Determination of the maximum grain width in fractions of grinding powders obtained by screening on test sieves

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Abstract. The article outlines the results of the study of the maximum and minimum grain width of black silicon carbide grinding powders with F60 grain size produced by Volzhsky Abrasive Plant, JSC, dispersed by fractions on test sieves. Grinding powders were sieved on a vibration stand in accordance with ISO 9284. Test sieves with the ISO 3310-1 cell size and tolerances were installed in the RO-TAP machine. The grain width was measured using electronic photos of the horizontal projection profile obtained by optical microscopy. Electronic images of grains were processed in specialized software. In each sample, at least 750 grains were measured, selected by quartering. It was found that the grinding powder made of black silicon carbide with a grain size of F60 meets the requirements of GOST R 52381 for grain composition. Visual inspection of the horizontal grain projection profiles showed that the grains are able to pass through the sieve cell, taking into account their possible orientation along the diagonal of the cell. The conditional pass-through size of the grain width in all fractions corresponds to the diagonal of the maximum average cell size of the upper sieve, taking into account the tolerance. The conditional non-passable size of the grain width corresponds to the lower limit of the average size of the cells of the lower sieve, taking into account the tolerance.

1. Introduction
The granulometric composition of grinding powders with a grain size of F4-F220 is determined by way of size-graded screening on test sieves (ISO 8486). The grain sizes of each fraction, except for the first one, are formed as a result of passing of certain-size grains through the upper sieve and settling of a part of grains, also of a certain size, on the lower sieve. Sieves are manufactured with cell size tolerances according to ISO 3310-1, which also determines the values of geometric dimensions of the grains of grinding powders remaining on each of the test sieves during screening.

Grains have different geometric parameters: length, width, thickness, area, volume, etc. [1, 2]. It is deemed that the method of screening through a sieve is mostly determined by the width of the grain. For example, the average width of silicon carbide grains of grain sizes from 120 to 600 mesh is directly proportional to the average nominal size of the adjacent sieve cells [1]. A similar pattern is observed for powders from other materials [3-8]. In some fractions, the relationship between the nominal size of the sieve cell and the average grain width has special features determined by the requirements of the standard for granulometric composition [9].

The purpose of this work is to determine the cell sizes of the upper and lower sieves, which are to a
greater extent corresponding to the maximum grain width in fractions obtained by controlling the granulometric composition of grinding powder grains by screening on sieves.

2. Research methods

The research was carried out with the use of a grinding powder made of black silicon carbide 54CF60 produced by Volzhsky Abrasive Plant, JSC. Screening of grinding powders was performed on five sieves installed in a vibrating machine of the RO-TAP type according to ISO 9284 standard. A sample of the powder was taken from each fraction by quartering. The grain width was measured using optical electronic photos of horizontal grain projection profiles obtained using an Altami CM0870-t microscope. Electronic photos of grains were processed using specialized software [10]. At least 750 grains were measured.

The grain width \( b \) was defined as the sum of the lengths of two perpendiculars 1 and 2 constructed from the grain length vector to the most distant points on each side of the profile. The grain length \( L \) was calculated as the distance between the two most distant points of the grain profile (Fig. 1)

![Figure 1](image)

**Figure 1.** Geometric parameters of the grain: \( L \)-length, \( b \)-width

The software [10] determines the coordinates of the grain profile and calculates grain size parameters, including width \( b \). Based on the results of measurements, the distribution of \( b \) in each fraction was determined.

3. Results and discussion

The grain composition of the grinding powder was determined by sieving on test sieves according to ISO 8486 (table 1). The sanding powder passes through a sieve with a nominal cell size of W1 without any residue, which meets the requirements of the standard.

On a sieve with a cell size of W2, the relative mass of Q2 powder is 12 %, and according to the GOST, it is to be less than 30 %. A sieve with a W3 cell size forms the main fraction of Q3 grains. The relative mass of Q3 should be more than 40 %, in fact it is 59 %. The weight of grains that are retained on the W4 sieve is not regulated separately. The total mass of the Q3+Q4 fractions must be more than 65 %. As a result of sieving, the relative mass of Q3+Q4=85 %, which is also consistent with the requirement of GOST R 52381. The weight of the Q5 powder is not regulated. The relative mass of fraction \( \Delta Q \) that passed through the sieve with the cell size W5 and remained on the bottom plate is 0.5 % (according to the GOST, it is not to exceed 3 %). Thus, the analyzed grinding powder meets the requirements of ISO 8486 in terms of grain composition.
Table 1. Grain composition of grinding powder 54CF60

| Sieve | W, µm | Fraction | The residue on the sieves, % according to GOST R 52381 | actual |
|-------|-------|----------|------------------------------------------------------|--------|
| 1     | 425   | Q1       | —                                                   | —      |
| 2     | 300   | Q2       | ≤30                                                 | 12     |
| 3     | 250   | Q3       | ≥40                                                 | 59     |
| 4     | 212   | Q4       | ≥65 (mass on 3+4 sieves)                            | 59+26=85|
| 5     | 180   | Q5       | not regulated                                       | 2.5    |
| 6     |       | Residue on the bottom plate | ΔQ | ≤3 | 0.5 |

Let us consider to what extent the maximum and minimum grain width will be determined by the size of the cells of the pass-through and non-pass-through sieves, taking into account the tolerances stipulated by ISO 3310-1.

For the Q2 fraction, sieve 1 is passable, and sieve 2 is impassable. As the assumed pass-through sizes of the sieve 1 cells, we select the nominal average size of W1=425 µm, the maximum deviation of the average cell size in the larger direction of W1-Y=441 µm, the limit cell sizes of W1+Z=471 µm and W1+X=506 µm (table 2). Cells with the size falling within the limit range, according to ISO requirements, must not exceed 6 % of sieve 1 cells. There are no larger cells on test sieve 1, according to the same requirements.

Table 2. Conditional division of the sizes of cells W and diagonals D of test sieve cells on pass-through and non-pass-through, µm (ISO 3310-1)

| Fraction | Sieve | Pass-through | Non-pass-through |
|----------|-------|--------------|------------------|
|          |       | W | W+Y | W+Z | W+X | D | D+Y | W | W+Y |
| Q1       | 1     | 425 | 441 | 473 | 506 | 601 | 624 | 425 | 409 |
|          | 2     | –  | –   | –   | –   | –   | –   | –   | –   |
| Q2       | 1     | 300 | 312 | 338 | 365 | 424 | 441 | 300 | 288 |
|          | 2     | –  | –   | –   | –   | –   | –   | –   | –   |
| Q3       | 3     | 250 | 260 | 284 | 308 | 354 | 368 | 250 | 240 |
|          | 4     | –  | –   | –   | –   | –   | –   | –   | –   |
| Q4       | 4     | 212 | 221 | 242 | 264 | 300 | 312 | 212 | 203 |
|          | 5     | –  | –   | –   | –   | –   | –   | –   | 180 |
| ΔQ       | 5     | 180 | 188 | 207 | 227 | 255 | 265 | –   | –   |

The lower retaining sieve 2 determines the minimum grain width. Therefore, on sieve 2, we select the minimum size of cells as non-passable: the nominal average size of W2=300 µm and the minimum deviation of the average size of W2-Y = 288 µm. ISO 3310-1 does not provide for further identification of tolerances in the direction of decreasing test sieve cell sizes, as is done for tolerances in the increasing direction.

Let us assume that the grain width limits are determined by the nominal cell sizes of the upper W1=425 µm and the lower W2=300 µm sieves. The limit sizes of the grain width in Fig. 2 are marked with vertical lines parallel to the ordinate axis. 83.5 % of grains fall within the range of 300-425 µm.
More than 16% of the grains were outside the range. Almost 12% of the grains have a width greater than W1. Grains with width of less than W2 make up 4.1%.

If the pass-through size is W1 + Y1, and the non-pass-through size is W2 - Y2, then the number of grains with a width greater than 441 µm decreases almost 2 times and reaches 6.3%. The content of grains with a width of less than 288 µm is reduced to 2.6%. The total number of grains with the width falling in the range of 288-441 µm increases to 91.1%.

The proportion of grains with size b greater than W1+Z1 is reduced to 1.9%. Since no more than 6% of cells may have size of W1+Z1, the probability of passing of grains through them is significantly reduced compared to the size of W1+Y1. If we consider the least likely case of sieving through cells with size of W1+X1, the proportion of large grains decreases to 0.7%.

When sieving, the grain may pass through the cell not only perpendicular to the face, but at any angle to it, including the diagonal of the cell. In the latter extreme case, the grain end in contact with the cell faces should have a double bevel at an angle of about 90° in the direction of the grain height. In this faction, there are no grains with a width exceeding the diagonal cell and the nominal size of D1=601 µm, especially those exceeding the cell diagonal with the average cell size deviation in the larger direction (hereinafter referred to as the maximum average size cell diagonal) of D1+Y1=624 µm.

The presence of grains of a smaller width, compared to the size of the retaining sieve 2 cell, should be explained, first of all, by the inevitable presence of cells smaller than W2-Y2, and secondly, by the possibility of small grains sticking together. In addition, when determining the width by optical microscopy, the grain may lie on its side when an electronic photo is made. The probability of such a position of the grain is low, but it can not be excluded. Then when processing an electronic photo of the grain projection, the height that is less than the width will actually be measured.

For the Q3 fraction, sieve 2 is passable, and sieve 3 is impassable. As pass-through, we consider the same set of sizes: the nominal size of the sieve cell of W2=300 µm, the maximum average size of W2+Y2=312 µm, the lower and upper limit sizes of W2+Z2=338 µm and W2+X2=365 µm (see table 2).

The nominal size of W2 cell in width exceeds almost 84.6% of the grains of the Q3 fraction, the size of W2-Y2 – 77.4%, the size of W2-Z2 – 56.4% and the size of W2-X2 – 32.6% (Fig. 2b). As noted above, the grains may pass through the cell diagonally. Based on this assumption, the width of only 1.3% of the grains exceeds the diagonal of the nominal cell size of D2=424 µm, and the diagonal of the maximum average cell size of D2-Y2=441 µm makes no more than 0.1% of the grains.

As the assumed non-passable sizes of the grain width of the Q3 fraction, same as for the Q2 fraction, we take the nominal lower sieve cell size of W3=250 µm and the lower limit of the average

![Figure 2. Distribution of grain width b in fractions Q2 (a) and Q3 (b) with selected control sizes of sieve cells](image-url)
cell size of \( W_{3+Y} = 240 \, \mu m \). The relative number of grains with the width of less than \( W_3 \) is 1.6 \%, and with the width of less than \( W_{3+Y} \) is 0.7 \%.

A similar analysis was performed for fractions Q3, Q4 and ΔQ, which settled on the bottom plate after passing through sieve 5. By the number of grains with the width exceeding the selected control values, similar values were obtained in the Q3-Q5 fractions, especially in the Q3 and Q4 fractions (table 3).

**Table 3.** The relative number of grains with the width exceeding the limits of the assumed pass-through and non-pass-through cell sizes, \%

| Fraction | Sieve | Pass-through | Non-pass-through |
|----------|-------|--------------|------------------|
|          |       | W | \( W_{3+Y} \) | \( W_{3+Z} \) | \( W_{3+X} \) | \( D_W \) | \( D_{3+Y} \) | W | \( W_{3+Y} \) |
| Q1       | 1     | 12,1 | 63 | 19 | 0,7 | 0,0 | 0,0 | – | – |
| Q2       | 2     | 84,6 | 77,4 | 56,4 | 32,6 | 1,3 | 0,1 | – | – |
| Q3       | 3     | 88,1 | 80,0 | 61,7 | 37,2 | 5,3 | 3,2 | – | – |
| Q4       | 4     | 87,3 | 80,7 | 61,6 | 37,6 | 4,9 | 3,1 | – | – |
| Q5       | 5     | 74,7 | 68,3 | 50,9 | 28,7 | 5,3 | 3,1 | – | – |

The ΔQ fraction differs from the Q3-Q5 fractions by the absence of a lower test sieve. Residue accumulates on the bottom plate. The actual grain content of ΔQ does not exceed 0.5 \%, so this sample is less representative. When using the diagonal of the nominal value \( D_5 \) or the diagonal of the cell with the maximum average size of \( D_{3+Y} \) as the pass-through size, the content of grains exceeding this value does not differ from the Q4 and Q5 fractions.

Table 3 shows that in various fractions, except Q2, there are grains with the width exceeding the diagonal of the cell of the maximum average size \( D_{3+Y} \). In the Q3 fraction, the number of such grains is about 0.1 \%. In fractions Q4 and Q5, their number reaches 3\%.

The shape of grains with the width exceeding the specified size was carefully analyzed for the possibility of grain passing through a sieve. It was found that such grains have a characteristic shape that allows them to pass diagonally through the sieve cell, bending in different directions (Fig. 3).
Figure 3. Passing of a grains 1 (a) and 2 (b) from the Q5 fraction \((D_w = 0.300 \text{ mm})\) with the width \(b\) greater than the diagonal of the maximum average cell size through a sieve cell

According to the content of grains exceeding the values of the assumed pass-through and non-pass-through sizes, the Q2 fraction stands out from the considered fractions (see table 3). If we exclude the \(\Delta Q\) fraction from the analysis, the content of grains with the width exceeding sizes \(W, W_{-Y}, W_{-Z}, W_{-X}\) in the Q2 fraction is almost 7, 13, 32 and 51 times less, respectively. It is impossible to make a numerical comparison by the size of the cell diagonals due to the absence of grains in the Q2 fraction with a width greater than the specified values. Grains with the width less than the assumed impassable size are 3-4 times larger in the Q2 fraction than in the Q3-Q5 fractions.

The observed regularity of significant depletion of the Q2 fraction in terms of large grains is due to the need to meet the requirements of the standard for the granulometric composition of grinding powders. According to GOST R 52381, the grinding powder must not contain the Q1 fraction grains. Guaranteed fulfillment of this requirement is possible if the Q2 fraction is depleted by large grains that can be retained on the first sieve.

4. Conclusions
Grinding powder made of black silicon carbide 54CF60 produced by Volzhsky Abrasive Plant, JSC, in terms the grain composition of fractions Q1, Q2, Q3, Q4+Q5 and \(\Delta Q\), obtained by screening on test sieves, meets the requirements of ISO 8486.

The conditional pass-through size of the grain width in fractions Q3, Q4, Q5 and \(\Delta Q\) obtained by screening the grinding powder on test sieves according to GOST R 52381 corresponds to the diagonal of the upper sieve cells of the maximum average size \(D_{+Y}\). The conditional non-passable size of the grain width of fractions Q2, Q3, Q4, Q5 corresponds to the average size lower limit of the lower sieve cells \(W_{-Y}\).

The number of grains of the Q2 fraction with the width exceeding the standard size of the upper test sieve cells taking into account the tolerances in the direction of their increase, is 5-50 times less than the corresponding number of grains in fractions Q3, Q4, Q5 and \(\Delta Q\). The marked difference indicates a relative silting of the Q2 fraction and is due to the requirement of ISO 8486, which excludes the grain residue on the upper sieve of this fraction.
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