Dynamic model of contact of grain with the surface of wood

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Abstract. Grinding holds the specific place among other types of machining of wood caused by specific features of the occurring physical phenomena and features of the tool. When processing the mechanical, chemical, thermal, electric and accompanying those phenomena arise a multiple-point cutting tool of preparations from wood or wood materials, naturally. The mechanical phenomena are shown owing to repeated contact of an abrasive paper from the preparation processed by a surface, that is, the fissile sliding friction. These phenomena are followed by a pollution of a cutting tool, including consolidation of space between abrasive grains that reduces operability of an abrasive paper. On the basis of the conducted theoretical researches and the analysis of the removed equations for determination of critical sizes of front corner, thickness of cut and speed of cutting, it is possible to draw conclusion that all listed parameters have significant effect on the size of bearing of the processed material abrasive grain, therefore, and on intensity of emergence of contact collapses. Increase in critical thickness of a cut leads to increase in deformation of near-surface layers of the processed material, and, therefore, and to increase in depth and the number of contact destructions.

1. Introduction
Basic purpose of process of grinding – surface treatment to finishing by elimination of roughnesses and defects of the previous processing.

Influence of various factors of process of grinding such as cutting speed, feed rate, clip pressure, graininess of the abrasive tool etc. on roughness of the processed surface was studied by many researchers [1-8]. Esthetic properties of wood, such as, the reflecting and absorbing ability, depend on roughness of the processed surface [9-11].

Regularities of a wear of the abrasive tool are directly bound to work of single abrasive grains. The phenomena of adhesion, diffusion, abrasive destruction, plastic flow of the shallow surface layers softened under the influence of high contact temperatures and pressure, chemical impact on an abrasive of a surrounding medium and the processed material are the cornerstone of the mechanism of a wear [1,7,8]. Under the influence of mechanical and temperature stresses, there is a cracking fissuring, shear of trimming blades, chunk-out from a linking of the separate abrasive grains and the whole complexes affecting quality of the processed surface.
2. Methods of research

Based on the theoretical analysis of process of abrasive cutting the following dynamic model of a formation of shaving is offered.

At high-speed impact of grain on the processed material, there is a dynamic hardening of a layer of the material, which is in immediate contact with abrasive grain. The maximum of dynamic hardening of material is reached already at speeds of deformation of 10-12 m/sec. The resistance to chok limit \( \sigma_{\text{ch}} \) is equal to the work of a limit of static durability \( \sigma_{\text{st}} \) on coefficient of dynamic hardening \( K_{\text{h}} \), which values for various materials fluctuate ranging from 1.5 up to 3.0.

Along with dynamic hardening impact pressure of material increases by the front surface of grain that leads to body height of a frictional force on a front surface. Thus, the part of material set in motion by grain has durability increased in comparison with material lump due to dynamic hardening and the raised cohesive force with grain due to increase in the frictional force caused by body height of impact pressure on the front surface of grain from the processed material at the increased strain rates. This strengthened part of material is future element of shift. Until the potential element of shift didn’t start moving, it is in the dynamic hardened condition. As it is affected by forces, which it is more than forces, acting on a ground mass of the material, on the conditional demarcation which is dynamically strengthened and not strengthened material there comes a shaving element shift relative to material ground mass. As soon as the element of shift has started moving, in its dynamic hardening at once disappears, disappears as well the dynamic pressure of grain upon shift element. It causes reduction of friction force swore on front surface, and, therefore, and forces of adhesion of element of shift with the front surface of grain. Therefore, at once after only the element of shift has started moving, forces, which have caused slippage of element of shift of rather fixed part of material, disappear and its slippage stops. At this moment, dynamic hardening of the following layer of material, which leads to formation of new element of shift, begins. This the new, dynamic strengthened shift element, sliding rather fixed part of the processed material, the previous element of shift of shaving forces to move concerning the surface of grain. Thus, slippage of elements of shaving on the front surface of the grain having negative front corner is carried out under the influence of again formed and dynamically strengthened shift elements.

If the processed material fragile, then in the course of shift shaving element completely separates from the lump of material and is carried away by grain. If the processed material plastic and at shift of element of shaving the plastic shift takes place, then the element of shift of shaving does not lose touch with ground mass of the material, and at formation of new elements all of them are connected among themselves in uniform chain and form shaving.

At grind of the materials having considerable rheological properties and high deformability such as rubber, thermoplastic materials and wood, such shift which does not lead to residual offset of elements of shift from each other, and deformation which is received by element of shift of rather fixed part of the processed material at the time of the beginning of its movement is essentially possible, has elastic character and is capable to be restored after the element of shift left direct zone of office of shaving. In this case, shaving turns out without the expressed shift elements. Proceeding from the above model, we will analyses a stressed state of a zone of a formation of shaving when cutting by grain, shaped a sphere. At introduction of grain in material and its movement on a trajectory, it is affected by the power factors arising owing to material deformation. Normally to the surface of grain tension works \( \sigma_{\text{fr}} \), and it is tangential to it the frictional force works:

\[
F_{\text{fr}} = N f_{\text{fr}}
\]

\( N \) – force of normal pressure, \( N; f_{\text{fr}} \) – friction coefficient.

The tangential stress caused by a frictional force will be expressed by a formula:

\[
\tau_{\text{fr}} = \sigma_{\text{st}} f_{\text{fr}}
\]

The “st” indexes designate that normal and tangent tension arises from action of the dead loads caused by material deformation that is without strain rate of material. Action of tension on material is
summarized, and total tension will be with a normal to the surface of grain a corner \( \phi \), equal in size to a sliding angle. Equally effective these two forces, force of standard static pressure and a frictional force creates the static stress of shift responsible for formation of shaving in material. The directions of action of the listed tension and corners between them are shown in Figure 1.

![Diagram](image)

**Figure 1.** The static and inertial reaction operating on abrasive grain in the course of cutting.

These dependences will be observed only in a statics or at low speeds of cutting, when there is no need to consider a dynamic factor. At significant increase in cutting speed, to be exact strain rate of the material, which is in a theoretical profile of a cut material from grain, will be affected by an additional power factor – high-speed selection or impact pressure. Emergence of an additional frictional force of material on the front surface of grain is result of impact pressure:

\[
P_{\text{din}} = SP_{\text{din}} f_{\text{fr}}
\]  

(3)

\( P_{\text{din}} \) – dynamic pressure, Pa; \( S \) – the area of grain which impact pressure affects, m².

If to carry a dynamic component of a frictional force to an unit area of contact of grain with material, then it will represent tension, tangent to the surface of grain:

\[
\tau_{\text{din}} = \frac{SP_{\text{din}} f_{\text{fr}}}{S} = P_{\text{din}} f_{\text{fr}}
\]  

(4)

that is the dynamic component of tension of a sliding friction is equal to the work of impact pressure on a friction coefficient.

Let us define the impact pressure \( P_{\text{din}} \), entering a right member of expression (4). For giving to the cut-off \( v \) speed shaving, it needs to report the kinetic energy equal:

\[
E = \frac{mv^2}{2}
\]  

(5)

The mass of the cut-off shaving is equal:

\[
m = V \rho
\]  

(6)
$V$ – shaving volume, $m^3$; $\rho$ – density of the processed material, $kg/m^3$.

The volume of shaving is equal:

$$V = L_{sh}S_{sh}$$  \hspace{1cm} (7)

$L_{sh}$ – cassettes length, m; $S_{sh}$ – shaving cross-sectional area, $m^2$.

The volume of the shaving peeled in time $t$:

$$V = vtS_{sh}$$  \hspace{1cm} (8)

therefore,

$$m = vtS_{sh}\rho$$  \hspace{1cm} (9)

By simple mathematical transformations, we receive:

$$E = \frac{vtS_{sh}\rho v^2}{2}$$  \hspace{1cm} (10)

Kinetic energy is equal to the work spent for reduction of shaving in the movement. Work is calculated by formula:

$$A = Nt$$  \hspace{1cm} (11)

$N$ – the power spent for reduction of shaving in the movement, $Wt$; $t$ – time of the movement, sec.

On the other hand:

$$N = vF_{in}$$  \hspace{1cm} (12)

$v$ – speed of the movement of shaving, $m/s$; $F_{in}$ – force of resistance to the movement, N.

After simple transformations, expression (5) will take form:

$$\frac{vtS_{sh}\rho v^2}{2} = vF_{in}t$$

therefore,

$$F_{in} = \frac{s_{sh}\rho v^2}{2}$$  \hspace{1cm} (14)

Specific dynamic pressure upon the surface of grain from the shaving set in motion:

$$P_{din} = \frac{F_{in}}{S_{sh}} = \frac{\rho v^2}{2}$$  \hspace{1cm} (15)

Respectively the dynamic component of tension of friction is equal:

$$\tau_{fr}^{din} = P_{din}f_{fr} = \frac{\rho f_{fr}v^2}{2}$$

Except tension of the friction having significant effect on shift tension, the material blanket, which is in direct contact piece to grain under the influence of high-speed pressure of grain, will receive dynamic hardening. If the static strength of the processed material was equal to allowable static stress of compression, then now, at high-speed loading strength on compression of the layer of material contacting to grain, dynamically strengthened will be equal to dynamic strength. Dynamic strength assumes increase in hardness and strength of material in comparison with its characteristics in static conditions. Therefore when calculating high-speed processes instead of static strength use dynamic strength. The size of dynamic strength depends on qualitative characteristics of deformable material and speed of loading. The maximum value of dynamic strength for each concrete material and its state is defined by dynamic reserve of elasticity or coefficient of dynamic hardening $K_{d,h}$, which represents the relation of the maximum value of pulse loading $\sigma_{max}$ (in practice $\sigma_{max} = \sigma_{din}^{str}$), maintained by material before collapse, to static strength.
3. Results and Discussion

Thus, dynamic strength of material with increase in speed of loading increases not infinitely, and up to some maximum size $\sigma_{\text{dmax}}$ various for each material. Value $\sigma_{\text{dmax}}$ is maximum tension, which can keep this material at high-speed loading. Therefore at dynamic loading existence of static strength is not considered and it is necessary to consider only dynamic strength.

Therefore, the maximum value of dynamic strength is constant for this material, and $\sigma_{\text{dmax}}$ reaches the sizes close to maximum already at loading speeds 10 - 12 m/s. Further increase in speed of loading does not lead to the noticeable growth of dynamic strength, as the dynamic reserve of strength is almost completely exhausted at these speeds of loading. Dynamic pressure of material upon the surface of abrasive grain, according to expression (7), increases in proportion to loading speed in the second degree. Therefore, the dynamic component of tangent tension of friction also increases in proportion to loading speed in the second degree.

As it has been told earlier, affect the material layer contacting to grain the static pressure $\sigma_{st}$, normal to the surface of grain, which is caused by material deformation. The maximum size of this pressure is equal to the strength of the processed material on compression $\sigma_{\text{str}}$, and as we consider forces arising in the course of material collapse, $\sigma_{st} = \sigma_{\text{str}}$. Under the influence of static safe pressure, there is tension of friction by means of which grain seeks to entrain material.

At dynamic loading normally to the surface of grain dynamic pressure $\sigma_{\text{din}}$ works, causing dynamic component of tension of friction $\tau_{\text{frin}}$, which, as well as $\tau_{\text{fr}}$ works concerning to the surface of grain and is summarized with $\tau_{\text{fr}}$.

$$\tau_{\text{fr}}^{\text{sum}} = \tau_{\text{frin}} + \tau_{\text{fr}}^{\text{din}}$$

(18)

The maximum tension, which can be realized in material in the direction normal to grain, is the tension equal to dynamic strength.

Therefore when determining total tangential tension of the shift arising in material under the influence of force of safe pressure and friction force as force, normal to the surface of grain, it is necessary to accept force which can be realized at greatest possible in these conditions by dynamic hardening of material. Moreover, as we consider the deformation speeds exceeding critical at which the maximum value of dynamic strength is reached, it is necessary to take the dynamic strength of this material into consideration.

Thus, the total tension of shift $\tau_{\text{shear}}^{\text{sum}}$ will be to equally vector sum:

$$\tau_{\text{shear}}^{\text{sum}} = \sigma_{\text{str}} + \tau_{\text{fr}}^{\text{in}} + \tau_{\text{fr}}^{\text{din}}$$

(19)

its absolute value:

$$\tau_{\text{shear}}^{\text{sum}} = \left(\sigma_{\text{st}}^{2} + \left(\tau_{\text{fr}}^{\text{in}} + \tau_{\text{fr}}^{\text{din}}\right)^{2}\right)^{0.5}$$

(20)

Let’s write down expression for the total tension of the shift arising in material under the influence of moving grain, having substituted the received dependences in formula (12):

$$\tau_{\text{shear}}^{\text{sum}} = \left(\sigma_{\text{str}}^{2} + \left(\sigma_{\text{str}}^{2} f_{\text{fr}} + \frac{\rho f_{\text{fr}} v^{2}}{2}\right)^{2}\right)^{0.5}$$

(21)

The vector of total tension $\tau_{\text{shear}}^{\text{sum}}$ forms with normal to the front surface of grain corner $\varphi_{\text{fr}}^{\text{sum}}$, which can be defined as follows:

$$\text{tg}(\varphi_{\text{fr}}^{\text{sum}}) = \frac{\tau_{\text{fr}}^{\text{sum}}}{\sigma_{\text{str}}^{2}} \text{ or } \varphi_{\text{fr}}^{\text{sum}} = \text{arctg}\left(\frac{\tau_{\text{fr}}^{\text{sum}}}{\sigma_{\text{str}}^{2}}\right)$$

(22)
4. Conclusions
The nature of influence of geometry of the cut-off layer and radius of curve of top of grain on condition of the beginning formation shaving is shown. The character and the law of redistribution of tension at the movement of grain on trajectory is established.

The dynamic model of process of elementary cutting is offered and analyzed by the abrasive grain having the sphere form. Based on the offered model the analysis of the power factors influencing abrasive grain in the course of formation shaving is carried out.

Formulas for determination of size of thickness of cut, front corner and speed of cutting are remove. In the removed formulas influence of static and dynamic strength of the processed material, friction coefficient between materials, grain top radius, firmness of material and mutual influence at each other of the speed of cutting, thickness of cut and size of front corner is considered.

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