The analysis of the interaction of the abrasive wheel working fluid with the treated surface when grinding wood and wood materials

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Abstract. In the mechanical technology of wood, a large amount of work falls on grinding operations, which are final in the manufacture of parts before finishing or gluing. The flow of these technological operations, the appearance and quality of products depends on the roughness of the polished surface. The use of abrasive wheels made of sphere corundum increases the productivity of the process of abrasive machining of parts. The field of application of hard abrasive tools for grinding wood and wood materials is expanding due to the reduction of tool salting and the elimination of burn-in of the treated surface. In the manufacture of an abrasive tool, the characteristics of the internal volumetric structure are regulated - granularity, grain content and ligaments. When grinding wood and wood materials, only the peripheral surface of the circle, its relief, takes a direct part in the work. The paper describes the relief of a circle made of sphere corundum and establishes a relationship between volumetric characteristics and its surface geometric parameters, which are necessary to determine the main indicators of the grinding process.

1. Introduction
The work of many scientists is devoted to the study of the grinding process of wood and wood materials with abrasive tools [1-4]. According to the results of the studies, the use of abrasive wheels for grinding wood and wood materials has certain advantages over the grinding sand, namely: high machining accuracy, good quality of the polished surface, high durability, and long service life of the abrasive tool, relatively low cost. In [5-8], it is noted that, depending on the grinding mode, the abrasive wheel can work with self-sharpening or with blunting.

The main characteristics of an abrasive tool that determine its working properties are graininess, hardness and structure. To obtain different hardness and structure, it is necessary to provide a certain ratio of abrasive grains, ligaments and pores per unit volume of the tool [9-11].
2. Methods of Materials

Two simultaneously proceeding processes accompany grinding wood and wood materials with abrasive wheels: blunting the wheel and self-sharpening it. The predominance of a process depends on the physic-mechanical properties of the grain, binder, characteristics of the wheel, the properties of the material being processed, the cutting mode, and so on.

In the process of grinding with conventional abrasive material, the grain wear sites increase, the radius of curvature and the rake angle increase, the different height of the grains decreases, and their density on the surface of the wheel increases. When the rake angle reaches its maximum value, abrasive grains cease to perform useful cutting work, and only elastic and plastic displacement of the material of the processed surface is performed. As a result, work on overcoming friction, plastic deformation increases, heat dissipation increases, forces acting on the grain’s side from the material increase. The further course of the process depends on the type of grain wear and bond strength. If only the abrasion of the cutting elements of the grinding grains occurs with the formation of sites on them and the forces of holding the grain in the bundle are large, then the wheel works in a dull mode and the abrasive cutting tool turns into a friction tool, cauterizing the surface to be treated. In this case, the cutting ability of the abrasive tool is restored by forcibly removing the dull grains during the dressing process. Loss of cutting ability also occurs as a result of filling intergranular space of an abrasive tool with chips.

In the case when, with an increase in the load on each grain, its micro-destruction occurs with the separation of small particles from it or macro-destruction with the separation of large particles commensurate with the grain size, or the complete breaking of the grains from the binder leads to an increase in the distance between the grains and into interaction with the processed material new downstream, dull grains come in. Thus, the working surface of the wheel is constantly updated, and it works in self-sharpening mode.

Self-sharpening is a hallmark of an abrasive tool. In a blade tool, destruction is a critical event leading to breakage and failure. In an abrasive tool, the destruction of cutting grains is a normal working condition, since the acting and permissible loads are quite close in magnitude. In this case, the tool operates in self-sharpening mode.

For abrasive wheels made of spherecorundum, the processes of wear and self-sharpening have their own characteristics. Self-grinding of abrasive wheels of spherecorundum is carried out not only by tearing and removing grains from the surface of the wheel, but mainly by exposing the sharp cutting walls of hollow spherical abrasive grains. Initially, when machining abrasive wheels by means of dressing, the sharp edges of the grains are exposed. However, it is important to determine the conditions under which the exposure of the walls during grinding occurs.

The spherical shape of the grain leads to the predominance of elastic and plastic deformations at most ratios of the penetration depth of abrasive grains into the processed material to the radius of abrasive grains arising during grinding. Destruction of abrasive grain can occur when the load on the part of the material to be processed \( P_{m} \) reaches the ultimate corresponding mechanical strength of the abrasive grain of spherecorundum:

\[
P_{m} = P_{d}
\]  

where, \( P_{m} \) – abrasive grain breaking load, N; \( P_{d} \) – load acting from the processed material on the implanting grain, N.

For plastic contact:

\[
P_{m} = S_{c} \cdot H
\]  

where, \( S_{c} \) – actual contact area, \( m^2 \); \( H \) – material hardness, \( N/m^2 \).

The actual contact area for a spherical abrasive grain is expressed through its diameter \( d \) and through the penetration depth, which in this case is the chip thickness \( a \):

\[
S_{c} = \pi \cdot d \cdot a
\]
Then:

\[ P_d = \pi \cdot d \cdot a \cdot H \]  

(4)

Therefore, the critical chip thickness corresponding to the destruction of abrasive grain:

\[ a_{cr} = \frac{P_d}{\pi d H} \]  

(5)

Knowing the mechanical strength of the abrasive grain of spherecorundum, its granularity and hardness of the processed material, we can determine the depth of penetration of the abrasive grain into the material at which the abrasive grain breaks and its cutting edges are exposed.

Calculations made according to formula (5) for different grit numbers of abrasive and wood species showed that the penetration depth necessary for breaking abrasive grain significantly exceeds the maximum possible chip thickness cut by one grain, therefore, in the grinding process, a single abrasive grain of spherecorundum cannot penetrate to such a depth at which the load from the side of the processed material would reach destructive. Therefore, the exposure of the cutting walls of the abrasive grains of spherecorundum during grinding occurs only due to their wear.

The equation for the maximum thickness of chips removed by one grain for the front wall of the grain of spherecorundum has the form [12]:

\[ a_{max} = \frac{V_s}{V} \left( \frac{h}{D} \right)^{0.5} \cdot \delta \]  

(6)

where, \( V_s \) – feed rate, m/s; \( V \) – cutting speed, m/s; \( h \) – grinding depth, mm; \( D \) – wheel diameter, mm; \( \delta \) – grain spacing, mm.

In the general case, substituting its expression (6) instead of \( a \), we obtain a relation between the destructive force \( P_d \) and the main parameters of the grinding process and the characteristics of the wheel:

\[ P_d = 2\pi \cdot d \cdot H \cdot \frac{V_s}{V} \left( \frac{h}{D} \right)^{0.5} \cdot \delta \]  

(7)

The load that destroys the completely abrasive grain of spherecorundum in the grinding process depends on the grinding conditions, the hardness of the processed material and the characteristics of the wheel. Depending on the hardness of the material to be processed, it is necessary to use an abrasive tool of the appropriate characteristics: granularity, hardness, structure, while using spherecorundum having optimal physical and mechanical properties, in particular, the grain wall thickness, which largely determines its breaking load.

The impact of the petals of the working fluid of the grinding wheel from a bulk non-woven material bearing an abrasive, fixed in it with a binder, is expressed as the resultant of friction forces. When installing the petals in the working fluid at an angle to the axis of the wheel, the resultant of the friction forces is the sum of the friction forces in the plane of the petal \( T_1 \) and the force \( T_2 \) normal to the plane of the petal. The friction force is determined from the expression: \( T = f \cdot N \). The normal pressure \( N \) will be determined by the direction of the force from the part relative to the petals, the number of petals in this direction and the degree of deformation of the working fluid of the wheel in the radial direction. The stiffness of a single petal in the normal plane is many times less than in the plane of the petal, so the friction coefficients in these planes will be different.

Consider the interaction process of a separate petal mounted at an angle \( \alpha \) to the axis of the wheel in its working fluid. We assume that grinding occurs with the same deformation in the radial direction of the wheel and the same forces from the side of the part with tangential and axial directions relative to the wheel. The front edge of the petal first interacts with the part in the direction of rotation (figure 1). The force \( P_r \) acting on the part side with the tangential direction of feed, is expanded in the plane of the blade and in the plane normal to its side surface: \( P_r^y = P_r \cos \alpha, P_r^x = P_r \sin \alpha \). Based on these formulas, for equal pressure of each petal with tangential and axial directions of feed, the angle \( \alpha \) should be equal to 45°. Nevertheless, this is without taking into account the nature of the preliminary
deformation of the petal from the action of forces from the part and the interaction of the petal with other petals in the working body of the wheel.

The deviation of the petal from the action of the force $P_r$, will occur mainly in the direction of least stiffness, that is, along the axis X-X in the direction perpendicular to the side surface of the petal. If in this way we sequentially consider the position of the peripheral zone of the petal from the action of the force $P_r$, then it will occupy a new position 2 (figure 1). The front edge of the petal deviates by a large amount, since in the direction the stiffness is less due to the small number of petals. Then, the deviation of the petals as the force acts along the peripheral zone of the petal decreases and has a minimum deviation at the end of the petal, since the stiffness of the working medium of the wheel increases due to an increase in the number of petals in the direction of the petal deformation.

Thus, the peripheral zone of the petal initially deforms under the action of the force $P_r$, a preliminary bias wave is ahead of the contact zone, and then deformed to the maximum permissible position 2, it exerts an abrasive effect on the part - the friction of the volumetric grinding cloth on the part occurs. If we compare the positions 1 and 2, then the petal is bent in the direction of supply of the part and additionally rotated relative to its original position. Therefore, the petal enters the grinding process rotated by a dynamic angle $\alpha'$.

With the axial direction of supply of the part, the deformation of an individual petal also occurs mainly in the direction perpendicular to the side surface of the petal (figure 2). At the beginning of the petal, the deformation is small, since the maximum number of petals is in the direction of the $P_{OC}$ force. Then the deformation increases and reaches a maximum at the end of the petal. The peripheral zone of the petal produces grinding being rotated by a dynamic angle $\alpha''$.

**Figure 1.** The deformation of the petal with the tangential direction of supply of the part relative to the circle.

**Figure 2.** The deformation of the petal with the axial direction of supply of the part relative to the circle.

### 3. Results and Discussion

In order for the wheel to have equal elasticity in the axial and tangential directions, provide the same working conditions in these directions, it is necessary that the following condition is met: $\alpha' = \alpha'' = 45^\circ$.

For abrasive interaction of the petal with the workpiece at an angle of $45^\circ$, the following conditions must be met (figure 3):

$$x_1 - x_2 = l\left(\sin45^\circ - \cos\alpha\right)$$  \hspace{1cm} (8)

where, $x_2$ – more deformation of the edge of the petal in the feed direction, mm; $x_1$ – less deformation of the edge of the petal in the feed direction, mm; $\alpha$ – static angle of rotation of the petals in the working fluid of the wheel with respect to its axis, $l$ – the length of the chord of the petal segment, mm, is determined by the formula:

$$l = 2(R + L)\sin\frac{\beta}{2}$$  \hspace{1cm} (9)
where, \( R \) – sanding pad radius, mm; \( L \) – the length of the petal free departure, mm; \( \beta \) – center angle of the petal segment,

![Figure 3](image_url)

Figure 3. Scheme for determining the angle of rotation of the petals for equal elasticity in the axial and tangential directions of the wheel.

We assume that the deformation of the petals \( x \) is inversely proportional to the number of petals \( n \) in the first degree:

\[
\begin{align*}
\alpha &= \arccos \left( \frac{1}{\sqrt{2}} - \frac{P_j}{(R+L) \sin \beta} \right) \\
\end{align*}
\]

This expression establishes the relationship between the angle of rotation of the petals in the working fluid of the wheel relative to its axis, which ensures equal elasticity of the wheel in the axial and tangential directions, with the size and number of elements of the wheel and forces arising from grinding.

4. Conclusions

During grinding, a single abrasive grain of spherecorundum cannot penetrate to such a depth that the load from the material being processed would reach a destructive value. Exposure of the cutting walls of the abrasive grains of spherecorundum during grinding occurs due to wear. The load that destroys the completely abrasive grain of spherecorundum during grinding depends on the grinding conditions, the hardness of the processed material and the characteristics of the wheel.

When the working medium of the wheel interacts from the volumetric sanding belt, the peripheral zone of the lobe initially deforms under the action of forces from the workpiece, a pre-displacement wave ahead of the contact zone, and then the lobe that is deformed to the maximum permissible state has an abrasive effect on the part.
The angle of rotation of the petals in the working body of the wheel from the volumetric grinding cloth relative to its axis, which provides equal elasticity in the axial and tangential directions of the wheel, is determined by the size, number of petals and forces arising from grinding.

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