Particle-size distribution of alumina slag after grinding

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Abstract. The paper considers the issues of energy consumption and effectiveness of using aluminous slag as an expansion agent compared to Portland cement. Aluminous slag is a difficult material to grind, but its use as an additive is in demand for building materials. The following research methods were used: grinding of materials, sieve analysis, electron microscopy. According to the results of studies, it was found that the use of aluminous slag as an expansion agent is effective compared to Portland cement.

1 Introduction

Cements with special properties have long been of interest to builders, either as the main cementing component or as an additive to conventional cements [1-4]. Such cements are used in the construction of buildings and structures, in the repair of concrete and reinforced concrete structures.

Scientists in turn are interested in studying the nature and mechanisms of expansion of special cements, determining the prospects for the use of expansion agents [5-8]. One type of such an additive is aluminous slag [9-10]. Slag is a product of secondary smelting of aluminum or aluminum-thermal ferroalloy production.

For expanding cements, the stress-related characteristics and hydraulic properties depend on the dispersion characteristics of the cements, such as grinding fineness, specific surface area, and grain composition.

Regulation of the stress-related characteristics of expanding cements can be achieved by changing the grain composition of self-stressing cement and expanding cements [11,12].

The grain composition of cements depends on both the grinding methods and the microstructure of clinkers, the microhardness of their constituent minerals, as well as on their grindability [13,14].

The grindability of materials is characterized by the functional dependence of grinding fineness on the specific electricity consumption for grinding.

While being ground, aluminous slag very quickly reaches a specific surface area of SSA = 300 m²/kg at a relatively low power consumption of 23.3 kW·h/t, but to achieve SSA = 400 m²/kg, power consumption of 42.0 kW·h/t is needed, which is comparable to Portland cement clinker.

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The fineness of material grinding varies under the same grinding conditions, and this difference is primarily due to the crystalline structure of minerals and their hardness[15].

2 Materials and methods

If we evaluate the grindability according to the residue on the sieve 008 ($R_{008}$), aluminous slag is difficult to grind (Table 1).

Table 1. Dependence between specific surface area and percentage of residue on sieve $R_{008}$ for aluminous slag (AS) and Portland cement clinker (PCC)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Specific surface, $m^2/kg$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>230</td>
</tr>
<tr>
<td>Residue on sieve AS, %</td>
<td>50</td>
</tr>
<tr>
<td>Residue on sieve PCC, %</td>
<td>19.1</td>
</tr>
</tbody>
</table>

As can be seen from the Table 1, when changing the residue on the sieve from 50% to 20% of aluminous slag, specific surface area increases relatively quickly to 390 $m^2/kg$, for each percentage decrease in the residue, increase in specific surface area is 5.3 $m^2/kg$. Between 20% and 15%, the specific surface area increases more slowly and reaches a value of 400 $m^2/kg$.

For aluminous slag with a large specific surface area of 300 $m^2/kg$ and 400 $m^2/kg$, the residue on the sieve $R_{008}$ is 34% and 16.8% respectively. This is due to the fact that slag particles have a very developed surface due to angularity and deep developed cracks across the surface of the grain.

Thus, it was found that for aluminous slag, there is no unique relationship between the specific surface area and the percentage of residue on the test sieve $R_{008}$. So, with an increase in the specific surface area above 300 $m^2/kg$, the value of the residue on the sieve is still quite high and amounts to 34%, above the value required by the standard for Portland cement ($R_{008} = 15\%$).

In order to establish the particle size distribution of aluminous slag, studies were performed on the distribution of particles by fractions. Many researchers have been involved in the mathematical description of the size distribution of particles in the composition of powders. Various equations have been proposed to describe distribution functions.

Particle distribution curves according to particle size analysis data for expansion agents have been plotted according to the Rosin-Rammler-Bennett equation [16]:

$$R = 100 \cdot e^{-(d/d_0)^n}$$

where
- $R$ is the residue on the sieve, %;
- $d$ is particle size, $\mu m$;
- $d_0$ is the actual coarseness of the material (characteristic particle size);
- $n$ is a power exponent characterizing the scattering of particles by coarseness (uniformity coefficient).

The distribution of particles by fractions (hereinafter, the size yield) was expressed as a percentage of the total weight of the sample. Size yields show how much material of the entire sample is larger than a given size. In addition to the yield of individual sizes, the total
yield of all sizes larger than a given size (total plus yield) and the total yield of all sizes smaller than a given size (minus yield) were calculated. Based on the data of particle size analysis, we plotted the graph of characteristics of coarseness.

3 Results

The distribution curves in RRB coordinates are shown in the figure 1. We used the slope ratio of the curves to find the value of $n$, and the intersection of the straight line for $R=36.8\%$ to determine the actual coarseness of the material. The calculation results are detailed in the table 1.

![Figure 1. The distribution curves in RRB coordinates for aluminous slag](image)

From the obtained results it appears that, for the expansion agent at a specific surface area of 200 m$^2$/kg is characterized by the presence of all fractions: large – more than 200 $\mu$m, medium – 60-80 $\mu$m, and small – less than 45 $\mu$m and the minimum difference in plus and minus for fractions is 45-80 $\mu$m.

As the specific surface area increases, this difference increases, and the size yield curve in the area of medium and large sizes flattens out indicating the growth of medium and small fractions.

**Table 1.** Actual size of the material

<table>
<thead>
<tr>
<th>SSA, m$^2$/kg</th>
<th>210</th>
<th>306</th>
<th>420</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tan \alpha$ or $n$</td>
<td>1.33</td>
<td>1.48</td>
<td>1.48</td>
</tr>
<tr>
<td>$d_0$, $\mu$m</td>
<td>62</td>
<td>44</td>
<td>37</td>
</tr>
</tbody>
</table>

As can be seen from the data obtained, the higher the specific surface area of the particles, the more uniform their distribution in the fine fractions, as evidenced by higher values of $n$, and the smaller the characteristic size of the particles in the set of fine fractions.

The characteristic particle size of finely ground expansion agents (SSA =400 m$^2$/kg) was 37 $\mu$m for aluminous slag. The distribution of particles smaller than 28 $\mu$m was determined using a Mastersizer laser granulometer. The distribution of particles by fractions is provided in the figure 2.
Next, the distribution of minerals by fractions was investigated. To do this, an X-ray spectrum was taken, and the line intensity for the minerals was determined. When grinding aluminous slag to $SSA = 210 \text{ m}^2/\text{kg}$, calcium monoaluminate is concentrated in the medium (80-60µm) and small fractions (<45 µm), and helenite in the large fractions (>80 µm). The spectrum analysis is shown in the figure 3.

**Fig. 2.** Content of aluminous slag fractions

**Fig. 3.** X-ray characteristics of alumina slag minerals. SSA 210

**Fig. 4.** X-ray characteristics of alumina slag minerals. SSA 306
When increasing the specific surface area up to 306 m$^2$/kg calcium aluminate (CA) is concentrated in the small fractions, and helenite and glass phases in the middle fractions (fig. 4). And with increasing SSA up to 420 m$^2$/kg the amount of CA in the small fractions increases, and helenite and glass phases remain in the middle fractions. X-ray spectra show a large amount of glass phase in the 63 µm particles, while the helenite remains in the 80 µm fraction (fig. 5).

4 Discussion

Distribution of minerals into fractions correlates well with their microhardness. The greater the microhardness, the harder the material is to grind, and the more it is in large fractions. In order to obtain an expansion agent based on aluminous slag containing calcium monoaluminate mineral in fractions of 63-45 µm, it must be ground to a specific surface area of 300 m$^2$/kg. To get aluminous slag additive with CA content in fractions less than 45 µm, it is necessary to grind the slag to a specific surface area of 400 m$^2$/kg.

References

6. S. Samchenko, D. Zorin, E3S Web of Conferences 164, 14002 (2020) DOI: 10.1051/e3sconf/202016414002

Fig. 5. X-ray characteristics of alumina slag minerals. SSA 420 m$^2$/kg