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STRUCTURE AND PROPERTY CHANGE OF TECHNOGENIC RAW MATERIAL SAMPLES AS A RESULT OF ELECTRIC PULSE PROCESSING

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This paper presents the problems and prospects of application of electric pulse technology for crushing and grinding of inorganic materials. Using scanning electron microscopy, a spectral analysis of samples of technogenic raw materials from Nurkazgan field was made after mechanical grinding and after electric pulse processing. The results of X-ray spectral microanalysis, obtained by using the ZAF method, show changes in microstructure and elemental composition of the samples of industrial raw materials as a result of electric pulse processing. It was established that the technology of electric pulse crushing and grinding of inorganic materials makes it possible to obtain not only a final product with desired size of fragmented particles, but also to change their physical and chemical properties. The results of the spectral analysis show an ambiguous effect of different modes of electric pulse processing on structure and elemental composition of raw material.

Keywords: underextracted metals, technogenic raw materials, "poor" ore, electric pulse processing, spectrophotometric analysis.

Introduction

The development of electrical engineering and electronics industry has increased the use of non-ferrous and rare metals, the demand for which is constantly increasing. Their extraction requires significant financial and labour intensive technological expenses due to the necessity to use technogenic raw materials and processed ores waste which quantity is constantly increasing. Therefore, in recent decades great attention is paid to the development of waste-free environmentally friendly methods of processing of industrial raw materials and low-grade ores. The relevance of this trend is substantiated by the fact that under extracted metals reduce economic and ecological parameters of ore processing. Methods of processing and enrichment should be primarily environmentally friendly, technologically and instrumentally easy, and effective to provide an increase in the degree of extraction fullness. The known methods of ore and concentrates processing of rare, precious, non-ferrous metals and existing industrial facilities using chemical and mechanical methods of processing of technogenic raw materials, require a lot of energy, but do not provide complete yield of net product. Their common drawback is the low efficiency and harmful ecological impact on the environment. Therefore, the considered technology of electric pulse disintegration of low-grade ores and industrial raw materials is strategically important and timely for the development of the domestic processing industry. The article deals with various aspects of the new processing technology of metal-containing and technogenic raw materials by electric pulse crushing and grinding in an aqueous medium to form the final particulate product with the preset parameters of the particles.

Problem statement

The importance of studying and development of electric pulse technologies that are more effective and economical as compared to conventional mechanical methods of materials processing, is caused by many factors, such as the need to optimize energy costs in technological processes of hard rocks crushing and disintegration, processing of accumulated recyclable tailings and waste rocks [1-3].

Mining and metallurgical industry in Kazakhstan is a strategic sector of the economy, which is focused on the export of raw materials and primary metals. Its priority task is gradual establishment of new processing facilities of metallurgical industry related to the output of products with high added value, ensuring both the growth of high-tech products output with expanding its exports to foreign markets and meeting the needs of the domestic market. The state policy of the development of mining and metallurgical industry of the country is aimed at stimulating the production of basic metals by large enterprises and the creation facilities of the final production of high quality products based on the processing of basic raw materials by small and medium-sized enterprises.

56 enterprises of non-ferrous metallurgy, 14 gold producing mills, 9 concentrating plants of ferrous metallurgy and 16 crushing and grading plants operate in Kazakhstan. During the decades of intensive mining and mineral processing, a huge amount of industrial waste has been accumulated in Kazakhstan. It must be regarded as an independent source of raw materials for metallurgical industry of the country. At the first Kazakhstan international congress on mineral resources and metallurgy, President Nursultan Nazarbayev said that " now in the country there has been accumulated in total more than 30 billion tons of secondary resources, including 20 billion tons of technogenic waste in mining and metallurgical industry", of which more than a third are toxic [4]. Annually about 700 million tons of industrial waste are generated, of which about 250 million tons are toxic. Just less than 2% of industrial waste is processed and recovered in the country.

Deposits of ferrous, non-ferrous, precious and rare metals in Kazakhstan are characterized by a low content of components that generates a need for pre-concentration of the mined ore. Ore concentration is accompanied by accumulation of large amounts of tailings, the output of which is 60-70%. The solution to economic and environmental problems of mining enterprises is possible through the introduction of new technologies of extraction and processing of ores with complete technological cycle of production and integrated waste management system for various technogenic mineral raw materials.

The importance of waste recycling system and the transition to resource-saving and integrated utilization of extracted non-ferrous, precious and rare metals is essential in order to improve the ecological situation, especially in areas with large amount of mineral mining enterprises, iron and steel plants and chemical companies. The most energy- and labour-intensive stage of raw material processing is obtaining fractions with desired degree of fineness, and this is important both during its enrichment, and for the subsequent processing. Mineral raw materials during processing are subjected to a series of successive operations, conventionally divided into preparatory, enrichment and auxiliary ones [5,6]. During ore dressing by machining, the chemical composition of the ore remains unchanged, only the ratio between the valuable minerals and waste rock changes in the original stock and the concentrate. The method of ore reduction proposed by the authors is based on the use of energy of the impulse shock wave resulting from a spark discharge in a liquid. It makes possible to find ways to solve a number of problems associated with the processing and enrichment of mineral and technogenic raw materials [7].

The experimental technique

Possibility to control the energy level in the discharge channel and the duration of the energy release, i.e. changing the electrical pulse repetition rate in combination with electrode systems of various design make it possible to change the processing mode depending on the properties of the raw material. It is possible to change the granulometric composition of the product by varying the parameters of a single impulse or series of them during electric pulse disintegration of the material. Analysis of the effect of electric pulse processing was carried out on the basis of comparison of the properties and structure of metal-containing and industrial raw materials after their machining and electric pulse processing with varying amounts of electrical discharges. To ensure identical conditions, the original raw material was ground to fractions size within the range $(0.1\text{-}0.5)*10^{-3}$m by machining and electric pulse processing.

Within the framework of this project a vibrating cone crushing mill VCCM-6 produced at the plant "Vibrotehnik", St. Petersburg, Russia was purchased for mechanical crushing and grinding of samples of raw materials.

The electric pulse processing of the technogenic raw materials samples was carried out with different amounts of electric discharges: n = 500, 750, 1000, 1250. In each case, the samples were ground to an identical degree of fraction fineness (size). It was achieved by varying other electrical parameters. The electric pulse processing was carried out by changing the interelectrode distance within the range $l_d = 3 \div 14 \cdot 10^{-3}\, m$ while adjusting the values of supplied pulse voltage $U = 8 \cdot 10^3 V \div 40 \cdot 10^3 V$. The capacitance value of the capacitor bank varied within $C = (0{,}25; 0{,}5; 0{,}75) \cdot 10^{-6}\, F$. The operational blocks, functional principle and electro-technical parameters of the electric pulse plant are described in detail in [7-9].

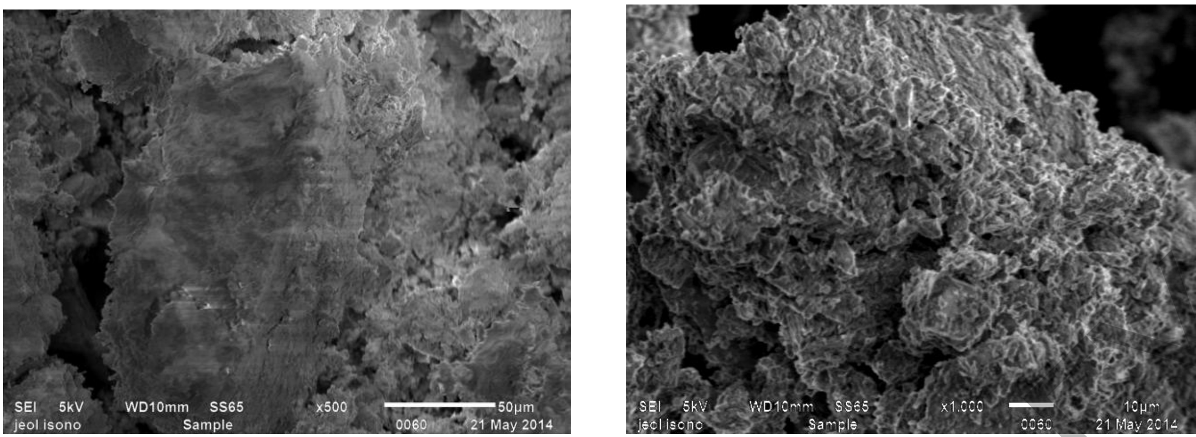
In order to ensure, the processing of each sample was carried out under the same conditions at least 5-7 times. Four trials of tests were conducted using the electric pulse crushing plant and one trial was carried out by a vibration cone crushing mill VCCM-6. To obtain accurate data, 5 processed samples were taken from each series of samples, for each of them photographs at various photographic enlargement were taken.

The microstructure and elemental composition of the processed samples of raw materials were investigated by means of spectrophotometric analysis at the scanning electron microscope JEOL, JED-2300, in Kazakhstan-Japan Centre, Almaty. Experiments using the electron microscope JEOL were carried out under the following basic parameters: Acc. Voltage: 7.0 kV; Probe Current: 1.00000 nA; Real time: 30.56 sec; Energy Range: 0-20 keV; Counting Rate: 961cps. The results of X-ray spectral microanalysis were obtained by using a rather known sufficiently accurate ZAF method, which includes three types of corrections in the data retrieval [10]. These corrections are represented in the title and indicate: Z_i - correction for difference in an average atomic number between the sample and reference standard, it is due to reflection and deceleration of electrons; A_i - correction for the absorption of X-rays in the sample, it is determined by the energy of the probe, emergent X-ray angle and mass absorption coefficient for the element of interest in the sample; F_i - correction for fluorescence due to excitation by the secondary X-ray emission of the *i* element by the radiation of other elements and by deceleration radiation.

Results and discussion

Investigations of the possibility to influence the dimensional characteristics of the finished product were carried out on mineral raw materials, such as metal-containing raw materials of the second-stage crushed ore from Nurkazgan field in Karaganda region. Figures 1-3 show photographs of the microstructure of technogenic raw materials samples from Nurkazgan mine after machining and electric pulse processing.

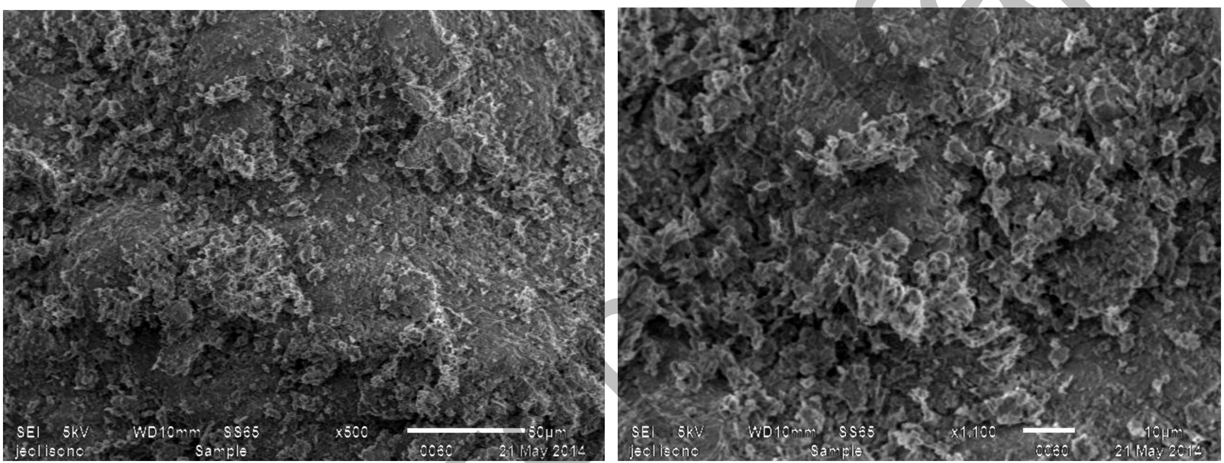
It is seen that after electric pulse processing, a complex structure of dislocations, microcracks and pores is formed in the samples of technogenic raw materials, concentrate and "waste" rock. Dislocations observed after electric pulse processing, differ both in shape and size. Instead of bulk three-dimensional tangling of dislocations there dominate their planar distribution. One of the reasons for this change in the dislocation structure caused by electric pulse processing effect is apparently an increased resistance to cross gliding. As soon as the first dislocations occur, they weaken the interatomic bonds and facilitate the subsequent motion of dislocations in the same way. Properties of dislocations in the concentrate are still poorly known in view of the complexity of these structures. Figure 4 shows energy spectra, obtained using the scanning electron microscope JEOL. On the horizontal axis there are the values of the energy (keV).



a) b)

magnification: a) by 500 times; b) by 1,000 times

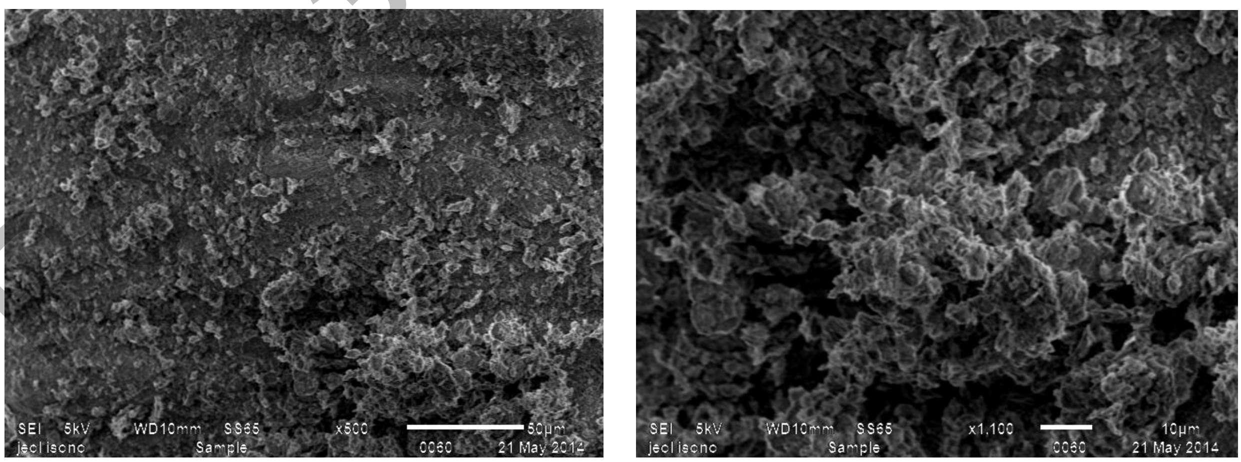
Fig.1. Photographs of the microstructure of technogenic raw materials from Nurkazgan mine after machining



a) b)

n = 500, magnification: a) by 500 times; b) by 1,000 times

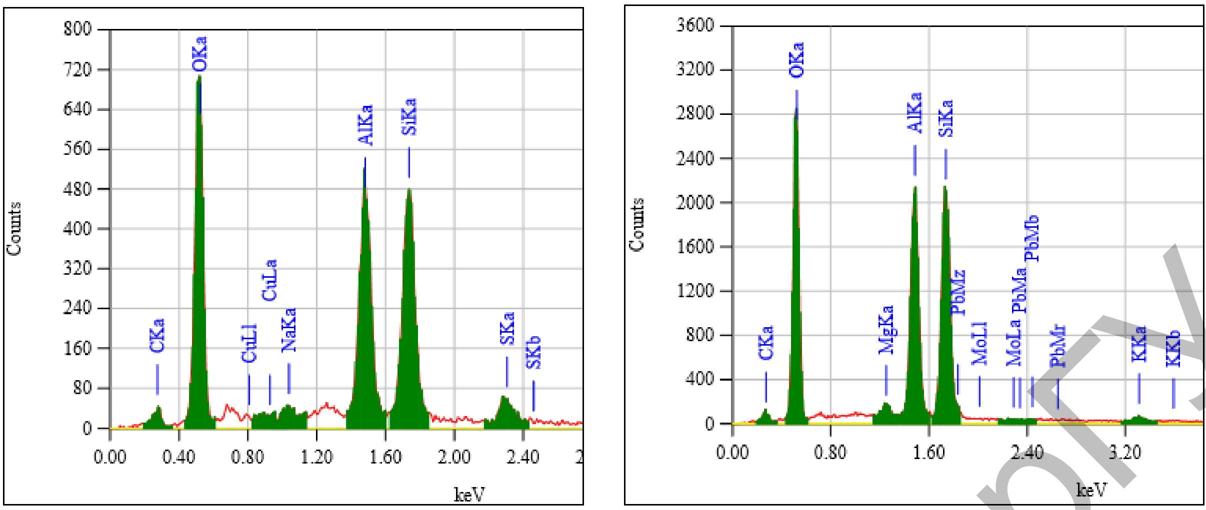
Fig.2. Photographs of the microstructure of technogenic raw materials from Nurkazgan mine after electric pulse processing



a) b)

magnification: a) by 500 times; b) by 1,000 times

Fig.3. Photographs of the microstructure of technogenic raw materials from Nurkazgan mine after electric pulse processing, n = 750



a) b)

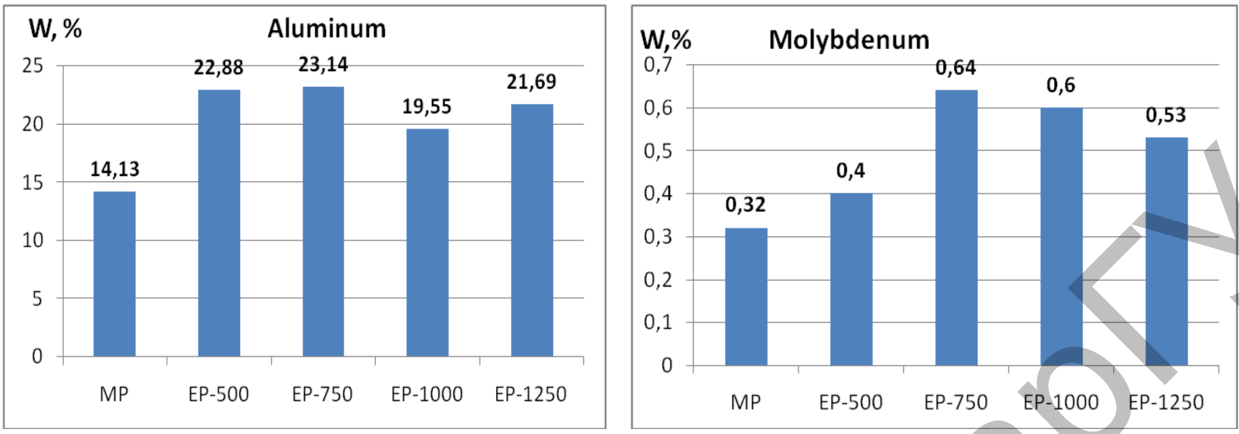
Fig.4. Energy spectra of samples of technogenic raw materials from Nurkazgan mine after: a) machining; b) electric pulse processing when n=1250.

The energy spectra show that the intensity of aluminum and silicon lines after electric pulse processing increased more than three times, there appeared lines of molybdenum, magnesium and others. Photographs of the microstructure and the corresponding spectra of the energy intensity were taken for all the samples. They clearly show changes in the main luminosity maxima of particular chemical elements in accordance with the electric pulse processing mode. The dynamics analysis of the obtained energy spectra of percentage of the elements W,% after machining and electric pulse processing shows that there are changes in the structure and chemical composition of the samples under processing. The resulting experimental data are shown in Table 1, where the numerical data of the mass concentration W,% were defined as the average of five repeated measurements.

Table 1. The elemental composition of technogenic raw materials samples from Nurkazgan mine

Element	Mass concentration of the elements W,% after:				
	machining	electric pulse processing (EP) with the number of electric discharges:			
		n = 500	n = 750	n = 1000	n = 1250
C	3,71	4,97	4,28	6,54	6,42
Na	0,44	0,66	0,51	0,7	0,57
Mg	0,86	1,18	1,36	1,14	1,17
Al	14,13	22,88	**23,14**	19,55	21,69
Si	17,68	**29,01**	28,84	25,57	27,74
Mo	0,32	0,4	**0,64**	0,6	0,53
Pb	1,28	1,72	1,53	1,24	0,78
K	8,25	9,86	10,2	7,45	8,56

Fig.5 shows the mass concentration diagram for aluminum and molybdenum, depending on the type and mode of processing. The results show that when increasing the number of discharges, some metals seem as if melt out; their concentration decreases. At the same time, the content of aluminum and molybdenum grow after the electric pulse processing, their maximum concentration is observed in the sample processed when the number of electric discharges n=750 (EP-750). But when the number of discharges increases during electric pulse processing, their concentration slightly decreases. The maximum concentration of silicon is observed after the electric pulse processing when n=500 discharges.



a) b)

Fig.5. Changes in mass concentration after processing the samples of raw materials from Nurkazgan mine: a) aluminum; b) molybdenum.

The spectral analysis shows the ambiguous impact of different modes of electric pulse processing on the concentration of chemical elements such as C, Na, Mg, K and others. In the course of experiments, the optimal electrical and technical parameters were determined in order to obtain the final particulate product with desired fractions parameters with respect to characteristics of processed raw materials. Despite obtaining a slight increase in the concentration of elements, in terms of accumulated tons of processed metal-containing and industrial raw materials, in practice, the net effect is a significant increase in the extraction of valuable and necessary elements.

Conclusion

The proposed technology of electric pulse processing of ore and technogenic raw materials is based on use of the pulse shock wave energy resulting from a spark discharge in a liquid.

Practice confirmed that the electric pulse technology of disintegration of metal-containing and industrial materials makes it possible not only to get quickly a finished particulate product with preset parameters of the particles, but it also can provide a more complete extraction of valuable components, reextracting them into saleable concentrates due to the simultaneous changes in the structure and properties of those particles. It is confirmed by X-ray spectral analysis of the samples of technogenic raw materials not only from Nurkazgan field, but also samples of industrial raw materials and "waste" (poor) rocks from Annensk and Akshatau mines in Central Kazakhstan [9, 11,12]. The experimental studies showed that the developed electric pulse technology provides more complete extraction of valuable components from industrial materials and utilization of mining and metallurgical industry waste.

In the future, the introduction of resource-saving environmentally friendly way with reasonable technological scheme of extraction of rare metals from metal-containing and industrial raw materials will make it possible to create a new, research-intensive, innovative domestic electric pulse technology of processing technogenic mineral formations for the processing industry.

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