The relation between the geometric parameters of grinding powders grains measured by laser diffraction and light-microscopical methods

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Abstract. The studies were conducted on grinding powders of black silicon carbide with F180-F60 grit produced by Volzhsky Abrasive Plant. The length, width, perimeter, area and reduced diameter of the grain area were determined by light-microscopical method, the equivalent diameter by the laser diffraction method. The distribution laws of geometric parameters are determined. A direct proportional relationship between the mean equivalent diameter and the average geometric parameters of the grain fractions (length, width, perimeter, equivalent diameter) and the power-law dependence with the average area of the grain fractions have been established

1 Introduction

The pressing issue of abrasive processing is the study of the geometric parameters of grinding powders grains. They affect the cutting ability and wear resistance of the abrasive tool, the force and temperature of cutting and the quality of the treated surface [1-3].

To measure the grain composition of various powders, express methods are widely used at present, including the laser diffraction method [4-6]. The laser diffraction method presents a grain in the form of a sphere whose volume is equivalent to the volume of the grain. If the density of the particles being analyzed is constant, this value can be considered equivalent to the mean size of a sphere with an equivalent weight. The laser diffraction method makes it possible to measure a large number of grains per unit time. For example, on Mastersizer devices, about 20,000 measurements are performed in 20 seconds [7].

Despite the significant advantages of laser diffraction, the equivalent sphere does not reflect the real shape of the particle, which is necessary to take into account when changing raw materials, technology, equipment, etc. Therefore, during the production of grinding materials, the microscopical analysis method remains relevant.

The objective of this work was to explore the relation between the equivalent grain diameter obtained by the laser diffraction method and the geometric parameters of grains obtained by the microscopical method.

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In accordance with the objective of the work the following tasks are formulated: to measure the geometric parameters of grinding powders grains by the laser diffraction and optical microscopy methods; to determine bonding force between the geometric parameters of the grains; to establish functional relations between the reduced diameter and the geometric parameters of grains obtained by light-microscopical method.

2 Research methodology

The target of research are the grinding powders from black silicon carbide 54C grade of F60, F70, F90, F120, F180 grit that are serially produced at Volzhsky Abrasive Plant PJSC. The powders of each grain size were screened into fractions according to GOST R 52381. A grain sample weighing about 4 g was taken from each fraction and divided into two parts. One part was used to measure the equivalent grain diameter by laser diffraction method; the other was used to measure the geometric parameters of grains by light-microscopical method.

The equivalent grain diameter *D* was measured on the Mastersizer 3000 device. The measuring range of the instrument is from 0.01 to 3500 μm. The measurement error for the median of a narrow unimodal log-normal distribution is not more than 1% [7].

The following geometrical parameters of the grains were measured by light-microscopical method: length *l*, width *b*, perimeter *P*, area *S*, reduced diameter *d*. In each fraction, 600 to 1000 grains were measured by the method [8] using the software “Zerno-NM” ("Grain-NM"). The relative measurement error of the geometric parameters of the grains by the microscopical method did not exceed 3-5%.

3 Research findings

The distribution of the equivalent diameter *D* obtained by the laser diffraction method is unimodal and has a positive skew (Fig. 1). A similar distribution pattern have the distribution frequency curves *D* of the grains of micro grinding powders of green silicon carbide, measured by Micro Sizer 201device [9].

The hypothesis that the distribution *D* belongs to the normal and log-normal distribution was determined by the Pearson criterion for significance level 0.05. When calculating the criterion, the sample size of the measurements was assumed to be 20000.

For all grinding powders fractions, the calculated values of the criterion exceeded the tabulated values. Nevertheless, it should be noted that for a log-normal distribution law, the differences between the calculated and theoretical values of the criterion were significantly smaller. The greater elongation of the log-normal distribution law is also indicated by the right-hand elongated branch of the presented graphs (see Fig. 1). Based on this, the statistical processing of the data was performed from the assumption that the samples of measurements belong to a log-normal distribution.

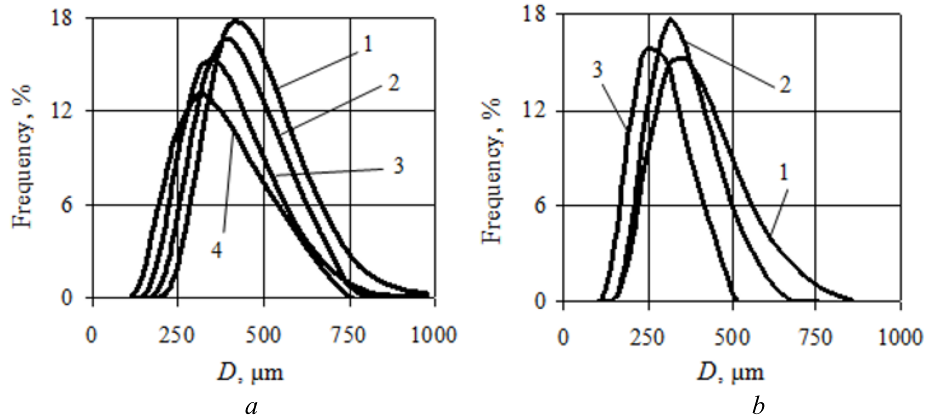


Fig. 1. Density of the equivalent diameter distribution D of grinding powders grain fractions of F60 (a) grit and fractions of various grit with a passing-screen mesh size W = 250 µm (b): a: 1 - Q_2; 2 - Q_3; 3 - Q_4; 4-Q_5; b: 1-Q_4 (F60), 2-Q_3 (F70), 3-Q_2 (F90)

Using the actual distribution D, the mean D_m and the variance S^2 (D) of the equivalent diameter of the grain fractions Q_2, Q_3, Q_4, Q_5 are determined (Table 1). The lower index in the symbol for the fractions corresponds to the number of the lower non-passing control screen, on which the fraction is retained during screening according to GOST R 52381.

Table. 1. Mean D_m and variance S^2 (D) of the equivalent diameter of grinding powders grain of various fractions and grit

Grit	Parameters	Fractions			
		Q_2	Q_3	Q_4	Q_5
*F*60	W, µm	425	300	250	212
	D_m, µm	422	403	364	339
	$S^2(D)$, µm²	42776	20645	20157	14660
*F*70	W, µm	355	250	212	180
	D_m, µm	360	336	313	307
	$S^2(D)$, µm²	9452	8773	9110	14945
*F*90	W, µm	250	180	150	125
	D_m, µm	271	236	215	193
	$S^2(D)$, µm²	6041	4561	4705	3954
*F*120	W, µm	180	125	106	90
	D_m, µm	181	179	144	153
	$S^2(D)$, µm²	2355	4964	2373	4961
*F*180	W, µm	125	90	75	63
	D_m, µm	135	120	103	87
	$S^2(D)$, µm²	2146	1600	1179	808

It should be noted that the D_m of fractions having the same mesh size, but belonging to different grain sizes, are not the same. For example, for Q_4 (F60), Q_3 (F70), and Q_2 (F90) fractions settling on a screen with a mesh of W = 250 µm, D_m are respectively 364, 336 and 271 µm. As a result of comparing the averages, their significant difference is established. Not only the means, but also the variances are significantly different.

One of the factors explaining the significant difference is the different sizes of the meshes of the lower retaining screen. When the fraction Q_2 (F90) is screened, the lower screen mesh is 180 µm, the rest are 212 µm. The residue formed on the screen with a smaller mesh will also contain smaller grains of the grinding powder, which leads to a decrease in the mean value of the equivalent grain diameter. This is evidenced by the distribution of the equivalent diameter of the grain fraction Q_2 (F90), located in Fig. 1*b* to the left of the remaining fractions distribution.

D_m of the fractions with identical values of the meshes of the upper and lower screens differ significantly. For example, the meshes of the upper and lower screens of Q_4 (F60) and Q_3 (F70) fraction, respectively, are 250 and 212 μm; D_m are 364 and 336 μm, respectively. As a result of comparing the means using the argument of Laplace function, the significance of their difference is established. A similar behavior is observed for other fractions with the same dimensions of the meshes of the upper and lower screens: Q_5 (F60) and Q_4 (F70); Q_5 (F70) and Q_3 (F90); Q_5 (F90) and Q_3 (F120).

The variances in these fractions differ significantly, as well. A comparison of the variances is made using the Fisher's ratio test for logarithmic values of the equivalent diameter.

With the same dimensions of the meshes of the upper and lower screens, fractions isolated from grinding powders of smaller grit have smaller means and variances of equivalent diameter.

Similar patterns between the means and variances of the grain fractions geometrical parameters with the same dimensions of the mashes of the upper and lower screens, but belonging to different grits, are established for the grain width [10, 11].

The bonding force between the mean equivalent diameters of the fractions grain D_m obtained by laser diffraction method and the geometric average parameters of the same grain fractions obtained by light-microscopical method (length l_m, width b_m, perimeter P_m, area S_m and reduced diameter d_m and non-isometric coefficient $k_m = l/b$) were evaluated by the pair correlation coefficients. For almost 70% of pairs of geometric parameters, the correlation coefficient exceeds 0.90 (Table 2), which indicates a very high bonding force.

The pair correlation coefficient within the grit for D_m and k_m parameters varies from -0.65 to -0.97. With an increase in the mean equivalent diameter of the fractions grain, the non-isometric coefficient decreases, i.e. grains become more isometric.

Table. 2. Correlation coefficients between the mean geometric parameters of the fractions grain D_m and l_m, b_m, P_m, S_m, d_m within each grit and over all grits F

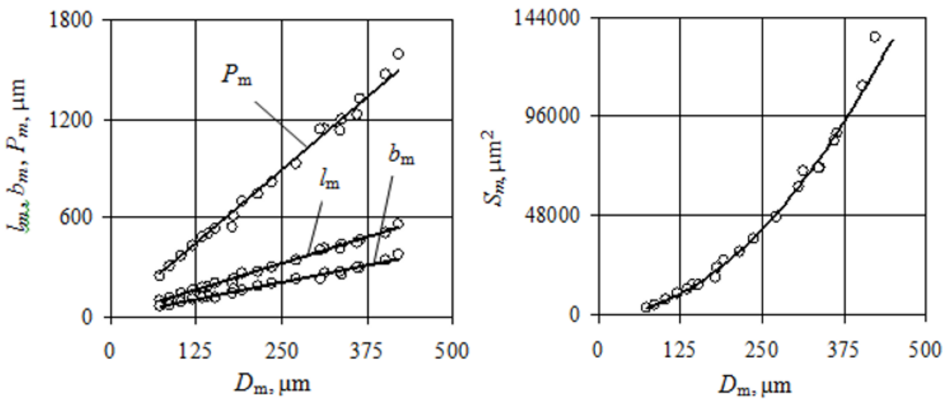
Grit	F60	F70	F90	F120	F180	F
l_m	0,97	0,82	0,98	0,73	1,00	0,99
b_m	1,00	0,91	1,00	0,87	1,00	0,99
P_m	0,99	0,80	1,00	0,83	1,00	1,00
S_m	0,99	0,94	0,99	0,86	1,00	0,97
d_m	0,99	0,94	1,00	0,87	1,00	1,00
K_m	–0,92	–0,74	–0,79	–0,65	–0,97	–0,05

The mean values of all parameters were combined into one sample. The coefficients of the pair correlation between D_m and l_m, b_m, P_m, S_m, d_m over all the grits have increased and approach 1, which also indicates a very high bonding force. The coefficient of pair correlation D_m and km at combining the data for all grits should be considered insignificant.

The connection between the parameters D_m and l_m, b_m, P_m, S_m, d_m is very strong, so it was described by the functional dependencies obtained by the least square method (Fig. 2):

$$l_m = 1{,}28D_m,\; b_m = 0{,}83D_m,\; P_m = 3{,}54D_m,\; S_m = 0{,}71D_m^{1{,}98},\; d_m = 0{,}91D_m.$$

The certainty factor of the approximation of the dependencies examined is 0.98-0.99.



a b

Fig. 2. Dependence between the mean geometric parameters of the fractions grains b_m, l_m, P_m (*a*), S_m (*b*), and D_m

4 Conclusions

1. In appearance, the distribution curves of the equivalent fractions grain diameter of grinding powders made of black silicon carbide with F180-F60 grit are closer to a log-normal law.

2. The mean and variances of the equivalent grain diameter of the fractions obtained by screening of the grinding powders in accordance with GOST R 52381 and having the same dimensions, respectively, of the upper and lower screens, grow up with increasing of the grinding powder grit.

3. The coefficients of pair correlation between the mean equivalent grain diameter of the fraction and the mean geometric parameters of the grains (length, width, area, perimeter, reduced diameter) obtained by the microscopic analysis within each grain size range from 0.7 to 1.0, over 70% of pairs has a correlation coefficient of more than 0.9. When the fractions of all grits are combined into one sample, the correlation coefficient is more than 0.97.

4. The correlation coefficient of the mean values of the parameters Dm and the coefficient of non-isometry of the grain fractions within each grain size has a negative value in the range from -0.65 to -0.97, which indicates a decrease in the non-isometry of the grains with an increase in the equivalent diameter within each grit. When combining the fractions of all the grains into one sample, the correlation coefficient becomes insignificant.

5. For F180-F60 grits, a direct proportional dependence is established between the average size of the equivalent diameter and the mean geometric parameters of the fractions grain (length, width, perimeter), the power dependence with the average fractions grain area.

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