Evaluating the influence of grinding method on the cement dispersion characteristics

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Abstract. Grinding methods of affecting the material being ground in a vertical roller mill and ball mill have fundamental differences. Subsequently, these differences have an impact on the dispersion of the crushed samples, the degree of defects in the surface of the grains, and as a consequence on strength characteristics of the ground products. This article studies the impact of the affecting method in the compared grinding units on the cement dispersion indicators.

1. Introduction
Development of technological equipment for cement production goes towards increasing the grinding degree, which has a positive effect on the hydration processes of cement grains by increasing its specific surface.

The majority of Russian companies use tube ball mill as the main grinding unit, which provides a high unit capacity, and the possibility of applying closed circuits of grinding. At the same time, the potential intensification of grinding is not limitless, even in spite of the grinding technology modernization with the use of automation and computer machines.

At present, the main "competitor" of the tube ball mill is a vertical roller mill. Operation of the latter provides reduced specific energy consumption in comparison with the tube ball mill. In this regard, there is great interest in determining the most optimal unit.

2. Materials and methods
In order to determine the impact of the grinding unit type on the obtained cements dispersity we used a semi-industrial vertical roller mill (in the laboratory Loesche GmbH) and a ball mill (laboratory VDZ). The single chamber ball mill (Fig. 1) with dimensions of 1.2×0.4 m provided capacity up to 30 kg/h (closed cycle), vertical roller mill - up to 300 kg/h (Fig. 2).

In the experiments, we used clinkers obtained in various ways: combined way - clinker 1, dry way - clinkers 2 and 3, and in the wet way - clinker 4.
Conducted petrographic analysis of the applied clinkers showed that clinker 1 has a fine-grained structure with porosity of 19%. Sizes of alite ranged from 4 to 30 microns or µm, on average 12 µm (Fig. 1).

The porosity of clinker 2 was 28%. The minerals with indistinct graining and inhomogeneous granular structure prevailed. Alite is represented with grains of 4-40 microns, the predominant size of 15 microns (Fig. 2).

Belite was mainly represented by aggregates forming the edges, while the grain size of belite was about 20 microns.

In the analysis of clinker 3 porous structure was observed, which was about 26%. The degree of this clinker graining was higher than that in clinker 2 (Fig. 3). Grains of alite are usually represented in the form of hexagons and polygons, as well as there were crystals of irregular shape. Alite sizes were in the range of from 3 to 40 microns, with a predominance of 15 microns, belite - 20 microns.

Fig. 1. Clinker microstructure 1 in reflected light, ×300

Fig. 2. Clinker microstructure 2 in reflected light, ×300
Analysis of clinker 4 showed that it has a coarse grain structure, with grain increased from the center to the granule periphery. Graining of minerals is distinct, with inhomogeneous granular structure (Fig. 4). The porosity is 10%. The average alite size was 25 microns, whereas belite - about 45 microns.

The mineralogical composition of the studied clinkers was determined by Glagolev's methods. Thus, clinkers of "dry" production method had slightly lower saturation coefficient than the clinker of "wet" production method, and therefore with a high content of hard-to-grind belite, as well as sufficiently different in terms of porosity (table. 1).

Table 1 Results of the petrographic analysis of clinkers

| Clinker       | Content of minerals, % | Satur ation coefficient | Porosity, % | Average size of crystals, µm |
|---------------|------------------------|-------------------------|-------------|-----------------------------|
|               | C₃S       | C₂S       | Interstitial material |             | Alite | Belite |
| No. 1 (combin.) | 60.8     | 20.0     | 19.2              | 0.90       | 19    | 12     | 25     |
| No. 2 (dry)   | 62.0     | 21.9     | 16.1              | 0.89       | 28    | 16     | 20     |
| No. 3 (dry)   | 59.9     | 21.3     | 18.8              | 0.89       | 26    | 16     | 20     |
| No. 4 (wet)   | 63.5     | 18.6     | 17.9              | 0.91       | 10    | 25     | 45     |

Fig. 3. Clinker microstructure 3 in reflected light, ×300

Fig. 4. Clinker microstructure 4 in reflected light, ×300
It is commonly known that the cement grinding system and the way of mechanical load affecting the material have a direct influence on the dispersion characteristics of the obtained cement [1-8], which in its turn determines the formation of certain technological properties.

To determine the impact of the type of grinder, the clinker and gypsum in a ratio of 95 wt. % and 5 wt. % were loaded in each of the mills, then they were ground in order to produce four values of specific surface in the range from 3000 to 4000 cm\(^2\)/g with a step of 200 to 300 cm\(^2\)/g. When having achieved mill operating mode with the desired fineness degree of the ground product, we selected about 20 kg to be tested. 32 samples of cement were obtained, later they were combined into 16 pairs. Each pair is represented by cement from the same clinker with the specific identical surfaces but obtained in different grinding units.

Samples of cement were marked according to the following principle:

The first figure corresponded to number of the clinker from which cement was obtained, the second figure is the ordinal number of the sample (1 – minimum specific surface, 4 – maximum specific surface), the "B" and "V" are samples of the cements obtained in the ball mill and vertical roller mill, respectively.

All samples of cement were subjected to specific surface area determination, particle size distribution – characteristic size \(x'\) and a uniformity coefficient \(n\) as well as sieve analysis.

The parameter \(n\) characterizes the width of the dispersed particle size. With increasing coefficient of uniformity the range of particles in the sample narrows [2]. The characteristic size of \(x'\) reflects the degree of fineness of the ground material; thus, by increasing the degree of grinding this indicator decreases, so, the average equivalent diameter or size of the particles reduces [3].

Clinker grinding in these grinding units allowed us to obtain sufficiently close dispersion compositions (Fig. 5, 6).

![Fig. 5. Cement crushed in a ball mill](image1)

![Fig. 6. Cement ground in vertical roller mill](image2)

Upon closer examination of the cement dispersion characteristics it is found that an increase in the uniformity coefficient \(n\) when the specific surface is in the range of 3000-4000 cm\(^2\)/g, it is characteristic of all the four cements (tab. 2).

It was also found that the uniformity coefficient value \(n\) in the beginning of grinding increases, and it decreases the width of the particle size distribution, at the same time, for certain values of specific surface area, the magnitude of this coefficient decreases. The probable cause of this phenomenon may be occurring agglomeration processes [9], which are observed in achieving the specific surface 3200 cm\(^2\)/g.
Table 2. Dispersion characteristics of cement ground in the ball mill and vertical roller mill

| Sample | Fineness cm$^2$/g | $\chi'$ | $n$ | Sample | Fineness cm$^2$/g | $\chi'$ | $n$ |
|--------|------------------|--------|-----|--------|------------------|--------|-----|
| 1-1-B  | 2940             | 19.1   | 0.88| 1-1-B  | 3120             | 18.7   | 0.87|
| 1-2-B  | 3420             | 14.7   | 0.95| 1-2-B  | 3350             | 14.7   | 0.94|
| 1-3-B  | 3730             | 12.5   | 0.87| 1-3-B  | 3890             | 12.0   | 0.87|
| 1-4-B  | 4240             | 10.9   | 0.94| 1-4-B  | 4470             | 11.1   | 0.92|
| 2-1-B  | 3140             | 18.2   | 0.84| 2-1-B  | 2860             | 17.2   | 0.83|
| 2-2-B  | 3470             | 15.1   | 0.88| 2-2-B  | 3520             | 14.7   | 0.89|
| 2-3-B  | 3890             | 13.8   | 0.88| 2-3-B  | 3960             | 13.0   | 0.87|
| 2-4-B  | 4250             | 11.3   | 0.93| 2-4-B  | 4150             | 10.9   | 0.93|
| 3-1-B  | 2950             | 18.2   | 0.83| 3-1-B  | 2940             | 15.4   | 0.86|
| 3-2-B  | 3280             | 13.9   | 0.88| 3-2-B  | 3350             | 13.9   | 0.87|
| 3-3-B  | 3610             | 12.0   | 0.88| 3-3-B  | 3620             | 10.7   | 0.84|
| 3-4-B  | 4130             | 9.4    | 0.93| 3-4-B  | 4190             | 9.7    | 0.96|
| 4-1-B  | 2890             | 14.8   | 0.92| 4-1-B  | 3130             | 15.3   | 0.88|
| 4-2-B  | 3210             | 13.3   | 0.96| 4-2-B  | 3140             | 15.5   | 0.95|
| 4-3-B  | 3610             | 12.7   | 0.89| 4-3-B  | 3660             | 13.7   | 0.88|
| 4-4-B  | 3970             | 11.0   | 0.95| 4-4-B  | 3930             | 11.6   | 0.95|

Another possible reason explaining the indirect dependency of the uniformity coefficient on the specific surface is that the distribution function of Rosin-Rammler-Sperling-Bennet with certainty describes the dispersed composition ranging from a few micrometers, and, hence, the ultra fine component is taken into account not accurately enough in the above equation, therefore the values of dispersion indicators can be adjusted.

To determine the differences in dispersion characteristics of the cement obtained in different grinding units we compared cement pairs that had the same value of the specific surface (Fig. 7).

It is established that with increase in the specific surface the increased proportion of large particles in the cement of ball mill is preserved compared with vertical roller mills.
Fig. 7. Dynamics of change of the ratio of fine and coarse fractions in cements, milled by vertical roll and ball mills

Conducted sieve analysis confirmed the pattern in obtaining the increased amount of coarse fractions (sieve 63 µm) using a ball mill (tab. 3), which cannot be said about the fine fractions, due to the use of minimum sieve of 20 µm.
Table 3. Results of sieve analysis of the cements obtained in the compared grinding systems

| Sample | Size of sieve |
|--------|---------------|
|        | 20 µm | 32 µm | 45 µm | 63 µm |
| 1-3- B | 34.40  | 15.65 | 8.60  | 3.90  |
| 1-3- V | 30.30  | 11.42 | 2.55  | 0.05  |
| 1-4- B | 27.90  | 11.50 | 6.20  | 2.85  |
| 1-4- V | 23.00  | 3.90  | 0.05  | -     |
| 2-1- B | 47.95  | 28.00 | 17.25 | 8.55  |
| 2-1- V | 50.20  | 25.10 | 11.80 | 3.50  |
| 2-2- B | 40.05  | 16.55 | 7.50  | 2.50  |
| 2-2- V | 42.80  | 12.80 | 4.00  | 0.75  |
| 2-3- B | 33.55  | 14.75 | 7.40  | 2.75  |
| 2-3- V | 31.80  | 5.65  | 0.40  | 0.05  |
| 2-4- B | 23.70  | 6.85  | 3.15  | 1.10  |
| 2-4- V | 20.10  | 0.50  | 0.01  | -     |
| 3-1- B | 47.60  | 28.25 | 17.70 | 9.15  |
| 3-1- V | 48.65  | 32.15 | 21.55 | 12.00 |
| 3-2- B | 37.85  | 18.55 | 10.15 | 4.75  |
| 3-2- V | 42.85  | 25.50 | 16.40 | 7.90  |
| 3-3- B | 33.25  | 16.90 | 9.30  | 3.85  |
| 3-3- V | 44.35  | 28.50 | 20.00 | 11.40 |
| 3-4- B | 22.00  | 7.30  | 3.50  | 1.40  |
| 3-4- V | 7.90   | 0.10  | -     | -     |
| 4-1- B | 49.35  | 30.15 | 18.70 | 9.90  |
| 4-1- V | 42.70  | 22.90 | 12.10 | 3.60  |
| 4-2- B | 34.70  | 18.50 | 10.90 | 5.50  |
| 4-2- V | 36.15  | 12.25 | 2.80  | 0.20  |
| 4-3- B | 32.65  | 16.60 | 9.50  | 5.00  |
| 4-3- V | 34.40  | 13.20 | 3.40  | 0.25  |
| 4-4- B | 25.65  | 11.70 | 6.50  | 3.25  |
| 4-4- V | 16.20  | 0.65  | 0.05  | -     |

3. Conclusion
Summarizing it can be noted that the use of ball mill allows obtaining a wider range of particle sizes, regardless of the grindability of clinker being ground. At the same time narrowing the granulometric composition with increasing specific surface area is observed regardless of the hardness and abrasiveness of the clinker and the applied grinding unit. With the increase in the specific surface of cements from different mills, the differences in the dispersion characteristics are reduced.

Acknowledgements
The article was prepared within the development program of the Flagship Regional University on the basis of the Belgorod State Technological University named after V.G. Shukhov, using equipment of High Technology Center at BSTU named after V.G. Shukhov.

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