_3 content increases with decreasing size class: in the class 20-63 microns – 22.7%; in the class 10-2 microns – up to 33.2%; in the class 5-10 microns 36.2%; in -5 mcm – 36.93%. For the content of iron oxides, a multiple increase is observed in the fraction -5 microns, from 0.61% for the class 63-20 microns, to 1.27% for the class -5 microns. At the same time, a significant part of the kaolinite substance is in the fine fraction -63 microns – about 55.2% of the substance, and for -5 mcm – 35.6%.

Thus, the analysis of the composition of bauxite and kaolins by class showed the dependence of the content of certain minerals on particle sizes.

Using a laser particle analyzer, we established the size distribution of particles for a highly dispersed (clay) fraction, which accounts for 20-30% of the ore substance. The obtained data on the particle size distribution are presented in the form of graphs in *Fig. 4*.

The graphs have local extremes corresponding to several fractions. A general range from 0.3 to 20 mcm is observed for all samples.
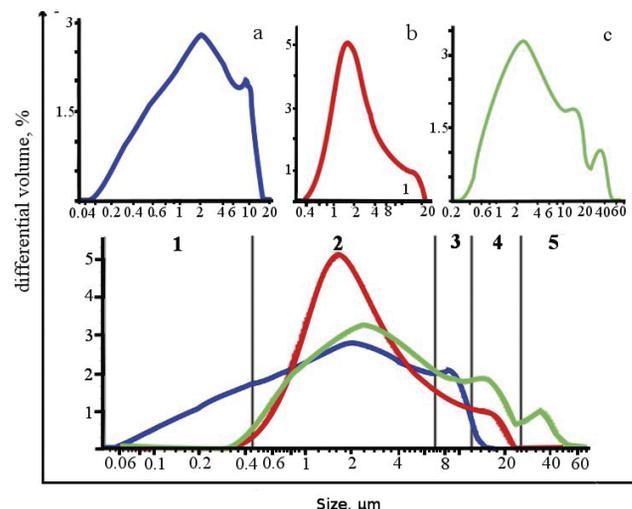
4. ábra   A Vezhayu-Vorykvinskoe lelőhely nyílt gödöréből származó minták szemcseméretének megoszlása (kék - VV-3, piros - MZB-1, zöld - VVK). A számok a mély frakcionálás feltételes zónáit jelzik: 1 - hematit-goetit, 2 - boehmit, 3-5 szilikát (szilícium-dioxid, alumínium-szilikátok, berthierine), 4 - titán (rutil, anatáz)
Fig. 4   Differential particle size distribution for samples from open pits of the Vezhayu-Vorykvinskoe deposit (blue - VV-3, red - MZB-1, green - VVK). The numbers indicate conditional zones of deep fractionation: 1 - hematite-goethite, 2 - boehmite, 3-5 silicate (silica, aluminosilicates, berthierine), 4 - titanium (rutile, anatase)

The particle size distribution for each sample has its own specifics (see *Fig. 3*). Comparison of the data of X-ray phase and particle size analyses, as well as literature, showed that the number of mineral phases correlated with the number of local extremes. In *Fig. 4* several zones, corresponding to the mineral phases (hematite-goethite, boehmite silicate, titanium, silicate kaolinite), can be distinguished.

There is a correlation in the distribution of volume fractions of the substance of bauxite and kaolinite clays in the ranges of these fractions (*Table 3*). The results conform with published data on the distribution of boehmite, hematite, goethite, and silica-containing minerals in the clay fraction [5].

Innovative processing methods are being developed for fine bauxite and kaolinite clay substances. For example, in [22-24] the authors show that radiation-thermal treatment in the studied

Size fractions, mcm	0,01-0,5	0,5-6	6-10	10-25	25-60
Ranges	1	2	3	4	5
Mineral phases	hematite- goethite	boehmite	silicate	titanium	silicate-kaolinite
Samples			Volume, %		
VV-3	24.42	61.66	1.47	2.49	-
MZB	1.7	83.29	8.25	6.76	-
VVK	2.5	66.77	11.87	14.17	4.7

3. táblázat   A bauxit és a kaolinit agyagok térfogatfrakcióinak megoszlása
Table 3   Distribution of volume fractions of substance of bauxite and kaolinite clays in the ranges of these fractions

iron bauxites results in a significant phase heterogenization, which opens the possibility of efficient extraction of industrial components from non-standard bauxites and red muds by environment-friendly methods.

4. Conclusions

The article compares data of X-ray phase and particle size analyses. Based on them, we have revealed a correlation between mineral phases of samples of Al ores of the Vezhayu-Vorykvinskoe deposit and corresponding extrema on the differential particle size distribution curves. The particle size distribution curves depend on the degree of resistance of mineral aggregates to mechanical stress, which is conditioned by the composition of these aggregates. Such technologies are promising for express assessment of quality of the ores at bauxite deposits.

New methods and approaches to technologies of deep fractionation of high-iron bauxite and kaolinite clays using LS 13 320 XR particle analyzer (based on the laser diffraction method and PIDS technology) allow determining particle size distribution and correlate ranges of size fractions with volume fractions of the specified minerals (boehmite, hematite, goethite and silica-containing minerals) and, thus, contribute to improve the quality of raw materials and the efficiency of mineral use in industry, when creating functional materials.

Acknowledgments

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