Dependence of abrasive tool wear-resistance on abrasive grain microstrength

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Abstract. Microstrength determined applying the microindentation method is an essential indicator of micromechanical properties of abrasive tools’ grains. Assessment is carried out according to the damage area dimensions and the imprint depth. The test results of various materials, including abrasive materials, in a friction machine revealed that relative wear-resistance of those materials depends on microstrength. The higher microstrength is, the lower wear-resistance of materials is. Such dependence was revealed in the course of studying the process of microcutting by single abrasive grains, as well as evaluating specific capacity of abrasive tools in operation. Thus, the microstrength parameter can be used to forecast operational efficiency of materials and tools.

One of the main performance parameters of abrasive tools, along with the cutting capacity, is wear-resistance of its composite material generally consisting of abrasive grains, a binding agent, and pores. Wear-resistance defines the tool service life to a great extent and therefore the economic effect of abrasive machining [1].

Wear-resistance of abrasive tools depends on many factors including tool parameters: the type and size of abrasive grains, hardness and porosity of the tool composite material, the type and amount of the bonding agent, and accuracy of the tool parameters [2, 3, 4]. Besides, the procedure and conditions of abrasive machining also have an impact [5].

Abrasive tools are mainly made of alumina-class materials: monocrystalline alumina, brown and white fused alumina, as well as zirconium, titanium, chrome, and chrome-titanium alloyed fused alumina. Materials of the silicone, zirconium, tungsten carbide class are used secondarily. Such super hard materials as natural and artificial diamonds, cubic boron nitride are distinguished as a separate class [6, 7, 8]. Brown and white fused alumina, certain alloyed fused alumina, and black and green silicone carbide are the most practicable.

An important characteristic of abrasive materials is physical and mechanical properties as they define the purpose and performance level of materials [9].

Due to powder-like features of abrasive materials, studying their micromechanical characteristics, including microhardness, microembrittlement, and microstrength, is of scientific and practical interest.

This paper comprises the results of studying dependence of abrasive tool materials on microstrength of abrasive grains.
The microindentation method was applied to determine microstrength. It consists in indentation of a square-section diamond pyramid into the grinding face of the studied abrasive grains at specific load. Assessment is carried out according to the damage area dimensions and the imprint depth [10, 11].

Grains of both fused alumina and silicone carbide abrasive materials with the grit size of 400 — 1250 µm were studied. Quartz sand particles were used for comparison. A microhardness tester with a diamond pyramid was used; the apex angle is 136°.

The area size of the brittle damage of the tested material layers around the imprint depends both on the rate of the external impact on those layers and the strength properties [12]. Thus, a criterion considering both impacts and the size of the brittle damage area near the imprint is suggested for evaluation of abrasive materials’ microstrength in case of pyramid indentation:

$$\sigma = \frac{1000P}{D_{cp}^2},$$

(1)

Wherein $P$ is indentation load.

$D_{cp}$ is the arithmetic-mean diagonal dimension of the damage zone.

Thus, the microstrength parameter $\sigma$ is the stress required for formation of a unit of the brittle failure area within the pyramid imprint.

According to the relation shown in figure 1, it is found that $\sigma$ depends on the pyramid indentation depth ($h$) into the grinding face. This relation can be expressed by the following formula:

$$\sigma = \sigma_0 h^{n_\sigma} = \sigma_0 h^{1},$$

(2)

Wherein $\sigma_0, n_\sigma$ are dimensional and dimensionless constants.

**Figure 1.** Microstrength of abrasive material grains depending on the penetration depth $h$ of the diamond pyramid into the grinding face, 1 — chrome fused alumina 34А; 2 — chrome-titanium fused alumina 91А; 3 — white fused alumina 24А; 4 — brown fused alumina 15А; 5 — black silicone carbide 54С; 6 — green silicone carbide 64С; 7 — quartz sand SiO2.
Applying the least square method, it was found that the dimensionless constant $n_\sigma$ is the same for all the abrasive materials tested and does not depend on the brittle behavior ($n_\sigma = -1.0$). It is indicative of the single nature of the abrasive material brittle failure, which accompanies their elastic-plastic strain in case of pyramid indentation. The dimensional constant $\sigma_0$ depends heavily on the brittle and strength behavior of abrasive materials and therefore can be used as a benchmark of their microstrength. According to formula (2), the numerical values of $\sigma$ and $\sigma_0$ will be equal at $h = 1$. Thus, the brittle microstrength criterion $\sigma_0$ equal $\sigma$ can be determined on the basis of figure 1 at $h = 1 \, \mu$m.

The results of previous studies [13] made it clear that the level of micromechanical properties of abrasive materials can correlate with the results of abrasive tool performance evaluation. The present studies ascertain and specify these provisions.

Preliminary studies of the correlation between the wear degree of various materials, including those abrasive, and their microstrength have been carried out. Dependencies of relative wear $\varepsilon$ of a number of abrasive materials, minerals, and high-melting compounds on the microstrength values of their particles defined by testing with the Shlif device (a friction machine) and using a cast-iron lap charged with diamond particles as a counterbody.

Being the most wear-resistant material among those tested, tungsten carbide was taken as the reference material. The value of $\varepsilon$ was calculated using the following formula:

$$\varepsilon = \frac{U}{U_{wc}},$$

Wherein $U$ and $U_{wc}$ are linear wear of the reference material and the test sample, $\mu$m.

A close directly proportional correlation between relative wear-resistance $\varepsilon$ and microstrength $\sigma_0$ of the tested materials has been established. This correlation is adhered to reliably within a very wide range of the criteria and described by the following formula:

$$\varepsilon = 2.76 \cdot \sigma_0^{1.1}$$

A dependence diagram of wear-resistance of abrasive grains and specific capacity of the grinding wheels made of the tested abrasive materials in case of microcutting and external grinding of a titanium alloy is shown in figure 2.

The grinding wheels with selected abrasive grains were made under the same conditions using a bakelite bond and had the grit size F60 and hardness N. Analysis of the test results reveals correlation of the micromechanical properties of the abrasive materials and their performance for both alumina and carbide groups: the higher microstrength of abrasive grains is, the higher wear-resistance is in case of microcutting and the higher specific capacity of the wheels made of such abrasive material is in case of grinding. Lower values of the performance parameters of alumina materials as compared to carbide materials are associated with their increased chemical reactivity towards titanium, which results in some mechanical degradation of the surface layers in case physical and chemical interaction with titanium.

A dependence diagram of relative resistance of general-purpose tools made of fused alumina on their microstrength is shown in figure 3. The relative resistance values are based on statistics, general operation experience, and testing of tools under production conditions. Analysis reveals a directly proportional relationship between relative resistance of abrasive tools and microstrength of abrasive materials on logarithmic coordinates.
Figure 2. Dependence of wear-resistance $U_m$ during microcutting (I, III, V) and specific capacity $g$ of grinding wheels in case of external grinding (II, IV, VI) of a titanium alloy with fused alumina (1 normal 14A, 2 — white 24A, 3 — chromium 34A, 4 — monocrystalline 45A) and silicone carbide (5 — green 64C, 6 — black 54C, 7 — cubic \(\beta\)-SiC, with tungsten carbide — 8) on microstrength of $\sigma_o$ abrasive grains.

Figure 3. Logarithmic dependence of relative resistance of $\varepsilon$ general-purpose abrasive tools on microstrength of $\sigma_o$ abrasive grains.
The research revealed a relationship between microstrength of abrasive grains with a wide range of types, sizes and the wear values, relative wear-resistance, and specific capacity during both microcutting of samples and operation of abrasive tools. Thus, the microstrength parameter can be recommended for assessment and forecasting of abrasive-material characteristics, wear-resistance and service durability of abrasive tools.

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