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The Analysis of Shape Coefficients for Selected Raw Materials

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Abstract: The study presents the results of shape coefficient calculation for mineral grains of sieve sizes below 0.3 mm. To perform the analysis, the photos from scanning microscope and computer image analysis were used It was found that for the analyzed material, the full mechanical similarity occurred with the grain communition and the shape coefficients did not change. The course of elongation for analyzed population may be described by the quadratic curve. The investigations are in progress.

Key words: Shape coefficients, image analysis

INTRODUCTION

During researches of the fine grinding processes of various materials being directed to mineral processing, mainly of mineral origin, it occurred that not only grain sizes were being lowered but also the phenomenon of particles of certain shapes creation occurred, which was connected with the sort of comminuted material. For the purpose of research, the fine mineral grains are the grains of sieve sizes lower than 0.3 mm. The experiments as well scientific efforts were conducted to systematize this phenomenon for chosen materials. Diabase, the mineral of natural origin, taken from domestic deposits of Diabase and Porphyre Mine in Krzeszowice was selected for the research. The analyzed material was of specific gravity equal to 2.69 g cm^{-3} and has isomorphic mechanical properties. During experiments the material sample was ground in a ball mill to obtain material of grain sizes below 0.3 mm to 1 μm. Both whole material grain populations and narrow grain classes selected by precise analytic sieves were investigated. By using the computer image analysis, for which rules are described (Serra, 1982; Tadeusiewicz and Korohoda 1997), ten different shape coefficients were calculated for every sample. The analysis of whole material conducted by using statistical methods allows some conclusions to be drawn. The most important is the fact that for the certain material, the grain shapes are mechanically similar to themselves with lowering grain sizes classes. For some characteristic shape coefficients the function of numerical value of shape coefficient changeability in dependence on class size and sort of material may be derived. These functions may be also described by quadratic equations. The results of the investigation, may be useful for people interested in classification, flotation, measurements problems, as well as other technologies (for example production of filters), for which the grain size and shape are important parameters.

APPROACH AND METHODS

Shape coefficients: The evaluation of fine grains shapes is difficult because of the lack of initial assumptions concerning the definition of shape in researches of mineral grains properties. The quoted shape coefficients in literature (Allen, 1992; Feda, 1982; Wojnar *et al*., 2002; Russ, 1986) are formalized numbers by taking into consideration the intuitive similarities of grains or their projections to certain geometrical figures or blocks. The coefficients calculated in base of linear quantities are the most often, the representatives of some characteristic feature of researched objects (grains). These may be: sphericity, elongation or corrugation allowing selection of certain units or another statistical division. The most known coefficient is Feret diameter. Other coefficients cannot be applied as universal ones. In the current study concerning the evaluation of fine grains shapes, the calculations for diabase were conducted, which grain shapes are rather typical for mineral powders of isomorphic resistance properties. This mineral was treated as model one for proposed calculations. It was assumed that for diabase, the direction of cracks propagation during grinding is incidental. The shape coefficients quoted in the study were calculated in base of views for narrow grain classes treated as sieve classes. The coefficient of filling K_1 should be treated with some distance because of the specific character of computer program, which fill the eventual not-filled fields of grain

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projections. Both, coefficient K_E and α representing elongation are higher, which may be also confirmed visually, where instead spheres, the blocks similar to rotative ellipsoids. In diabase composition there is a lack of significant differences in objects shapes of small grain sizes, what is also confirmed by graphs. This proves the well known theory of comminuted objects mechanical similarity as well as the isomorphic properties and material homogeneity mentioned. The more precise analysis of diabase allows selection of two types of grains in all of the presented compositions. The grains which are traditional may be treated as cubic grains, which means that they are similar to equilateral cubes or tetrahedrons as well as grains of cubic shapes, in which one of the sides is longer than the others.

The most often applied shape coefficients are:

- Projected diameter d_p-diameter of circle of the same surface as grain,

$$d_p = \sqrt{\frac{4A}{\pi}} \tag{1}$$

- Coefficient of sphericity K_{C1}-sphericity of object, maximum is equal to 1 for circular objects,

$$K_{c1} = \frac{4\pi A}{Cr^2} \tag{2}$$

- Wadell's coefficient of sphericity K_W-ratio of grain perimeter to circle perimeter of surface equal to grain surface

$$K_w = \frac{L}{L'} \tag{3}$$

- Filling coefficient K_1-number of pixels of area divided by product of grain height and width. This parameter is equal to 1 for ideal rectangle and achieves values near 0 for the very simple structures,

$$K_1 = \frac{n}{x \cdot y} \tag{4}$$

- Convexity parameter K_2-parameter is equal to 1 for convex areas and higher for areas containing concave ones,

$$K_2 = \frac{L}{2y + 2x} \tag{5}$$

- Elongation (relative to ellipse) K_E-an ellipse is featured on grain, which has axes a_1 (longer one) and b_1 (shorter). With growth of value of this parameter, the elongation of grain becomes higher. This coefficient achieves values below 1,

$$K_E = \frac{a_1 - b_1}{a_1 + b_1} \tag{6}$$

- Elongation (relative to circle) α-ratio of width to height of rectangle featured on grain (b>a). The coefficient achieves the minimal value equal to 1 for circle or rectangle and is higher for elongated shapes,

$$\alpha = \frac{b}{a} \tag{7}$$

- Grain surface corrugation coefficient β-coefficient is very sensitive to irregularity of grain shape and at the same time very insensitive to elongation. Its minimal value is equal to 1 for circle and achieves higher values for every other shape,

$$\beta = \frac{L^2}{4\pi A} \tag{8}$$

- Conciseness coefficient K_Z-this parameter is equal to 1 for square and smaller for shapes of not so regular boundaries,

$$K_z = \frac{16n}{L^2} \tag{9}$$

- Symmetrical measure of grain elongation-logarithm from quotient of grain height and width,

$$K_s = \log_{10}\left(\frac{y}{x}\right) \tag{10}$$

where:

x = Area width, difference between highest and lowest co-ordinate X of the area or horizontal Feret diameter-$d_{F,h}$;
y = Area height, difference between highest and lowest co-ordinate Y of the area or vertical Feret diameter;
n = No. of pixels;
L = Perimeter of object;
A = Surface field of object;
Cr = Crotton perimeter

Crotton perimeter is defined as the mean intersection length in direction 0, 45, 90 i 135□. Lengths of intersections in directions 45 i 135□ are being revised (normalized) by coefficient $\sqrt{2}/2$;

L' = Circle perimeter of surface equal to grain surface;
a_1 = Length of longer ellipse axis featured on object,
b_1 = Length of shorter ellipse axis featured on object.

where:
$d_{F,max}$: Maximum Feret diameter,
$d_{F,h}$: Horizontal Feret diameter;
$d_{F,v}$: Vertical Feret diameter;
$d_{M,h}$: Horizontal Martin diameter;
$d_{M,v}$: Vertical Martin diameter;
a_1 : Length of longer ellipse axis featured on object;
b_1 : Length of shorter ellipse axis featured on object;
a : Height of rectangle featured on object;
b : Width of rectangle featured on object;
A : Surface field of object, □m^2
L : Perimeter length, number of pixels in object, which neighbour pixel not belongs to object (Xu and Guida, 2003).

Materials to investigate: The sample of diabase was sieved for experimental purpose by means of precise analytic sieves into six grain classes of measures 0.16, 0.1, 0.08, 0.071, 0.063, 0.04 and 0,032 mm. From each class the microscopic sample were prepared for scanning microscope analysis. The work was conducted by magnification from 600 to 2000 times and the microscopic pictures were then initially processed electronically in purpose to obtain binary contours from real photos. It is presented on Fig. 1. The applied shape coefficients were

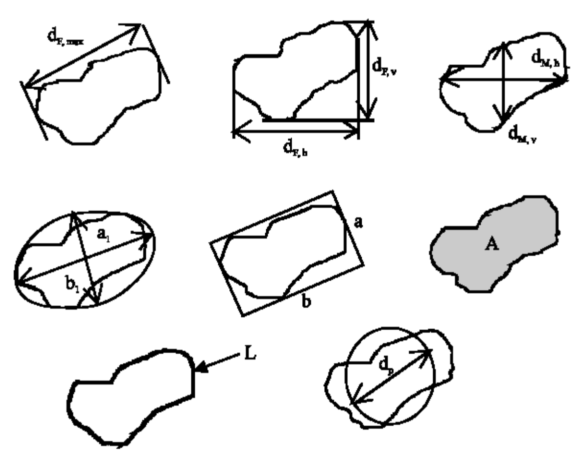

Fig. 1: Contours of binary grains and interpretation of shape coefficients

listed in the left most column in Table 1. In case of osculant or ambiguous grains, the program analysis and treating procedures were applied to eliminate these disturbances. It is assumed that the resulting error is no higher than 5%.

RESULTS AND DISCUSSION

All the microscopic grains were analyzed, photographed and stored as picture files and then processed ed electronically for the purpose of calculation of shape coefficients as defined above. The grain size, which was the basic model parameter among the others was assumed as the so-called projective diameter (diameter od circle of surface equal to grain surface d_p). The synthetic measurement results are presented in Table 1, where the symbol μ represents grain class size (in μm) in the top row and in the other rows are values of individual shape coefficients. The presented values are arithmetic means of all grains in certain class. Twenty to one hundred grains were measured, which is 30 grains in an average in every class and experiment. Table 2 shows statistical data of shape coefficients values in relation to the whole researched population, without showing the grains division into classes. First column of Table 2 shows arithmetic mean for population calculated as mean of means in every class. The next column contains the values of standard deviations for population and confidence intervals for mean, calculated for the confidence level 0.95. Next two columns contain additional information, which is the minimum and

Table 1: Shape coefficients values for grain classes

α	32-40	40-63	63-71	71-80	80-100	100-160
d_p	65.780	62.760	71.050	87.460	96.200	113.700
K_s	0.003	-0.036	-0.019	-0.045	-0.036	-0.020
K_1	0.063	0.631	0.637	0.637	0.657	0.673
K_2	1.043	1.040	1.038	1.027	1.045	1.034
K_{C1}	0.717	0.746	0.752	0.802	0.766	0.795
K_z	0.559	0.573	0.583	0.631	0.591	0.613
K_E	0.462	0.383	0.366	0.363	0.355	0.391
β	2.326	2.246	2.200	2.041	2.183	2.104
α	1.627	1.484	1.372	1.398	1.371	1.411
K_W	1.521	1.497	1.482	1.427	1.475	1.448
K_F	1.062	1.128	1.075	1.163	1.131	1.116

Table 2 : Statistical data of shape coefficients in context of whole population

	Mean	Stand. dev.	From +	From -	Max ca	Min ca
K_s	-0.026	0.017	-0.006	-0.045	0.342	-0.394
K_1	0.557	0.243	0.837	0.278	0.862	0.387
K_2	1.038	0.007	1.045	1.030	1.181	1.000
K_{C1}	0.763	0.032	0.800	0.726	0.974	0.433
K_z	0.592	0.026	0.622	0.461	0.856	0.357
K_E	0.387	0.039	0.433	0.341	0.898	0.014
β	2.183	0.101	2.300	2.067	3.568	1.488
α	1.444	0.099	1.557	1.330	3.697	1.000
K_W	1.475	0.034	1.514	1.436	1.889	1.220
K_F	1.113	0.038	1.156	1.069	2.478	0.455

Table 3: Parameters of coefficients □ for grain classes

Alpha	32-40	40-63	63-71	71-80	80-100	100-160
A	1.1215	0.9280	1.06145	1.0724	1.0285	1.09521
B	0.0001	0.0316	0.00221	-0.0054	-0.0007	-0.01320
C	0.0002	0.0005	0.00118	0.0008	0.0008	0.00317

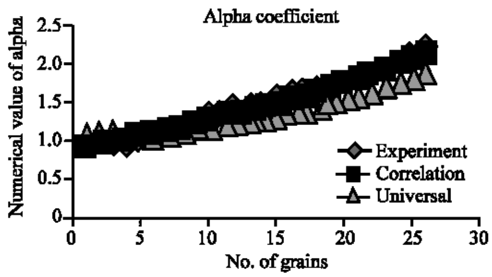

Fig. 2: Graphical presentation of alpha coefficients changeability

maximum values of coefficient occurred during experiment. The minimum value is an interesting one, but cannot be analyzed meritorically. Figure 2 contains only the information concerning the α coefficient. This factor determines the level of elongation For the symmetrical figures α is equal to 1,0 and with the elongation of one dimension becomes higher. The abscissa axis of the axis shows the amount of grains with higher values of α. The ordinates of the axis shows its absolute value. The curve represents the experimental data of one of the samples, the second one the quadratic regression curve and the last one the quadratic regression of □ coefficients for all grains of researched population.

CONCLUSIONS

The experiment and measurements allow to draw some conclusions. The grain class size of researched material does not influence significantly on shape coefficients values. This confirms the hypothesis that sieve classification of grain population do not classify the material according to the grains shapes. It may be said that both the thick grains class as well as the others has the same shape properties. The statistical evaluation of mean value allow to assume that the course of shape coefficients values is described by normal distribution function. Figure 2 illustrates the trend of changeability of α coefficient in cumulative order. This trend can be described by a parabolic equation parameters presented in Table 3. The table contains parameters of shape coefficient α for every grain class. The last curve presents universal trend, for the whole population of analyzed material. It is worthy to note that the smaller class of 0.03-0.04 mm is rather exceptional, for which higher spread of shape coefficients occurred. This fact may be explained by analytical difficulties. In case of very fine grains, the phenomenon of grains pasting and their harder separation occurs. It is also observed that the mean grain size in this class is rather irrationally higher than the expected sieve size. This known observation can be explained by impreciseness of separating devices, particularly the measuring instruments. But, this situation is important from the technological point of view and is not important in the quoted calculations.

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