Influence of various types of spherocorundum on the performance of grinding wheels

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Abstract. The effect of introducing filled spherocorundum and hollow spherocorundum into the composition of grinding wheels on epoxy resin on the grinding coefficient, cutting ability, constituent cutting forces, temperature and quality of treated surfaces during implementation of a flat grinding operation is investigated. It has been established that replacing 40% of abrasive grains of electrocorundum in grinding wheels with filled spherocorundum with the same chemical composition and grain size reduces tool wear by 42%. It was also found that replacing 40% of abrasive grains with a hollow spherocorundum of similar grain size leads to a decrease in heat generation during grinding by 25%, as well as a significant reduction in deformations of the processed material during processing, compared with grinding wheels without adding spherocorundum.

1. Problem formulation
One of the main criteria for improving the design of grinding tools is to reduce their wear during operation. There are many directions for solving this problem. [1] Among them - increasing the strength of the abrasive used, creating binders with increased strength, selecting rational compositions for specific processing conditions, increasing the strength and working speed of grinding tools by reinforcing them with grids, bushings, etc. [2, 3] The strength of abrasives is increased by changing their chemical composition, for example, by alloying electrocorundum with Ti, Cr, Zr oxides [4], or by ordering the shape of grains. For example, the standards for diamond grains used in the production of grinding tools provide for their separation according to shape, so that fractions of diamond grains are used for the toughest materials, where more than 80% of these grains have an isometric shape with shape factors $K \leq 1.3$ (the shape factor in this case is the ratio of length to grain width) [5]. A similar approach to ordering the shape of grains is also effectively used for ordinary abrasives in various types of grinding tools [6]. The technology for producing isometric grains of monocorundum without crushing them is also known. Here, $\text{Al}_2\text{O}_3$ charge mixture is melted in the presence of iron chips, which are oxidized and separate $\text{Al}_2\text{O}_3$ droplets. The cooled ingot is washed off with warm water, which removes interlayers of $\text{Fe}_2\text{O}_3$ between grains [7]. In addition, there are technologies for producing corundum, where $\text{Al}_2\text{O}_3$ charge mixture is extruded, formed into billets of grains of the desired shape and size, and then sintered [7, 8].

There are known technologies for producing spherical grains (spherocorundum), due to spraying of electrocorundum melt poured from an electric arc furnace by various methods.
Hollow spherocorundum is obtained by feeding a jet of electrocorundum melt onto a rotating disk, as a result of which droplets are formed, which during the flight transform into hollow thin-walled spheres and crystallize before landing. The material for hollow spherocorundum is, as a rule, white electrocorundum. By adjusting the volume of the supplied melt, the disk rotation speed and other operating parameters one can obtain spherocorundum of various grain sizes. Grains formed by this method were initially used as heat insulators with a low bulk density ($\approx 1 \text{ g/cm}^3$) for high-speed high-altitude aircrafts. A little later, hollow spherocorundum was used as abrasive grains in grinding tools for processing soft materials that are sensitive to temperature: wood, rubber, leather, plastic, non-ferrous metals. Here, despite low strength of such grains, due to the micron thicknesses of the walls of the spheres, they turned out to be effective both as cutting elements and, at the same time, as large pores that significantly reduce processing temperature. For grinding steels as abrasive grains, hollow spherocorundum proved to be ineffective, due to its low strength and intensive wear. However, such grains have proven themselves very well as pores in grinding tools for processing viscous steels and alloys.

Filled monolithic spherocorundum are produced using simplified technology and high performance. Here, a jet of molten electrocorundum is poured by means of compressed air supplied through a nozzle located under the outlet of an electric arc furnace. The overwhelming majority of grains obtained in this way has a spherical shape with some admixture of ellipsoidal grains. The material for the filled spherocorundum, as a rule, is normal electrocorundum. Filled spherocorundum is used as proppants, i.e. components for injection into oil wells to extend their service life.

An analysis of the data shows that the experience of using filled spherocorundum as abrasive material is unknown [9, 10, 11, 12]. At the same time, it should be noted that this type of grain has an almost perfect isometric shape, obtained without crushing the ingot or sintering the charge mixture. Thus, such grains should have the greatest strength among others with the same chemical composition and their addition to the grinding tool can increase its wear resistance. The limiting factor in using filled spherocorundums as cutting grains is their smooth surface. Such a surface is less effective for grinding compared with the developed surface of crushed grains. This determines the possible use of filled spherocorundum solely as an additive to the grains of the main fraction. At the same time, a smooth spherical surface of the grains can create the effect of smoothing and reducing roughness, which requires practical verification.

Thus, testing the introduction of filled and hollow spherocorundum into the grinding wheel composition and comparing the performance of such tools with the performance of wheels with the original composition without spherocorundum is relevant and reasonable [13, 14, 15, 16].

2. **Purpose, objectives and research methodology**

To conduct the study, the issue of choosing a polymer binder that is close in properties to a bakelite binder and does not require heat treatment was resolved. An epoxy resin was used as such material; and grinding wheels with dimensions of 160x15x32 mm reinforced with 2 fiberglass meshes were made on its basis. The wheels were tested for strength, and then tested on the flat grinding operation. The initial volumetric composition of the wheels: normal electrocorundum grade 13A 63H (F24) - 61.5%, resin - 27.7%, cryolite - 2.8%, pyrite - 7.98%. In addition to the reference wheels with the original composition, three varieties of experimental tools were made:

- with a composition where 20% of the total volume of abrasive grains of grade 13A 63H (F24) were replaced by proppants of grade 16/30, grain size 63 (F24), TU 2-036-00221066-016-96 (Fig. 1, a);
- with a composition where 40% of the total volume of abrasive grains of grade 13A 63H (F24) were replaced by proppants of grade 16/30, grain size 63 (F24), TU 2-036-00221066-016-96;
- with a composition where 40% of the total volume of abrasive grains of grade 13A 63H (F24) were replaced by hollow spherocorundum of grade ES with grain size 63 (F24), TU 2-036-1020-88 (Fig. 1, b).
The chemical composition of the filled spherocorundum corresponded to normal electrocorundum grade 13A, the hollow spherocorundum corresponded to white electrocorundum grade 24A.

Figure 1. Appearance of grade 16/30 proppants with grain size F24 (a) and hollow spherocorundum grade ES with grain size F24 (b).

For carrying out strength tests, a stand was used with the ability to smoothly control the spindle speed located in a closed armored chamber. Grinding wheels were tested at a speed of 1.5 higher than the working one, with a shutter speed of 3 minutes.

To assess the performance of grinding wheels, a model 3G71 surface grinding machine with a two-component dynamometer was installed. The grinding wheel working speed was 22.5 m/s.

During the tests the following things were evaluated:
- wheel grinding coefficient, as the ratio of the polished metal mass to the mass of the worn part of the wheel;
- cutting ability of wheels, as the mass of metal removed in one cycle of workpiece processing;
- values of radial (Py) and tangential (Pz) components of the cutting force, as well as their ratio;
- grinding temperature;
- appearance of the wheels’ working surface after grinding;
- machined workpiece surfaces at 100x magnification.

One cycle of processing a workpiece consisted of octuple grinding of its surface (100x20 mm) with a cutting depth of 0.01 mm, followed by octuple sparking-out. The transverse feed was 1.2 mm/stroke, the longitudinal feed was 20 mm/ min; workpiece material - steel IIIX15 (GB 2S135) in the delivery state (HB 200).

To measure the mass of wheels and billets, electronic scales with a division value of 0.01 g were used, and an optical pyrometer with a measurement limit of 950 °C was used to control the temperature of the billets. The temperature was measured after octuple grinding of the workpieces’ surfaces.

3. Results and discussions

The comparative tests showed (Fig. 2) that the substitution in grinding wheels of 20% and 40% of abrasive grains of electrocorundum 13AF24 with filled spherocorundum with the same chemical composition and grain size enables to increase the grinding coefficient (reduce tool wear) by 13% and 42%, respectively. Replacing 40% of abrasive grains with hollow spherocorundum of similar grain size, on the contrary, leads to a sharp decrease in the grinding coefficient of tools by 65%. Moreover, the cutting ability of grinding wheels decreases with an increase in the percentage of grains replaced by spherocorundum, regardless of its type. This effect is most significant for instruments with hollow spherocorundum. Thus, the cutting ability of wheels, where 20% of the grains is replaced by filled spherocorundum, is 12% lower compared to the reference tool. Replacing 40% of grains with filled spherocorundum leads to a decrease in cutting ability of circles by 29%, and replacing a similar percentage of grains with hollow spherocorundum leads to a decrease in cutting ability of tools by 59%. The results obtained for wheels with the addition of filled spherocorundum are explained by the
fact that such grains have an almost perfect isometric shape. They do not have microcracks, since spherocorundum is obtained without crushing, the strength of such grains is higher than that of a crushed abrasive with a similar chemical composition and grain size. As a result of the use of such grains, the grinding coefficient of the wheels increases. The negative aspects of using filled spherocorundum are the smooth surface of these grains and the most negative rake angles, causing increased deformations and heating of workpieces (Fig. 2, c, d), which reduces processing productivity.

A significant difference in the performance of grinding wheels with the addition of hollow spherocorundum is explained by the fact that hollow spheres with thin walls are weakly involved in the cutting process during steel processing. They, in this case, play the role of large pores, the presence of which leads to a decrease in the heating of the workpieces (Fig. 2, c, d). Thus, the replacement of 40% of grains with hollow spheres (i.e., pores) leads to a significant change in the structure of the wheel. A smaller number of cutting edges on the working surface of the tool determines an increased load on them and greater wear, as well as a general decrease in the cutting ability of the tool. Such a situation could be avoided by replacing not cutting grains, but fillers, such as cryolite and pyrite by hollow spherocorundum in the composition of the compared wheels. In this case, the volumetric structure of the tools and the number of cutting edges would remain unchanged and the influence of the hollow spherocorundum on the performance of grinding wheels would be evaluated in a purer form. Nevertheless, in the case under consideration, despite the increased load on single grains, the presence of a significant percentage of hollow spherocorundum in the tool composition led to a 25% reduction in the amount of heat generated during grinding. Here we are talking about the temperature increment of the workpieces after grinding (Fig. 2, d).

![Image](image_url)

**Figure 2.** The grinding coefficient (a), cutting ability (b) of the experimental wheels, temperature of workpieces (c) and temperature increment of the workpieces after processing the experimental wheels (d), where: 1 - wheels from normal electrocorundum 13A F24; 2 - wheels in which 20% of abrasive grains of grade 13A F24 is replaced by filled spherocorundum of grade 16/30 F24; 3 - grinding wheels in which 40% of grains of grade 13A F24 is replaced by filled spherocorundum of grade 16/30 F24; 4 - wheels in which 40% of grains of grade 13A F24 is replaced by hollow spherocorundum of grade ES F24.
Due to the fact that the selected processing scheme (flat grinding) is intermittent and with a small cutting depth (0.01 mm), the heating temperature of the workpieces for all tools is very insignificant (Fig. 2 c) and it is more expedient to estimate the amount of heat generated by temperature increment to the initial temperature of the workpieces. The initial temperature of the workpieces was 24.5 ºС.

The data obtained (Fig. 2) are additionally confirmed by the results of evaluating the components of cutting force Py and Pz and their ratios (Py/Pz) during grinding with experimental tools (Fig. 3, a, b, c).

Replacing 20% and 40% of crushed electrocorundum grains in grinding wheels with filled spherocorundum leads to an increase in the cutting force component Py by 4% and 47%, respectively, and also to a decrease in Pz component by 11% and 35%, respectively. Substituting 40% of grains with hollow spherocorundum leads to an increase in Py by 60% and an increase in Pz by 19%. An analysis of the ratios of components Py to Pz shows that the larger is the percentage of grains replaced by spherocorundum, the greater is this ratio, especially for instruments with filled spherocorundum.

An analysis of appearance of the working surfaces of the experimental wheels after grinding (Fig. 4) shows that replacing 20% of ordinary grains with filled spherocorundum leads to the appearance of a small number of salting microcenters; and replacing 40% of grains with filled spherocorundum leads to a very noticeable number of such microcentres on the working tool surface. The revealed result puts a restriction on a further increase in the percentage of filled spherocorundum in grinding wheels, because reduction of tool wear will be offset by the need to dress it or to do it more frequently.

![Graphs showing cutting forces and their ratios](image)

**Figure 3.** Component cutting forces Py (a), Pz (b) and their ratios (c) when working with experimental grinding wheels, where: 1 - wheels from normal electrocorundum 13A F24; 2 - wheels where 20% of abrasive grains of grade 13A F24 is replaced by filled spherocorundum of grade 16/30 F24; 3 - wheels where 40% of grains of grade 13A F24 is replaced by filled spherocorundum of grade 16/30 F24; 4 - wheels where 40% of grains of grade 13A F24 is replaced by hollow spherocorundum of grade ES F24.
Figure 4. Appearance of the working surface of experimental wheels after grinding, where: a) - a wheel of normal electrocorundum 13A F24; b) - a wheel containing 20% of abrasive grains of 16/30 F24 spherocorundum; c) - a wheel containing 40% of the grains of 16/30 F24 spherocorundum; d) - a wheel containing 40% of the grains of ES F24 hollow spherocorundum.

An analysis of the workpieces’ appearance (at a magnification of x100) processed by experimental grinding wheels (Fig. 5) indicates a significant effect of the presence of spherocorundum in the tool on the quality of processed surfaces.

Figure 5. Appearance of the surfaces of workpieces (x100) after grinding: a) by a wheel of electrocorundum grains 13A F24; b) by a wheel containing 20% of abrasive grains of 16/30 F24 spherocorundum; c) by a wheel containing 40% of the grains of 16/30 F24 spherocorundum; d) by a wheel containing 40% of the grains of ES F24 hollow spherocorundum.

Thus, the effect of smoothing of the workpieces processed by grinding wheels with addition of filled spherocorundum is quite clearly noticed. This is especially noticeable on a workpiece processed with a wheel containing 40% of filled spherocorundum (Fig. 5, c). Here, the number of roughness grooves per unit surface area becomes significantly larger, and their depth is less. It should also be noted that the surface of a workpiece treated with a wheel with 40% hollow spherocorundum (Fig. 5 d) is characterized by reduced deformations and waviness of the roughness protrusions compared to a workpiece treated with a conventional grinding wheel (Fig. 5, a).
4. Conclusions

The results show that resistance of grinding wheels can be improved by introducing filled spherocorundum into their composition with a chemical composition and grain size similar to the main abrasive fraction. At the same time, the replacement of 20% of ordinary grains in the instrument with filled spherocorundum has a moderate effect on the change in its operational indicators. The grinding coefficient is increased by 13%, the cutting ability is reduced by 12%. Replacing 40% of the grains with filled spherocorundum leads to a very significant change in the operational parameters of grinding wheels - the grinding coefficient increases by 42%, the cutting ability decreases by 29%, the smoothing effect of the machined surfaces is clearly manifested, which is accompanied by an increase in the temperature of the workpieces and the appearance of a significant number of microcenters of salting on the working surface of the tool. As a result, a range of 20–40% can be recommended for further establishment of a rational percentage of filled spherocorundum in grinding wheels, since outside it the effect of increasing the resistance will either be insignificant or leveled out by the need for dressing or more frequent dressing of the tool.

Replacing 40% of abrasive grains with hollow spherocorundum, despite a very significant decrease in grinding coefficient (by 65%) and cutting ability (by 59%) in experimental tools, enabled us to reduce the temperature increase of the workpieces by 25%, which is critical for some grinding operations. Due to the fact that when processing steel, hollow spherocorundum mainly plays the role of large pores, to obtain balanced characteristics of grinding tools it should be recommended not to reduce (or reduce very slightly) the percentage of the main abrasive, and the introduction of hollow spherocorundum into the composition should be done by decreasing the percentage of other fillers, for example, pyrite and cryolite.

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