Increase of grinding wheel durability

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Abstract. The durability of grinding wheels on epoxy resin and bakelite bond reinforced with fiberglass and carbon fiber meshes was investigated. The durability of wheels was evaluated by means of their destruction due to the action of centrifugal forces during rotation in the test armored chamber. It was discovered that the speed of destruction of carbon reinforced wheels is 30% higher than the speed of destruction of fiberglass reinforced wheels. This kind of increase in the durability of the wheels allows to increase their maximum working speed, reduce tool wear, increase processing productivity, reduce roughness of the machined surfaces and the temperature during grinding.

1. Problem formulation
In all areas of industrial production, there is a tendency to increase processing productivity. For grinding processes, this is achieved, as a rule, by increasing cutting modes, in particular, by increasing grinding speed. Increasing grinding speed, along with productivity, improves the tool grinding coefficient, reduces grinding temperature, power loads and roughness of the treated surfaces.

The maximum possible tool working speeds are limited by their durability, namely the tensile strength. This is explained by the fact that the most dangerous for the wheel destruction are tangential tensile stresses arising from the action of centrifugal force and proportional to the square of the wheel rotation speed. In this case, the most dangerous zone is the zone near the wheel mounting bore, where these stresses are at their maximum. It is known that the area near the mounting bore is strengthened, for example, by local thickening, increasing its density (and hardness), drenching (impregnating), introducing reinforcing elements (metal bushings and rings), as well as metal, fiberglass (polymer binder tools) and basalt meshes [1–15]. The zone at the mounting bore of the wheels can also be strengthened with fine grains of controlled shape [16, 17], by applying detonation tightening coatings or by making wheels without a central hole. The properties of binding materials can also be improved. Grinding wheel assemblies with metal bodies have the highest working speeds. However, the scope of their application is limited to the processing of viscous, heat-resistant materials and complicated by the need for constant tool balancing [18, 19].

The most preferred, from the point of view of durability increase, is a straight wheel with reinforcing elements, which are placed in the mold during manufacture. Fiberglass meshes quite successfully cope with this task when manufacturing grinding wheels with resin binders. Thus, the use of fiberglass meshes for bakelite wheels allowed to increase grinding speed from 50-60 to 80-100 m/s or more. Fiberglass meshes are also successfully used as reinforcing elements in construction, aircraft and shipbuilding. However, the capabilities of fiberglass are largely exhausted. At the same time, new, high-strength and heat-resistant materials appear, which are superior to fiberglass in many respects. These materials
include carbon fibers, as well as carbon-based fabrics and meshes. They are successfully used in conjunction with resin binders to manufacture casing and power elements of aircrafts, automobiles and space crafts instead of fiberglass-based materials, which reduces weight, increases durability and heat resistance of products [20–22].

Literature analysis shows that so far there is no experience of using carbon fibers for hardening grinding wheels. Thus, testing the use of carbon fibers for reinforcing grinding tools is relevant and timely.

2. Purpose, objectives and methodology of research

At the first stage of research, the issue of selecting a resin binder, which was close in properties to the bakelite binder and did not require heat treatment was resolved. An epoxy resin was used as such a material. Grinding wheels reinforced with fiberglass mesh or carbon fiber fabric were made on basis of it (Figure 1). They were tested for durability, and then (for flat grinding operations) – at various operating speeds.

![Figure 1. Appearance of fiberglass mesh (on the left) and carbon fabric (on the right), which were used to manufacture test grinding wheels.](image)

Bakelite bonded grinding wheels reinforced with fiberglass meshes, with the same percentage of grains, binder and fillers, were also used as a comparative reference. The volumetric composition of the wheels consisted of abrasive (grade 13A63H normal electrocorundum) - 61.5%, resin - 27.7%, cryolite - 2.8%, and pyrite - 7.98%.

To conduct durability tests, we used a stand with the option of smooth control of the spindle speed and with a lockable armored chamber mounted on a table. To assess the performance of grinding wheels, a surface-grinding machine with a two-component dynamometer was used.

During the tests the following parameters were evaluated:
- wheel grinding coefficient (as the ratio of the polished metal mass to the worn wheel mass);
- wheel cutting ability (as the metal mass removed in one cycle of workpiece treatment);
- values of radial (Py) and tangential (Pz) components of the cutting force, as well as their ratio;
- grinding temperature;
- roughness of treated surfaces Ra and Rz.

The transverse feed was 1.2 mm/motion, the longitudinal feed was 20 mm/min; the workpiece material was steel 12X18H10T (HB 300).

An electronic scale was used to measure the masses of wheels and workpieces, and an optical pyrometer with a measurement limit of 950 °C was used to control the temperature of the workpieces. The temperature was measured after an octuple grinding of the workpieces’ surfaces. Roughness of the treated surfaces was measured using Talysurf 5–120 profilograph – profilometer.
3 Results and discussion

To conduct durability tests, wheels with an outer diameter of Ø150 mm, a diameter of a mounting bore of 32 mm, a height of 4 mm, reinforced at the ends with two fiberglass meshes, or with a carbon fabric with a tensile strength of 4.38 GPa were made. These wheels were destroyed on a testing stand in the armored chamber by gradually increasing their rotation speed. An indicator of the wheels’ breaking point was the values of their rupture speed. As a comparative standard, bakelite bonded wheels reinforced with two fiberglass meshes were used; and the rupture speed of those was estimated in a similar way.

As a result of durability tests, it was found that the use of carbon fabric instead of fiberglass mesh can increase the breaking speed of epoxy resin wheels by 30%, i.e. from about 100 to 140 m/s (Figure 2, a). The values of maximum working speeds of the wheels being compared, calculated through the safety factor (1.8), adopted for this type of tools, indicate that the use of carbon fabric instead of fiberglass mesh makes it possible to increase the speed of grinding with epoxy resin wheels from 55 to 80 m/s (Figure 2, b).

Visual analysis of the images of destroyed test wheels (Figure 3) shows that carbon fabric is characterized by better adhesion to the bond and practically does not peel off from the grinding wheel composite when it is being destroyed.

![Figure 2](image-url)

**Figure 2.** Rupture rates (a) and the maximum possible working speeds (b) of test grinding wheels, where: 1 - epoxy bond wheels, reinforced with fiberglass meshes; 2 - epoxy bond wheels, reinforced with carbon fabric; 3 - bakelite bond wheels, reinforced with fiberglass meshes.

![Figure 3](image-url)

**Figure 3.** Appearance of the destroyed test wheels: a - an epoxy resin wheel reinforced with fiberglass meshes; b - an epoxy resin wheel reinforced with carbon fabric; c - a bakelite resin wheel reinforced with fiberglass meshes.
To assess a positive effect of increasing the durability and maximum working speed of grinding wheels due to their reinforcement with carbon fiber fabric, some comparative surface grinding tests were carried out. Due to the lack of standard tools for stepless adjustment of the spindle speed on the machine, grinding wheels of various diameters were manufactured and tested in order to grind at different speeds with a constant speed of tools. Thus, epoxy resin grinding wheels with dimensions of 150x15x32 mm, reinforced with 4 fiberglass meshes and wheels with dimensions of 200x15x32 mm, reinforced with 4 layers of carbon fiber fabric, were made and tested. Such difference in diameters provided a proportional ratio of the test wheels’ working speeds by the value corresponding to the previously revealed difference in the destruction speeds and the maximum working speeds of the test grinding wheels (Figure 2). As a comparative standard, bakelite bond wheels with dimensions of 200x15x32 mm reinforced with 4 fiberglass meshes were tested. Layers of fiberglass meshes (or carbon fabric) were arranged in the wheels as follows: two - at the ends of a wheel and two - in its middle part at equal distances between adjacent layers. In wheel manufacture, these reinforcing layers were laid in a mold with an angular displacement of the threads in adjacent layers by 22.5°. In all tools, the percentage of abrasive, binders and fillers was the same.

Comparative tests showed that an increase in the grinding speed by 1.3 times in the case under consideration allowed us to reduce tool wear by 50%, increase the cutting ability by 32% and reduce the temperature during processing by 8% (Figure 4).

An increase in grinding speed by 1.3 times also led to a decrease in the cutting force components Py and Pz by an average of 40%, while Py/Pz ratio changed only slightly (Figure 5). Comparison of the
The performance of bakelite bond and epoxy resin grinding wheels at the same operating speeds shows that these tools have similar performance.

Figure 5. Component cutting forces \( P_y \) (a), \( P_z \) (b) and their ratio (c) when working with test grinding wheels at various operating speeds, where: 1 - epoxy bond wheels reinforced with fiberglass meshes (\( V = 22.5 \) m/s); 2 - epoxy bond wheels reinforced with carbon fabric (\( V = 30 \) m/s); 3 - bakelite bond wheels reinforced with fiberglass meshes (\( V = 30 \) m/s).

An exception is the wear parameter. Thus, bakelite bond wheels are characterized by a larger (by 18%) grinding coefficient (Figure 4, a).

Figure 6. Roughness \( R_a \) (a) and roughness \( R_z \) (b) when treating workpieces with test grinding wheels at various operating speeds, where: 1 - epoxy bond wheels reinforced with fiberglass meshes (\( V = 22.5 \) m/s); 2 - epoxy bond wheels reinforced with carbon fabric (\( V = 30 \) m/s); 3 - bakelite bond wheels reinforced with fiberglass meshes (\( V = 30 \) m/s).
The study of the treated surface roughness showed that a 1.3-fold increase in grinding speed made it possible to reduce the treated surface roughness (Ra) by 16% and (Rz) - by 9% (Figure 6).

4. Conclusions
The obtained results are consistent with the studies by other authors. Thus, studies of operability of test assembly grinding wheels at speeds up to 225 m/s show that in the speed range of up to 120-130 m/s, an increase in the grinding speed has a positive effect on the tool performance. A further increase in speed requires fulfilling significantly higher requirements of balancing the tool and the machine, otherwise a negative effect is observed [18]. Consequently, the use of carbon fiber fabric and meshes as reinforcing elements in resin binder grinding wheels opens the prospect of a significant increase in strength, working speed and other operational indicators of grinding tools. To assess the potential positive effect of the use of this material, it is advisable to make and comprehensively test bakelite bond grinding wheels reinforced with carbon fiber at the highest possible operating speeds and modern equipment. The technological properties of carbon fiber fabrics (cutting and chopping possibility, as well as heat resistance) allow them to replace fiberglass meshes in grinding tool production. A positive effect from using carbon fiber to reinforce grinding tools (for example, tool wear reduction by 50%) is comparable to the increase in their cost and, in combination, can give greater economic returns than the cost of using this material.

As a result, the use of carbon fiber and fiber-based fabrics and meshes for reinforcing grinding tools is a very up-to-date direction to increase the operational capabilities of these tools.

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