Stability evaluation of cutting edges in operation of composite materials for instrumental purposes based on a metal matrix

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Abstract. The authors analyzed the existing methods for assessing the stability of cutting grains in the article. The most optimal method for assessing the performance of abrasive grains was selected based on the results of the analysis. This method was used to calculate the concentration of diamond grains on the working surfaces of samples of a composite material made on the basis of bronze. The results of the studies showed that when testing the samples for friction and wear, the number of active abrasive grains and the relative solids content of natural diamond grinding powders show the stability of the cutting edges.

1. Introduction
The performance evaluation of grinding tools is made by the value of the specific diamond consumption (by weighing or counting the number of grains dropped), by measuring the linear and mass wear of the tool, productivity and roughness of the treated surface, which is a very time-consuming and costly procedure. However, it is known that grinding performance and processing quality significantly depend on the stability of the tool cutting properties, that is, the stability of the number of active diamond grains during its operation. Tool stability is an indicator characterizing the constancy of the diamond abrasive disk’s cutting properties. Therefore, when developing abrasive composite materials, it is especially important to determine the change in the number of active grains during friction and wear.

Most researchers determine the number of active (cutting) grains by various experimental methods. When deriving an equation for calculating the number of grains on the sintering tool surface, one of the main characteristics is their shape. The actual grain shape differs from the indicated models and depends on the brand of diamonds.

All the described methods for calculating the number of grains are not universal; they are developed for special cases of research, taking into account the features of the objects producing [1–8]. Existing calculation methods make it possible to calculate the initial volumetric concentration of active grains in a binder, however, they do not allow to determine its change during the operation of the tool.

The content of grains in the working layer is an important characteristic of a diamond tool, significantly affecting its cutting properties, durability and service life, as well as the forces and temperature that occur during cutting.
2. Methods

The object of the study is a standard binder – tin bronze M2-01 (20 mass% tin, 80% copper) with additives from 0–4 mass% of ultrafine natural diamond.

Samples (cylindrical, with a height and diameter of 1 cm) were made by sintering in vacuum (0.1*10^-3 Pa) in an SNVE furnace. Joint sintering ensured the constancy of the process conditions for a given batch of samples. Empirically determined that the optimal temperature is 700 °C. The sintering time was 60 minutes.

The calculation and experimental method used to determine the number of active abrasive grains with a statistically uniform distribution in the volume of composite material that was developed in [9] is used. When developing the method, we proceeded from the assumption that abrasive grains are a collection of particles of arbitrary shape and different dispersion, distributed in the bulk of the material statistically uniformly with a random spatial orientation.

When modeling grinding processes, it is important to use the shape of abrasive grains as the base model. In the scientific literature there are various views on the choice of such models: in the form of a cone with a rounded top, a ball, an ellipsoid of rotation, a cylinder, a cube. Given these differences, various models were compared and regulated according to the degree of approximation to the experimental data [10].

In a number of cases, the grain located on the plane is located so that the dimensions visible in the plan and taken as the length and width are smaller than the third size, conventionally called the height and visible on the second projection. Therefore, to select a geometric model of the shape of a real diamond grain, it is necessary to most accurately determine the linear dimensions of the grain from volume measurements in two projections.

The grain size characteristics necessary for simulating the control sieve screening procedures were determined from two projections obtained using a SEM XL-20 scanning electron microscope (Philips) in the secondary electron mode. Measurement of the length and width of the projection of grains, their height by SEM photographs (figure 1).

![Figure 1. SEM images of grains of diamond grinding powders for modeling grains in two projections.](image)

Method for determining the relative solids content in biphasic alloys.
Along with methods for calculating the quantity and size distribution of microparticles, there is a point analysis method that does not require geometric modeling of particles and the derivation of the distribution law, and which can be used to establish the volume fraction of the second phase. The method of point analysis is based on the fact that the proportion of points randomly printed on the micrograph that fall on the images of the phase under study is equal to the volume fraction (or area fraction) of this phase. In order for this principle to be fulfilled, points must be applied randomly to the micrograph. The volume fraction of phase $\alpha$ is given by the fraction of points that fell on the areas occupied by the studied phase.

In practice, it is usually inconvenient to deal with a random set of points and you can use an ordered point system. Figure 2 shows the application of the method of point analysis to determine the volume fraction of the solid phase (diamond particles) in the volume of the composite based on tin bronze (M1) and the study of their changes during friction and wear.

It is assumed that the microstructural components are distributed randomly. This assumption is mainly satisfied for most ordinary microstructures, but it must be remembered in cases where a completely regular arrangement of structural components is observed.

![Figure 2. The friction surface of composite materials based on M1 - grinding powders from natural diamonds 315/250 microns.](Image)

3. Results and discussion

As is known, the shape coefficient $Kp$ of an individual grain is defined as the ratio of the length of its projection to its width. The isometricity of grains (in percent), following the methodology of the standard [10], was determined by the formula

$$u = \frac{u_1}{n} \cdot 100,$$

where $u_1$ is the number of isometric grains, $n$ is the number of measured grains. The number of isometric grains $u_1$ was calculated by calculating the shape coefficient. Grain is considered isometric, if the shape coefficient $Kp$ does not exceed 1.3. The obtained values of the grain isometricity are shown in table 1.
Table 1. Analysis of the adequacy of the choice of the basic model of diamond grains.

| Grinding powder | Grain, μm | Geometric model of grain | Isometricity, % |
|-----------------|----------|--------------------------|-----------------|
|                 | By GOST  | Rectangular box | ellipsoid | spheroid | cube | octahedron |
| ND I            | 50/40    | 0.18          | 0.11     | 0.12     | 0.123 | 0.13       | 26.3 |
| ND II           | 80/63    | 0.13          | 0.14     | 0.17     | 0.12  | 0.14       | 41.81 |
| ND III          | 125/100  | 0.21          | 0.19     | 0.23     | 0.156 | 0.17       | 49.3 |
| ND IV           | 315/250  | 0.25          | 0.19     | 0.27     | 0.19  | 0.18       | 39.5 |

A visual examination of SEM – images of diamond grinding powders grains showed that the synthetic diamonds grains have a rounded shape, and natural diamonds grains are mainly lamellar and needle-shaped, there are crystals with a clear cut and sharp edges. The variational range of values is wider, the frequency is lower, and its modal value lies in the range of values of the shape factor greater than 1.3 for natural diamond powders. The consequence of this is a significant difference in the isometricity of the grains.

The method developed in [9] was used to calculate the concentration of diamond grains on the working surfaces of samples based on the M1 metal binder with 6% by weight of natural diamond powders with a grain size of 315/250 μm in the initial state and after testing on a friction machine (figure 3). The principle of operation of the machine is the abrasion of a pair of test samples pressed against each other by force P.

The calculation of the number of particles of the k-th size group \( N_k \) was carried out according to the formula obtained using the probability distribution \( F_i \) for cubic particles [9]:

\[
N_k = \frac{1}{H_k} (2.433 n_k - 0.971 n_{k-1} - 0.270 n_{k-2} - 0.097 n_{k-3} - 0.044 n_{k-4} - 0.019 n_{k-5} - 0.012 n_{k-6} - 0.007 n_{k-7} - 0.007 n_{k-8} - 0.007 n_{k-9}),
\]

where \( H_k = 1.5 h \) – average cube height if \( h \) is the cube edge (\( h \) was defined as the half-sum of the sides of the rectangle described around the projection of a random grain section [11]).

Figure 3. Friction surfaces of composite materials M1 – grinding powders from natural diamonds 315/250 microns.

The relative change in the number of active grains in the binder during friction and wear \( C = (n_0 - n_e / n_0) \times 100\% \) characterizes the stability of the number of active grains in the binder.

Figure 4 shows the size distribution of diamond particles in the metal matrix of the studied tin bronze composite materials with 6% by weight of natural diamond grinding powders with a grain size of 315/250 microns.
Figure 4. The size distribution of diamond particles in the composite on the working surface in the initial state and after a wear test with 6% by weight of natural diamond grinding powders with a grain size of 315/250 microns.

The volume fraction \( p_\alpha \) of phase \( \alpha \) is determined from the expression

\[
p_\alpha = \frac{n_\alpha}{n},
\]

(2)

where \( n_\alpha \) — число the number of points located on the phase \( \alpha \), \( n \) — total number of points plotted on the microstructure image.

The standard deviation of the volume fraction depending on the number of points used in the analysis:

\[
\sigma_{p_\alpha} = \left[ \frac{p_\alpha (1 - p_\alpha)}{n} \right]^{1/2}.
\]

(3)

This expression is also valid for the analysis of microstructures containing more than two phases.

The results of determining the volume fraction of the solid phase (diamond particles) based on a metal binder (M1) are presented in table 2.

Table 2. Determination of the volume fraction of the solid phase (diamond particles) in the volume of the composite based on a metal binder (M1).

| Sample                  | \( n \) | \( n_\alpha \) | \( p_\alpha \) | \( \sigma_{p_\alpha} \) |
|-------------------------|--------|----------------|---------------|------------------------|
| Sample with 315/250    | 59     | 15             | 0.294237      | 0.056688367            |
| before testing         |        |                |               |                        |
| Sample with 315/250    | 36     | 8              | 0.21223       | 0.069289952            |
| after testing          |        |                |               |                        |
The method of point analysis, which does not require geometric modeling of particles and the derivation of the distribution law, which is used to establish the volume fraction of the solid phase, can be used as an indirect express method for determining the health of composite materials with superhard materials powders fillers.

4. Conclusions
The results of the studies showed that when testing the samples for friction and wear, the number of active abrasive grains and the relative solids content of grinding powders from natural diamonds with a grain size of 315/250 μm show the stability of the cutting edges in the self-sharpening mode in a metal matrix based on tin bronze.

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