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Investigation of mechanical activation of steelmaking slag and obtaining fine filler

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Abstract. The article presents the results of the mechanical activation of steel-smelting slag affecting the properties of the gypsum composition. As a result of the study, parameters were identified that characterize the reactivity of the slag during mechanical activation. It was established that the increase in the number of Bronsted active adsorption centers on the surface of the formed powders is responsible for their reactivity. However, the maximum increase in surface activity leads to a large percentage of residue on the sieve. Also, polynomial models were obtained that adequately describe the entire process of mechanical activation of waste from metallurgical production.

1 Introduction

The most common man-made waste used in manufacturing building materials is blast-furnace and steel-smelting slags, waste from producing ferrous and non-ferrous metallurgy. Using waste as a filler for a gypsum mixture saves the gypsum binder by 20% [1, 2]. Therefore, metallurgical waste is widely used in the USA, Japan, and other industrialized countries as a filler in producing composite gypsum binders and building products [3].

It has been proven that finely dispersed mineral fillers in gypsum mixtures compact and strengthen the structures of gypsum stone by reducing capillary pores. It should be noted that all processes of directional structure formation occur at the optimum dispersion of the mineral filler. It is also important that most man-made wastes have different activity (or do not have pozzolanic activity at all). An important technological method for achieving the required surface activity and dispersion of mineral fillers is the grinding process (mechanical activation) [3].

At the metallurgical plants of Uzbekistan, large-tonnage wastes have accumulated that require disposal and are valuable fillers for improving the physical, mechanical, and operational characteristics of composite gypsum binders and building products based on them.

Considering the previous, this article presents the results of studies on the study of the mechanical activation process of metallurgical slag of Uzmetkombinat JSC with the aim of their further use as a microfiller in the production of composite gypsum binders and building products based on them.

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2 Objects and methods of research

Mechanical activation of metallurgical slag was carried out in a laboratory ball mill in shock-attrition mode. The study dried metallurgical slag to constant weight at a temperature of ±105ºC. The dried slag was loaded into the drum in the required amount for grinding. The grinding process was carried out before the onset of particle aggregation.

The grinding fineness was evaluated by the specific surface on a PSKh-11A surface meter. The aggregation phenomenon was determined on a No. 008 sieve. The granulometric composition of the crushed material was determined on a laboratory sieving device SS-300 using sieves of the following sizes, mm: 0.5; 0.425; 0.355; 0.3; 0.25; 0.212; 0.18; 0.15; 0.125; 0.106; 0.09; 0.075; 0.063; 0.035. The chemical composition of metallurgical slag by a fraction is given in table 1 [9-18].

Table 1. The chemical composition of steel-smelting slag JSC "Uzmetkombinat"

Fraction size, mm	**Content of oxides by mass, %**								
	CaO	SiO_2	MgO	Al_2O_3	SO_3	P_2O_5	MnO	Fe_2O_3	humidity
0-5	42.2	27.3	5.6	6.9	0.8	0.10	2.1	10.8	0.9
5-20	32.8	25.4	6.7	10.5	0.8	0.2	4.8	15.9	0.3
70-120	32.1	25.2	7.1	11.2	0.5	0.3	4.9	16.6	0.2

3 Results and discussion

The main waste of Uzmetkombinat JSC is steel-smelting slag. The American Standard for Materials Testing (ASTMC125) classifies steelmaking slag as a non-metallurgical waste mainly consisting of oxides of calcium, silicon, aluminum, etc. [3].

Research [3] found that fine steel-smelting slag in the process of forming the structure of a gypsum binder plays the role of an active center, creates a strong bond between the microfiller and binder monominerals and subsequently helps to reduce structural defects that form as a result of shrinkage or compaction of gypsum mixtures.

The study's main objective is to increase the surface activity of steel-smelting slag using a gypsum mixture as a filler.

Increasing the surface activity of the slag allows you to unlock the full potential of their capabilities and solve several important problems: how to improve the physical, mechanical, and operational characteristics and reduce the consumption of the production of gypsum binder and products based on them.

Several indicators based on the ratio of oxides contained in the waste and allowing indirect assessment of their hydraulic activity have been proposed. First, these evaluation criteria include basicity modulus (Mo) and activity modulus (Ma).

The slag basicity modulus is the ratio of the sum of Ca and Mg oxides contained in it to the sum of Si and Al oxides(mass %) [3]:

$$M_o = \frac{CaO + MgO}{SiO_2 + Al_2O_3} = \frac{42{,}2 + 5{,}6}{27{,}3 + 6{,}9} = 1{,}4$$

Based on this, depending on the nominal value, the basicity modulus of the slag can be basic when the basicity modulus is greater than 1 or acidic when the basicity modulus is less than 1.

Another criterion for assessing the activity of slag is the activity modulus [3]:

$$M_a = \frac{Al_2O_3}{SiO_2} = \frac{6{,}9}{27{,}3} = 0{,}25$$

The activity of slag, in most cases, increases with an increase in the modulus of basicity, and the modulus of activity increases [3]. According to the modulus of basicity, steel-smelting slag has a value of more than one, 1.4, respectively, and is classified as basic. The activity modulus for steelmaking slag is 0.25. The data obtained indicate that this type of slag has hydraulic activity. To enter into a chemical reaction with a gypsum binder, it is necessary to additionally increase its surface activity.

The analysis of previous works [4, 16, 17, 18] shows that a significant increase in the surface activity of slags can be achieved through mechanical activation.

Many scientists in fracture mechanics and solid-state chemistry note that the activation of substances during grinding is explained by dislocations in the solid and amorphization of the crystal lattice, which, in turn, accumulate and move in certain quantities, contribute to the destruction of the material.

Changes in the structure, composition, and properties of minerals during mechanical activation are most often caused by the following phenomena (Fig. 1).

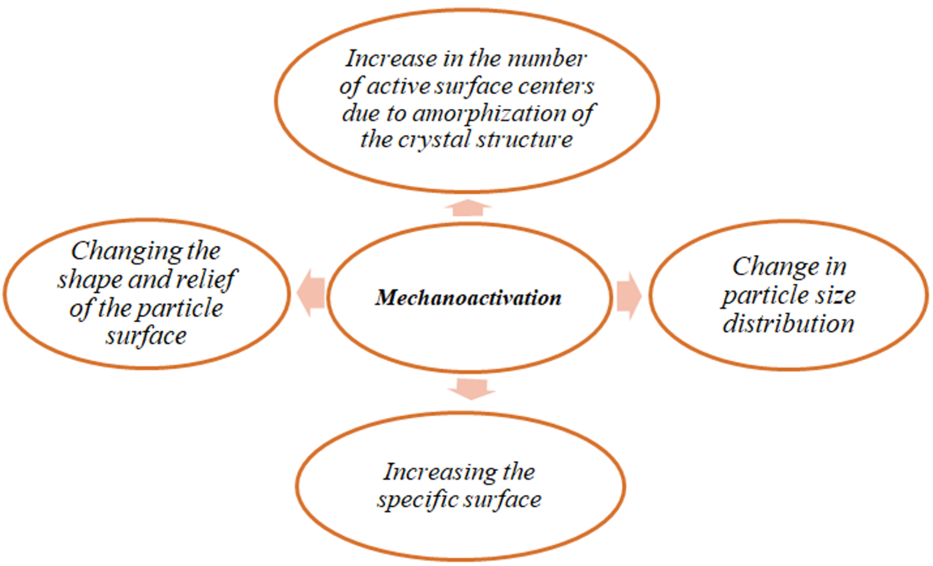

Fig. 1. Main parameters characterizing the reactivity of materials during mechanical activation

In the process of mechanical activation of slags, the specific surface of the material increases, the shape and relief of particles change, and the crystal lattice is amorphized with the formation of active centers.

Studies [1, 4, 16, 17, 18] found that with an increase in the dispersion of mineral fillers, there is an increase in the number of Bronsted active adsorption centers on the surface of the formed powders, which are responsible for their reactivity. However, this trend is observed up to a certain specific surface area (Srs), after which the process slows down considerably.

Therefore, when using a fresh ground filler, it is important to determine precisely the rational value of S_{rs}, above which the activity of the surface of its particles increases insignificantly and, therefore, further grinding is impractical.

The results of studies of the grindability of steel-smelting slag are presented in Table. 2. and in Fig. 2-6.

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Table 2. Influence of grinding time on fineness of grinding of steelmaking slag with sieve residue 008

Material	Grinding time	True density, g/cm^3	Bulk density in compacted state, g/cm^3	Porosity, %	Specific surface area	Average particle diameter
Steelslag	0	2.65	1.40	0.48	947	23.5
	10	2.71	1.18	0.57	1756	12.6
	20	2.97	1.21	0.60	2101	9.6
	30	3.08	1.19	0.61	2229	8.7
	40	3.29	1.20	0.63	2295	7.9
	50	3.24	1.20	0.63	2592	7.1

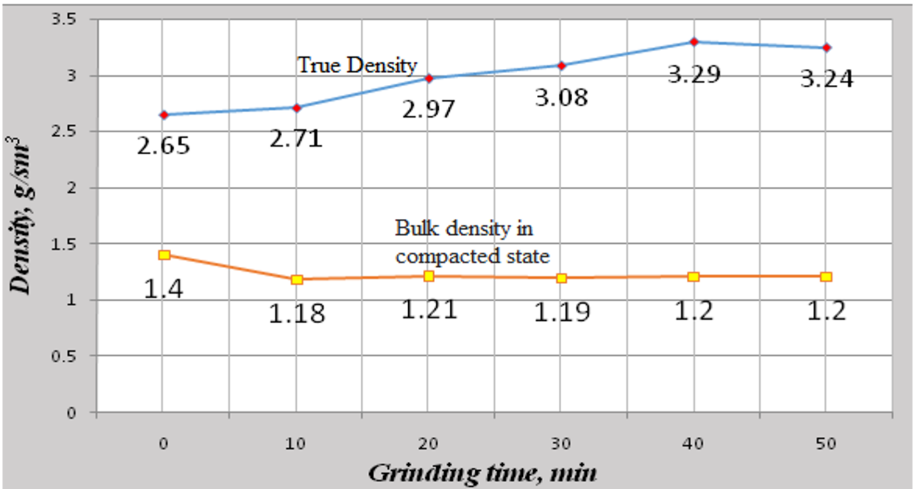

Fig. 2. Influence of the duration of grinding on the value of true and bulk density in the compacted state of steel-smelting slag

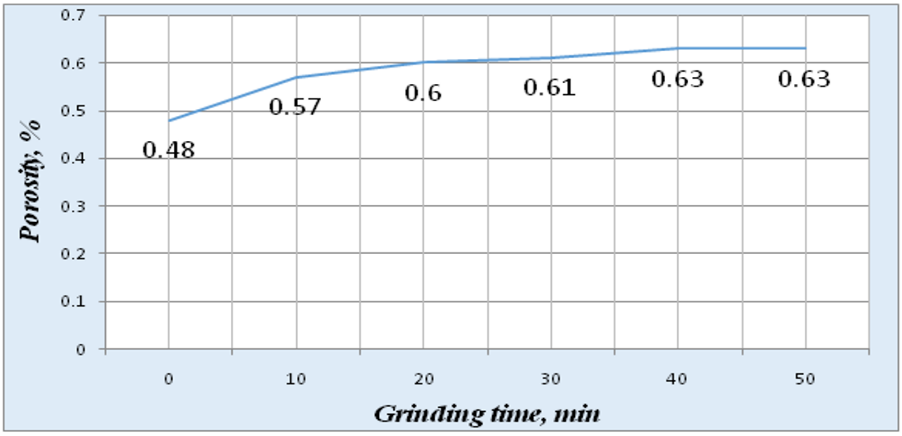

Fig. 3. Influence of the duration of grinding on the porosity of steel-smelting slag

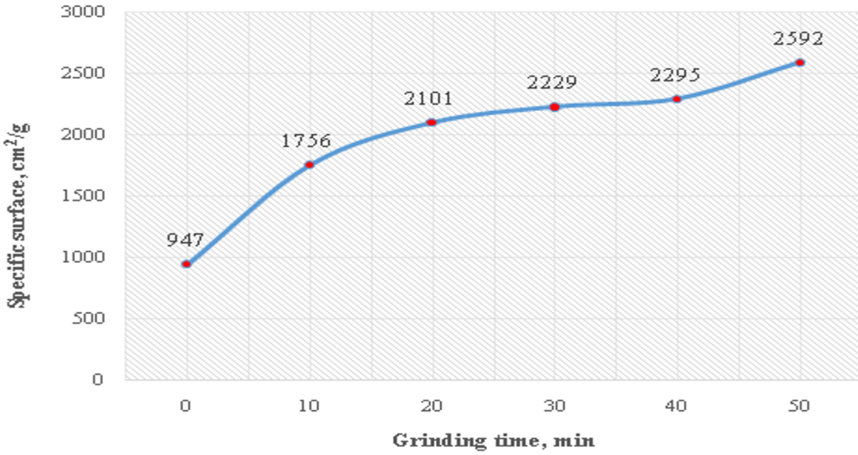

Fig. 4. Influence of the duration of grinding on the value of the specific surface area of steel-smelting slag

The obtained results of the change in the specific surface area show that, after 50 minutes of grinding steel-smelting slag, the specific surface area reaches a value of 2295 sm^2/g.

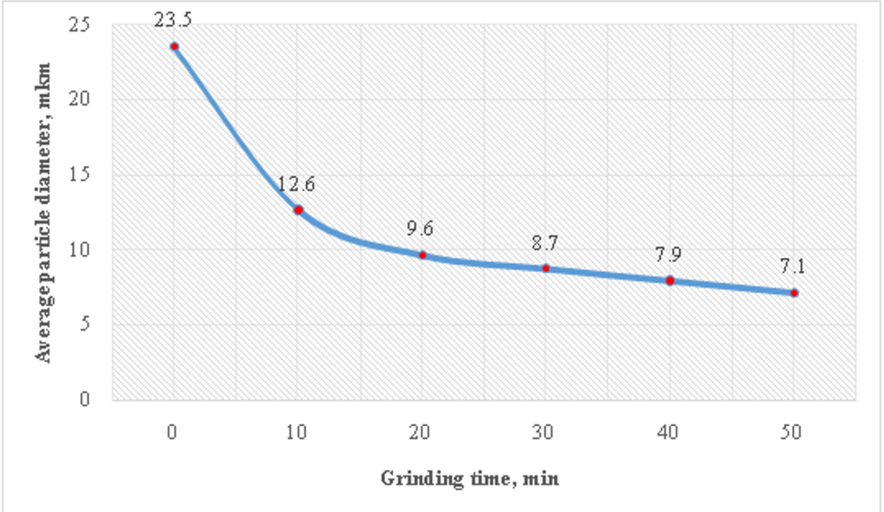

Fig. 5. Influence of the duration of grinding on the value of the average diameter of the particles of steel-smelting slag

At the same time, the average particle diameter of the steelmaking slag decreases from 23.5 µm to 7.1 µm.

With a decrease in each particle's size, the crushed substance's total surface increases rapidly, while the volume of the particle remains constant when the fragments are added. The surface, which rapidly increases with grinding, has a reserve of surface energy, which is subsequently consumed when forming products from a mixture with reactions occurring along the interfaces.

When a certain dispersion limit is reached, the potential energy of the surface can increase, which often leads to the spontaneous aggregation of particles with a decrease in the specific surface area and an increase in the inhomogeneity of the initial product.

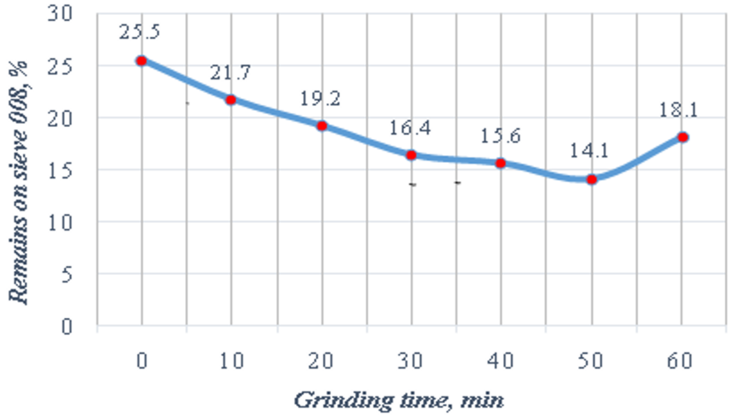

Fig. 6. Influence of the duration of grinding on the aggregation of particles of steelmaking slag

With a grinding time of steel-smelting slag of 60 minutes, the phenomenon of aggregation and sticking of particles is observed, as evidenced by the data shown in Fig. 6. For 40 minutes of grinding steel-smelting slag, the residues on sieve No. 008 are reduced from 68.5% to 24.2%. Further, this value is stored, the line goes into a horizontal plane, and the residue on the sieve is stored for some time. After 50 minutes of grinding, the amount of residue begins to grow, and the phenomenon of particle aggregation occurs. Further continuation of grinding is impractical due to the adhesion of particles, which in the future may increase the amount of residue on the No. 008 sieve.

In addition to the fineness of grinding (specific surface area), the technical characteristics of the mineral filler are significantly influenced by its granulometric composition. Data on the granulometric composition of crushed steel-smelting slag are shown in Fig. 7.

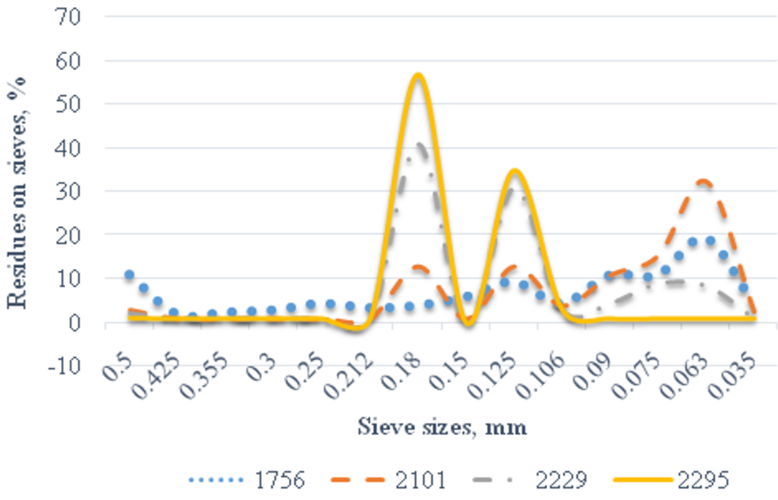

Fig. 7. Granulometric composition of mechanically activated steel-smelting slag.

It can be seen that the powder with S_{rs}=1756 cm^2/g is characterized by a high content of fraction particles from 0.5 mm to 0.25 mm. Further grinding contributes to the reduction of large particles with an increase in the proportion of fine fractions, which confirms the data on the granulometric composition with S_{rs}=2101 cm^2/g from Fig. It follows from Table 7 that an increase in S_{rs}=2229 cm^2/g to S_{rs}=2592 cm^2/g reduces the total fraction of particles with sizes from ≤0.09 mm to 0.035 mm by an average of 10%. The content of particles of fractions from 0.106 mm to 0.212 mm increases by 31% and 62%, respectively.

In our opinion, this is due to the beginning of an increase in the surface energy of particles, which ultimately leads to spontaneous sticking.

4 Conclusion

Mechanical activation of steel-smelting slag used as a filler changes the gypsum mixture's qualitative characteristics, making it possible to obtain a gypsum product based on a composite gypsum binder with improved physical, mechanical, and operational properties.

In the course of comparing the values of the fineness of grinding crushed steel-smelting slag, it was found that the shock-abrasive mode of a ball mill is capable of grinding steel-smelting slag in 50 min to a specific surface of 2295 cm^2/g and an average particle diameter of up to 7.1 mkm.

It has been established that after reaching the value of the specific surface area of the steel-smelting slag S_{rs}=2592 cm^2/g, further dispersion increases the amount of residue on the No. 008 sieve. Thus, it can be argued that the further dispersion process leads to the aggregation of material particles.

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