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System and criterial method of the identification and quantitative estimation of the geometrical shape of the abrasive powder grain projection

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ABSTRACT

A new method of identification and quantitative estimation of geometrical shape of the projection of abrasive powder grains has been proposed. The method is based on the system and criterial approach. As analogs of 2D geometric figures (circles, ellipses, triangles, canonized shapes of tetragons, regular pentagons, hexagons, and octagon) that admit nonadditive analytical representation of the area via generating parameters, whose number does not exceed three, have been taken. Differential and integral characteristics of the shape similarity are introduced and the analytical apparatus of determining the characteristic values is proposed. The results of the appraisal of the method using mesh-size powders of synthetic diamond, tungsten carbide, garnet, and electrocorrundum are discussed.

1. Introduction

The spatially-volumetric (3D) shape of grains of diamond and other abrasive powders is a clear sign of their quality. It has been established by experimental studies that the diamond grain shape affects abrasive properties of micron powders [1,2], statical strength of mesh-size powders [3], and parameters of machining with tools made of diamond [4]. Usually the shape of grains is judged visually. Not the visual but the automated identification of exactly 3D shape of an individual grain and estimation of the shape of a predominant collection of grains is an extremely complicated problem that expects the solution. Therefore, in practice in the analysis of processes of diamond–abrasive machining and characteristics of superhard material (SHM) powders, the shape of the grain projection, i.e., the 2D grain image or 2D analog of its spatially-volumetric shape, is considered. However, even in this simplified formulation the problem of automated identification of a projection shape of individual grains of diamond powder and evaluation of the prevailing shape for a grain population always was actual problem for the applied science. Now it is also an actual problem as demonstrated by a great number of publications concerning both abrasive powders and related materials in other spheres of human activities (geology, medicine, agricultural and bio engineering, etc.). In subjects these publications may be arbitrary divided into two directions. To the first of them there belong the already mentioned publications [1–4] concerning experimental studies of the effect of the 3D shape (and the projection shape) of abrasive powder grains (mainly of natural and synthetic diamond powders) on the efficiency of diamond–abrasive machining.

There are papers concerning the theoretical and applied aspects of the identification of shape projections of grains of powders and related materials by computer-aided and digital processing of images (the so-called IMAG-technologies), for example, at the indentation of the grain image boundaries and the image valuation [5,6]. Recently many papers on the development of an analytical apparatus of the identification of a shape of grain projection have been published in this series. Such a mathematic apparatus is oriented to a quantitative analysis of particular classic geometric figures as analogs of the real projection. A circle, ellipse with different axial ratios, square, rectangle with different side ratios, equilateral triangle and hexagon are proposed to be used as analogs of the real shape.

An important role in such studies is assigned to the search and analytical presentation of criteria of the shape similarity. Usually the following characteristics of the image shape like circularity, sphericity, aspect ratio, and Feret elongation [7] are used for these purposes. In turn these functional characteristics are based on the relationship among the primary signs of images like the area and perimeter of real and convex projections, diameters of inscribed and escribed circles, sides of escribed triangle, and extreme Feret diameters.

To define the criteria of the shape similarity, the values of these characteristics for various model projection shapes of those listed above are

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defined. However, thus found criteria are adequate for a projection in the shape of a circle. For other shapes of projections they are nonadequate because of the ambiguity of the interpretation of the finite result.

The inefficiency of the analytical presentation of these characteristics as criteria of the identification of the grain projection shape is pointed out in [8] as well. The authors of [8] propose to use the following new characteristics as the criteria of the shape similarity:

- reciprocal aspect ratio $RAR = \frac{b}{a}$, where a is the major axis of ellipse, and b is the minor axis of ellipse ($a \geq b$);
- rectangularity $RTY = \frac{A_{ef}}{H_b W_b}$, where H_b and W_b are the height and width of an equivalent rectangle (with an area equal to the ellipse area), respectively, A_{ef} – ellipse area.
- Feret major axis ratio $FMR = \frac{D_f}{a}$, where D_f is Feret diameter of the particle projection.

It is noted that using these three shape factors separately or in combination of two the authors were able to classify the test shapes.

Our attention has been engaged by the absence in the known publications, including those listed above, an understandable concept of the results of the identification of the grain projection shape. An illustration as an electron photograph of the sample of grains of the corresponding powder and a table (or a diagram) of the grain distribution according to shape with the indication of a relative error of the shape replacement is the most visual and convincing.

Taking into account the aforesaid, the aim of the present study is to develop a new approach and based on it a method of the identification of a grain projection shape of abrasive powders, and related materials, which should be based on a succession of the known approaches. This succession is the use of a system of basic analogs of the real projection shape, which we extended from 8 to 16 figures as compared with [7,8]. In addition, an absolutely new methodology of devising criteria of shape similarity is proposed. Total 48 criteria will be obtained (three for each basic analog).

One more novelty of the method proposed: it is oriented to modern computerized devices of automated diagnostics of abrasive powder quality (in size, geometric, and morphological characteristics). The Bakul Institute for Superhard Materials, where the present study was performed, has one of such devices, namely DiaInspect.OSM (Vollstädt Diamant GmbH, Germany) [9]. It is used for studying morphometric characteristics of abrasive powders and a new extrapolation and affine 3D model of a grain, which was applied to develop original computer and analytical methods of indirect determining such important operational characteristics of these powders like external specific surface [10], a number of grains in a carat of a powder [11], a number of cutting edges and mean edge angles [12].

In the present paper this list is added by a new system and criterial method of the identification and quantitative estimation of the shape of the grain projection. After diagnostics of morphometric characteristics of abrasive powder on a DiaInspect.OSM (or any other device of the similar function) you may for some minutes have reliable information about the listed operational characteristics and assess its quality.

In the present paper we discuss the method of solving this problem based on a system and criterial approach and data of the diagnostics of the powder morphometric characteristics using modern automated devices. The method is developed by us.

2. System and analog algorithm of identification

The essence of our method comes to the identification of the real geometric shape of the grain projection by the search for its most adequate (close in the shape) analog from the preliminary specified collection of grains. With this purpose a system of the basic shapes–analogs (BSA) is introduced. The collection of BSA was formed based on the available empirical knowledge of the shape of synthetic diamond grains and possible shapes of their projection. The requirement that the basic shapes–analogs should allow the possibility of their identification process was one more criterion of the formation of the BSA collection. In the proposed method such a possibility is provided due to the fact that the BSA forming parameters and analytical representations of the BSA perimeter and area via the BSA forming parameters are suggested to be known.

The BSA collection formed according to these requirements included the following known plane geometric shapes: circle, ellipse, four versions of triangles (general, equilateral, isosceles compressed, and isosceles elongated), square, rhomb, rectangle, parallelogram, isosceles trapezoid in three versions (harmonic ($D > b > h$); compressed ($b > D > h$); elongated ($D > h > b$); where D is the diagonal, b is the longer base of trapezoid, h is the height), regular pentagons, hexagons, and octagons. Using the terminology of the digital processing of images, we note that the BSA forming parameters combined with the analytical representation through them the perimeter and area are the BSA signs. The following morphometric characteristics: maximum (F_{max}) and minimum (F_{min}) Feret diameters, the $F_e = F_{max}/F_{min}$ ratio called Feret elongation, area, and perimeter were taken as the signs of the real projection. From now on the signs of images will be specified by z_i, ($i = 1, 2, 3, 4, 5$).

Between the BSA forming parameters and the above signs of the image a correspondence is established for each BSA in the form of relations: $t_k = G_k\,(z_1, z_2, z_1, z_1, z_1)$, where $k = 1, 2,\ldots M$ is the number of a BSA, and M is the amount of them. In special cases that there is the exact correspondence between the forming parameters of BSA with number k and the i sign of the image, we assume $t_k \equiv z_i$. Otherwise the analog of the corresponding sign is looked for among the parameters derived from the forming parameters. The further procedure of the establishing the correspondence comes to the substitution of the corresponding sign of the image (F_{max} or F_{min} as a rule) into analytical representation of the interrelation between the derived BSA parameter with forming parameters. Let us illustrate this by the example of the BSA in the form of a rectangle having the perimeter L and area S. As the forming parameters in this case it is advisable to take the a and b sides of the rectangle ($a > b$). The analog of the Feret minimum diameter will be the smaller side of the rectangle and the analog of the Feret maximum diameter will be rectangle diagonal d, which is outside the forming parameters of the given BSA. Therefore, we have:

$$t_1 = \sqrt{F_{\max} - F_{\min}}, \quad t_2 \equiv F_{min}, \quad S = F_{\min}\sqrt{F_{\max} - F_{\min}}.$$

For each geometrical figure of their basic collection a system of signs of its shape similarity (three signs for each) is introduced. These signs are the generalization of images of a characteristic, which is called a shape factor [2,13], that is infused into the identification and digital processing from the topology. This dimensionless characteristic, which is denoted here by $ff_{cr,}$ is traditionally used for a quantitative estimation of the similarity degree of the projection shape of a real figure to a circle shape. It becomes equal to 1 only in the case that the real shape of the identifiable figure coincides exactly with the circle and is defined by the relation

$$ff_{cr} = \frac{L^2}{4\pi S}, \tag{1}$$

where L and S are the perimeter and area of the figure under recognition, respectively; π is the mathematical constant. For a circle of radius R the $L = 2\pi R$ and $S = \pi R^2$ and using Eq. (1) we have $ff_{cr} = 1$. For other identifiable figures that differ from a circle having other L and S values, the ff_{cr} calculated by Eq. (1) differs from 1. It should be noted that in [13] the characteristics of roundedness is introduced as the relation L^2/S and for a circle is $4\pi \approx 12.56$. However, in our opinion the estimation of the roundedness by relation (1) is more useful for solving the problems of a comparative analysis and other applied problems.