Increasing the durability of grinding wheels by reducing the wear of its limiting sections of the profile

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Abstract. Due to the edge wear and natural running-in, abrasive wheels do not have equal resistance to the profile. After flattening, the most weakened grains are removed from the wheel. Further, the wheel wears out in accordance with the law of natural running-on. The work on the basis of a systematic approach solved two main tasks: to analyze the relationship of resistance to self-sharpening; to develop and implement measures to improve the resistance of areas of the wheel, exposed for any reason the greatest wear or blunt. The paper analyzes the wear of the wheels during grinding and flattening. The finite element method is used to estimate the thermal stress in the ruling elements and grains. Not only a high probability of the formation of thermal microcracks was established, but also the destruction of grains at the moment of their exit from the contact zone. Edging device for flattening has been designed. A new scheme of forming a rectangular profile is proposed. New conditions for the grinding of the corner wheels were proposed.

The increasing complexity of the designs of modern machines and mechanisms involves the manufacture of precise complex shaped parts. Despite the great capabilities of CNC systems, some of them should be processed by profile grinding. Primarily in the manufacture of mating parts with congruent surfaces.

In this regard, the work aimed at improving the durability of shaped wheels is relevant. Uneven wear of the shaped wheel on the working surface depends on the conditions of flattening, the geometric characteristics of the contacting areas of the surfaces of the wheel and the workpiece [1-16].

In this regard, grain wear is of considerable interest. The mechanism of grain wear due to thermal loads is least studied. It is of particular interest for profile wheels, increased wear of individual sections of which significantly limits the overall durability, increases the complexity of grinding. Such areas include projections and depressions with a small radius of curvature, as well as having a relatively small angle of inclination between the tangent to the profile at the considered point and the longitudinal feed vector [2-7, 10].

In areas with narrow protrusions, a small number of weakly fortified grains work. For example, with a protrusion radius of 0.5 mm, a chain of grains with a maximum size in the diameter of 400 μm — no more than one, with a size of 250 μm — no more than three, with a size of 160 μm — no more than five [14] and etc. Distance between grains along the perimeter of the ledge: \( t_3 = \pi D_k / n \), где \( D_k \) -
wheel diameter; \( n \) – number of grains. The value of \( t_3 \) – depends on the depth of cut and is significantly greater than the distance between the grains on the cylindrical part of the wheel. The protrusion with such a number of grains is subject to bilateral force and heat and is prone to edge wear, the value of which is 5-12 more than natural [2, 4, 6, 7, 10, 15, 16].

The smaller the grain, the stronger the grains are held in the ledge. However, the strength characteristics of the grains with a decrease in grain size are reduced, and the self-sharpening of the wheel deteriorates. The probability of breakage of the grains from shock, thermal cycling, etc increases.

Narrow cavities create unfavorable conditions for the process of grinding the protrusion on the workpiece: intensive heating, deterioration of self-sharpening of the surface of the wheel, difficulties in the supply of cutting fluid (coolant) in the treatment area and more. After grinding on the workpiece defects are detected.

Common drawbacks of multi-level deep profiles of wheels are different allowances and dimensional tolerances, the same cut-in feed for shaping plunging into different surfaces in geometry and accessibility, which creates unequal operating conditions for abrasive grains.

Features of processing areas with a small angle of inclination to the vector of inset feed and end processing, is a small thickness of sections (for ends theoretically zero), falling on a single grain. Because of the small depth of penetration into the workpiece, the grains do not cut the material, but slide over the surface of the workpiece, contributing to the “clogging” of the working surface of the wheel. In order to process such surfaces, it is necessary to change the direction of feed, as is done with round face grinding, when the outer diameter and the end-face combined with it are polished simultaneously.

In modern conditions, as a rule, the abrasive tool does not work in the mode of full blunting. Its resistance is limited by the specifics of the technological operation. For profile grinding, the specificity is the impossibility or inexpediency of ensuring equal durability throughout the profile.

In studies of the profile grinding process [2-9], the analysis of the self-sharpening mechanism of the wheel does not take into account the total wear of the grains from the force and heat, physical and chemical interactions, does not consider the role of chips and the thickness of a single slice. In particular, in the works [3-5] it is stated that the smaller the thickness of the cut, falling on a single grain, the less wear of the wheel. The ambiguity of this statement is indicated in [6, 7, 10]. The relatively large thickness of the cut, falling on the grain contribute to its rapid breaking out of the ligament. Small thickness removed by grains, located in the pits of the wheel, do not provide sustainable cutting of the metal. Energetically activated piles form on the sides of the well-formed from the grain. In the contact zone, there are high temperatures that contribute to the setting of the grain with the activated metal. An increase in the growth leads to the appearance of salting on the wheel. In this case, the growth mainly performs a protective role on the grain – reduces the thermocyclic effect. Pulling out grains, reliably covered by a bundle in the cavity, is unlikely.

The high heat intensity of the flattening processes by various methods can be seen through the coolant as a white band (spot) of combustion. Traces of graphitization are found on diamond grains, traces of destructurization are found on other abrasive grains. Structural changes were observed not only in the ruling elements but also on the grains of the working wheel.

We studied the slurry after the flattening and grinding. The strength of grains for crushing was determined, the grain composition was studied. It has been established that the grains after grinding are stronger than the grains after flattening. When grinding, large grains are crushed to a greater extent than when flattening, which indicates the presence of not only chemical-abrasive but thermocyclic wear. The strength of the grains from the sludge is 4 – 8 times less than the strength of the grains from the wheel, which indicates their defect.

To check the possibility of destruction of the ruling elements and abrasive grains from the effects of temperature and cyclic fatigue by the finite element method (FEM), temperature stresses are calculated. The technique developed at the Institute of superhard materials was used [11, 12].

The temperature distribution in crystals was considered to be exponential:
where \( a \) and \( b \) are coefficients; \( z \) is the distance from the contact area.

In the computational model (see Figure 1) the crystal is represented by an ellipsoid of rotation, embedded in a metal bundle.

\[
T = a * e^{-bz},
\]

Figure 1. [11] A computational model: 1 - wear pad; 2 - bundle; 3 - crystal

The basis of FEM is the problem of functional minimization [11 - 13]. The relationship between stress and strain was taken according to the Duhamel-Neumann model [11 - 13]. The components of the strain tensor were found through displacements using Cauchy relations, and the minimum of the functional was found using circular triangular elements. The following boundary conditions are accepted [11 - 13]: working surface AB (see Figure 1) free from stress, on the surface of the aircraft moving along the axes R and Z are absent, on the surface of the AC on the axis R are absent.

In formula (1), based on the data of [11, 12], for diamond, \( b \approx 1.7 \); for cubic boron nitride (hereinafter CBN) according to data [11 - 13], \( b = 2.4 \); for white electrocorundum according to \( b = 2.8 \) [11 - 13].

Voltages were determined at two temperature regimes: for diamond and white electrocorundum – 1700 K and 700 K, for CBN – 1200 K and 600 K.

According to numerous studies, these modes correspond to the stress and average operating conditions of the grains during grinding and flattening.

Physical and mechanical characteristics are taken from works [11 - 13]. For diamond: modulus of elasticity \( E=1138 \) hPa, Poisson’s ratio \( v = 0.072 \); coefficient of linear expansion \( \alpha_p = 1.2 \cdot 10^{-6} \) 1/K, for CBN \( E=720 \) hPa; \( v = 0.1 \); \( \alpha_p = 2.5 \cdot 10^{-6} \) 1/K; for white electrocorundum \( E = 400 \) hPa; \( \alpha_p = 7.5 \cdot 10^{-6} \) 1/K.

These calculations are given in Table 1.

According to the calculations a temperature level of 1700 K is invalid for of diamond and electrocorundum, and also 1200 K – CBN. In this case, compressive stresses occur in all crystals that exceed the compressive strength. Therefore, there are microcracks that gradually destroy the abrasive grains in any contact.

As follows from Table 1, the crystal of CBN at a temperature of 1200 K should collapse. Diamond and electrocorundum crystals at 1700 K at voltages of about 3 hPa turn into powder [12, 14].

Temperatures of 600÷700 K cannot cause microcracks in crystals from thermoelastic stresses. They only contribute to the growth of cracks formed due to thermal shock, thermocyclic fatigue, significant thermoelastic stresses, shock effects or other causes.
To prevent chipping of grains together with a bunch of wheel edges and to preserve their number, we developed a special device (see Figure 2).

Figure 2. Flattening the edges of the wheel

On plate 1, two diamond bars 2 are exposed with a grain size 1-2 numbers less than the grain of abrasive grains 3 in the wheel 4.

The gap Z must be equal to the tolerance on the radius of the wheel R.

The device is fed to the wheel at an angle equal to half the angle of the wheel profile. For figure 2, the angle is 45°.

To save one of the corners of a wheel from a chip when flattening a cylindrical surface with a diamond pencil, it is necessary to cut into it so that the bundle of the wheel works in compression during a straight course and in tension during a course without feed. To preserve both corners, the wheels are adjusted to the middle on one side, then on the other. Then two scrubbing passes are made over the entire surface.

To increase the efficiency of grinding a rectangular profile, it is necessary to unload the protruding middle part of the wheel (see Figure 3).

Figure 3. Scheme of forming a rectangular profile: a – traditional; b - proposed

When grinding with a traditional method, the shape of the wheel rubs in a parabola. If the middle part is not participating in work, the edges of the wheel become worn and the effect of running-in wear does not have time to affect. The approximate width of the sample

\[ l = \frac{L - 2l_1}{2} \]

where \( L \) – the width of the groove; \( l_1 \) – the width of the projections of the wheel.

The smaller width of the contact wheel with the workpiece involves less pressing in the processing system and vibration.

When round-grinding, there are no clear recommendations on the choice of the angle of inclination (reversal) of the axis of a complex-shaped corner wheel with respect to the axis of the workpiece. The peculiarity of the wheel profile is the individual working conditions and the stability of the wheels of each point. With increasing angle \( \alpha \) (see Figure 4) the thickness of the cut when processing the end surfaces and self-sharpening of the surface of the wheel increases.
Processing conditions of cylindrical, base surface deteriorate. As our research shows, it is possible to activate the processes of wear and self-sharpening of the end surfaces by applying screw grooves to them. The direction of the screw groove should facilitate the coolant supply to the cutting area. The screw should end with an annular groove, spaced from the most loaded point C (see Figure 4) at a distance equal to 3 – 4 values of the grain of the wheel. Point F of the profile should be blunted by a facet of at least 1-2 grain sizes of the wheel. Otherwise, the possible cleavage of the wheel, breaking the integrity of the form.

Surfactants were used to increase efficiency and reduce wear of the wheel sections. The most technological method developed by us [10], which allows strengthening corundum grains in the basis of the wheel with aluminum, turned out to be the most technological.

Heated aluminum is easily smeared on the ledges of the wheel, grapples with grains, penetrates into the pores of the wheel. A small mass of aluminum does not disturb the balance of the wheel. Application of aluminum is carried out on a dry wheel. The resistance of "metalized" areas increases up to 2 times.

Another easily implemented method is the impregnation of the ends of the wheel with epoxy glue with abrasive filler. The resistance of near-end surfaces increases in 1.2 – 3 times.

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**Figure 4.** Grinding with complex angular wheels

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