Cutting ability of abrasive grains in the processing of billets of plastic materials

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Abstract. When processing billets of plastic and adhesive-active materials, the loss of the cutting ability of the grinding wheel is mainly due to the adhesion of the workpiece material particles to the abrasive grains (AG). To develop recommendations aimed at reducing the intensity of adhesion, it is necessary to identify the relationship of the intensity of this process with the physical and mechanical properties of abrasive grains. The dependence for the calculation of the voltage at the contact area of the clip with the AG after the AG out of contact with the workpiece is obtained. Numerical simulation of local temperature when microreserve (scratching) samples of steel 3KH3M3F abrasive grains of various materials. According to the obtained dependences, the deformation of the excrescence and the stresses resulting from this deformation were calculated, and the ones acting on the connection of the 3KH3M3F steel excrescence with grains from materials having different coefficients of linear expansion. It is established that with the increase in the difference of the coefficients of linear expansion of the billet materials and AG, the stresses that contribute to the separation of the excrescence from the surface of AG increase, which allows to predict a lower intensity of sticking of the billet material to AG from such materials. It is established that with the increase in the difference of the coefficients of linear expansion of the billet materials and AG, the stresses that contribute to the separation of the excrescence from the surface of AG increase, which allows to predict a lower intensity of sticking of the billet material to AG from such materials. Experimental studies, during which micro-cutting of samples by single abrasive grains was carried out, showed that AG from elbor wear out and are salted to a lesser extent. Elbor has the maximum value of the coefficient of thermal conductivity among the tested materials and to a lesser extent wears out, so the local temperatures when cutting grains from Elbor are minimal. In addition, the difference between the linear expansion coefficients of the material excrescence and elbor has a maximum value. Therefore, at the site of contact AG from elbor with the adhesive there are stresses that contribute to the separation of the excrescence from this surface, which is the reason for the small value of the coefficient of salting AG from elbor. As a result, AG was ranked from various materials according to the criteria characterizing their wear and salting. Confirmed identified analytically the relationship between the intensity of broning of grain with a coefficient of linear expansion and thermal characteristics of the materials AG.
1. Introduction
The cutting ability of the grinding wheel decreases with increasing operating time due to blunting and salting of its working surface. When grinding blanks from plastic and adhesive-active materials, the loss of cutting ability is mainly due to salting, the primary cause of which in most cases is the sticking of the workpiece material particles on abrasive grains (AG). To develop recommendations aimed at reducing the intensity of adhesion, it is necessary to identify the relationship between the intensity of AG salting with its physical and mechanical properties.

It has been established analytically and experimentally confirmed [1] that the adhesion intensifies with increasing local temperature in the areas adjacent to the grain, and the latter depends on the thermal characteristics of the AG material [2, 3].

The excrescence held on the surface of the grains by mechanical and adhesive forces, and most permanently in the cavity of submicropores AG [4]. After the release of AG from contact with the workpiece in the volumes of the excrescence and AG, stresses appear, which are the result of their cooling. The analysis of these stresses and the assessment of conditions affecting the strength of the compound with AG excrescence have not yet been performed.

2. Analytical studies and discussion
It is most likely that the destruction (cut) of the formed bridge of the workpiece material setting with AG will occur at the level of the tops of the AG submicropore, since the allowable stresses on the slice of the material of the excrescence (workpiece) decrease with increasing temperature, and the latter is higher in the surface layers of the workpiece and AG [5].

Based on the accepted forms of microwave AG [4] and calculations showing that the depth \( h_k \) of the implementation of the workpiece material into cavities on the surface of AG may be less than the maximum height of asperities \( h_w \), that stuck in the cavity presented in the form of a truncated cone (Figure 1).

![Figure 1. Scheme to the calculation of stresses in the lime tree, located in the cavity of submicropores AG: 1 – AG, 2 – the excrescence](image)

The size of the excrescence is determined by the size of the microroughnesses at the gas station [4], i.e. calculated by the size of the order of the micrometer. When considering the properties of objects of such dimensions, it is legitimate to use the mechanics of continuous media. Since the orientation of individual excrescence crystals is a probabilistic event, and the excrescence itself can consist of several grains differently oriented to each other, we assume that the properties of the excrescence are the same in all directions. We believe that the physical and mechanical properties of the excrescence coincide with the corresponding properties of the material of the workpiece (sample).
After cutting the bridge, the external pressure ceases to act, which caused the deformation of the material of the burl, and the residual deformation in the volume of the latter generates forces acting on the part of the burl on the surface of the cavity of the submicroprofile AG. For Figure 1 all forces are conditionally applied to one point located on the contact surface of the excrescence and AG.

The dependence for the calculation of the initial elastic deformation of the excrescence \( \Delta \ell_n \) (in the direction of the force \( W \)) at the temperature \( T_n \) (at which the adhesive interaction of the materials of the excrescence and AG):

\[
\Delta \ell_n = \frac{(d_1 + d_2) \cdot \sigma_{PR_n}}{2E_{T_n}},
\]

where \( d_1 \) and \( d_2 \) are the diameters of the truncated cone, in the form of which the excrescence is represented in the cavity, m (see Figure 1); \( \sigma_{PR_n} \) – the maximum stresses in the material the excrescence, which are fair Hooke’s law, when the temperature \( T_n \), Pa; \( E_{T_n} \) – is the modulus of elasticity of the material the excrescence at a temperature \( T_n \), Pa.

The deformation of the excrescence in the process of cooling it together with the grain to the temperature \( T \) will change by an amount equal to

\[
\Delta \ell_{1T} = (\alpha - \alpha_{ag}) \cdot (T_n - T) \cdot \frac{d_1 + d_2}{2},
\]

where \( T_n \) – is the local temperature at which the adhesion interaction of the excrescence with the grain, K; \( T \) – is the temperature to which the AG and the excrescence, K; \( \alpha \) and \( \alpha_{ag} \) – the coefficients of linear expansion of the material, respectively, of the excrescence and AG in the temperature range \( T \) … \( T_n \), K\(^{-1}\).

The deformation the excrescence at a temperature \( T \) will be:

\[
\Delta \ell_T = \Delta \ell_n - \Delta \ell_{1T};
\]

\[
\Delta \ell_T = \frac{d_1 + d_2}{2} \cdot \left( \frac{\sigma_{PR_n}}{E_{T_n}} - (\alpha - \alpha_{ag}) \cdot (T_n - T) \right).
\]

During cooling the excrescence to the temperature \( T \) of the tension at the site of contact with excrescence and AG make

\[
\sigma_{nT} = \frac{2 \cdot E_T \cdot \Delta \ell_T \cdot \cos^2 \frac{\alpha_w}{2}}{d_1 + d_2},
\]

where \( E_T \) – is the modulus of elasticity of the material the excrescence at a temperature \( T \), Pa; \( \alpha_w \) – the angle of depression (see Fig. 1).

If \( \Delta \ell_{1T} < \Delta \ell_n \), i.e. \( \Delta \ell_T > 0 \), after cooling on the site of contact with AG the excrescence will act compressive stresses. When \( \Delta \ell_{1T} > \Delta \ell_n \), i.e. \( \Delta \ell_T < 0 \), thermal distortion the excrescence in the process of cooling will exceed the initial deformation and compression the excrescence will be replaced by tension and, at the site of contact with the excrescence I will stress appears \( \sigma_{nT} \), contributing to the separation the excrescence from this surface. In this case, the probability of separation on the Linden from the surface of the AG will be higher. The parameter \( \Delta \ell_{1T} \) depends on the values of the coefficients of linear expansion of the materials excrescence and AG and increases with increasing their difference. From the dependencies (1) – (4) it follows that to obtain tensile stresses \( \sigma_{nT} \) and reduce due to this intensity of adhesion should be used AG from materials, the coefficients of linear expansion of which differ significantly from the coefficients of linear expansion of the workpiece material.
The magnitude of the stress $\sigma_nT$ also depends on the local temperature of the $T_n$, at which the interaction of the excrescence grain occurred. Local temperatures in the process of scratching the sample material with a single AG were calculated using the technique and software described in [1, 5]. This technique takes into account: the real forms of objects (sample, AG and chips); the presence of heat sources in the deformation zone and in the areas of chip contact with AG (for AG, performing micro-cutting) and AG with the sample; the dependence of the thermal properties of the materials of objects on temperature; the relative movement of objects (AG relative to the sample and chips relative to AG). Thermal processes were modeled on the basis of a joint solution of differential equations of thermal conductivity with General boundary conditions in the contact zone of objects. The forces of micro-cutting and the power of heat sources were calculated from the analytically obtained dependences [1, 5].

Numerical simulation of local temperatures (as well as subsequent experimental studies) was performed for AG from normal electrocorundum (material № 1), zirconium electrocorundum: material № 2 made in Austria ($ZrO_2$ – 40%, $Al_2O_3$ – 60%), material № 3 – is made of UralNIIASh ($ZrO_2$ – 39.6%, $Al_2O_3$ – 59.4%, C – 0.49%), material № 4 also is made of UralNIIASh ($ZrO_2$ – 42.6%, $Al_2O_3$ – 56.5%, C – 0.48%), and also from elbor LKV 50 (material № 5). These materials have different thermal characteristics (thermal conductivity, specific heat and density), as well as the coefficient of friction in the contact zone with the sample.

As a material of samples used heat-resistant die steel 3KH3M3F, which has a sufficiently high plastic properties and viscosity.

In the process of modeling of local temperatures, the maximum depth of AG introduction into the material of the $a_z$ sample was varied, taking it equal to 3 and 6 microns, and the size of the blunt area $\ell_2$ upon AG – 20 and 100 microns. The 20 microns area is formed at the filling station after grinding wheel (SHK) straightening; after several tens of minutes of SHK operation, the area size reaches 100 microns [6].

The maximum values of local temperatures are fixed when the sample is scratched by grains from material № 4, having a minimum value of thermal conductivity, the minimum temperatures are obtained when scratching grain from elbor (material № 5), having a maximum coefficient of thermal conductivity [7, 8] and a minimum coefficient of friction on steel (table 1, 2). Small values of local temperatures are also obtained when scratching grains of electrocorundum normal, the conductivity of which is higher than that of zirconium corundum. The temperature of the grains performing micro-cutting ($a_z = 6$ microns), on average 70 – 80 % higher than that of the grains performing plastic deformation of the sample material ($a_z = 3$ microns). The increase in the size of the $\ell_2$ blunt area from 20 to 100 microns led to an increase in local temperatures by an average of 75 %.

According to the dependences (1) – (4) the deformation of the excrescence and the stresses resulting from this deformation were calculated, and the 3KH3M3F steel the excrescence ($\alpha = 12.2 \cdot 10^{-6}$ K$^{-1}$) acting on the connection with grains of abrasive materials having different coefficients of linear expansion of $\alpha_{ag}$. The maximum value of the coefficient of linear expansion, the closest to the coefficient of the material of the excrescence, has an electrocorundum [7], so the condition is fulfilled $\Delta\ell_{tp} < \Delta\ell_{ag}$, and at the contact site of the excrescence with the AG will act compressive stresses (table 1, 2). The magnitude of these stresses is much lower than the tensile strength of the material of the excrescence (for steel 3KH3M3F tensile strength is 1500 MPa), so the probability of failure of the excrescence. The maximum difference with the coefficient of linear expansion on the Linden has a corresponding coefficient of elbor. Deformation the excrescence located in the cavity of submicropores grain of this material, in the process of cooling is greater than its initial deformation, therefore contact area the excrescence with AG, any tension $\sigma_nT$, contributing to the separation the excrescence from the surface of AG.

For this reason, it is possible to predict a less intense sticking of the workpiece material particles on AG from elbor in comparison with grains from other materials. The linear expansion coefficient of zirconium corundum and stress values for these abrasive materials, occupy an intermediate position between the tested materials № 1 and № 5. Thus, the intensity of adhesion of the workpiece material
particles on the AG should decrease with increasing difference in the coefficients of linear expansion of the workpiece materials and AG \((\alpha - \alpha_{ag})\).

### Table 1. Results of numerical simulation of local temperatures at the AG contact site with the sample and of stress \(\sigma_{nT}\) in the excrescence: \(a_z = 3\) microns, \(\ell_2 = 20\) microns; \(\alpha_w = 30^\circ\)

| Material number | AG | Average local temperature, K | Voltages \(\sigma_{nT}\), MPa |
|-----------------|----|------------------------------|-----------------------------|
| 1               |    | 710                          | 380                         |
| 2               |    | 750                          | 150                         |
| 3               |    | 790                          | 110                         |
| 4               |    | 790                          | 90                          |
| 5               |    | 670                          | -60                         |

### Table 2. Results of numerical simulation of local temperatures at the AG contact site with the sample and of stress \(\sigma_{nT}\) in the excrescence: \(a_z = 6\) microns \(\ell_2 = 20\) microns; \(\alpha_w = 30^\circ\)

| Material number | AG | Average local temperature, K | Voltages \(\sigma_{nT}\), MPa |
|-----------------|----|------------------------------|-----------------------------|
| 1               |    | 1250                         | 60                          |
| 2               |    | 1340                         | -530                        |
| 3               |    | 1380                         | -580                        |
| 4               |    | 1380                         | -585                        |
| 5               |    | 1150                         | -650                        |

### 3. Pilot studies and discussion

Experimental studies were carried out on the installation created on the basis of a 3G71 plane grinding machine. Instead of the grinding wheel on the spindle of the machine was installed faceplate holder (indenter), which was fixed (sealed) AG. Grain was sharpened on a cone with an angle \(\gamma = 120^\circ\) by a diamond circle. In this case, the holder (indenter) was installed in a special device. The longitudinal feed of the circle relative to the sharpened grain was 0.25 m/min. Thus, the conditions for grinding the grain were as close as possible to the conditions for editing the WK with a diamond ruling tool.

To estimate the intensity of the sample material particles sticking to the AG during single grain micro-cutting we used:

- square the excrescence metal sample on AG \(F_n, \text{m}^2\);
- AG \(K_z\) salting coefficient:

\[
K_z = \frac{F_n}{F_{pl}}
\]  

where \(F_{pl}\) – the area of the pad wear on AG, \(\text{m}^2\);

- linear wear AG \(h_n, \text{m}\):

\[
h_n = \frac{\ell_2 - \ell_2'}{2 \cdot \tan \gamma}
\]  

where \(\gamma\) – half the angle at the top of AG, \(\text{grad.}\); \(\ell_2, \ell_2'\) – the size of the area of bluntness on AG, fix edit after sharpening and micro tune sample, respectively, \(\text{m}\);
The area of the $F_n$, the number excrescence and dimensions of the area of wear on AG $\ell_2$ and $\ell'_2$ was determined using microscope PME.

The penetration depth of grain in a sample of AG ranged 3 ... 8 microns. At AG = 3 microns AG performs plastic deformation of the sample material, at great depths – microcutting [8].

The maximum values of $K_z$ and $h_u$ fixed when scratching samples of normal abrasive grains of electrocorund (material № 1), having among the tested abrasive materials minimum hardness and heat resistance. The coefficient clogging and wear of AG zirconium corundum is much less. From zirconium electrocorund, the minimum values of $K_z$ and $h_u$ were obtained by micro-cutting AG from the material № 2 made in Austria: in comparison with the normal electrocorund $K_z$ and $h_u$, they were less by 60 and 110 %, respectively.

The intensity of the clogging and wear of the grains of zirconium electrocorund, is made of UralNIIASH (materials № 3, 4) was lower than that of the grains of electrocorundum normal by 60 and 40 %, but higher than grains from the Austrian zirconium electrocorundum (material № 2) at 20 and 30 %, respectively. The grain of thematerial № 4 showed slightly better results than as material № 3: $K_z$ and $h_u$ if scratched with beans № 4 was 15% lower. AG from elbor wear out and are salted to a lesser extent than grains from other studied materials. The local temperature at the AG contact site with the sample (workpiece) decreases with increasing thermal conductivity of the grain material and increases with increasing blunt area [1]. Elbor has the maximum value of the thermal conductivity coefficient among the tested materials and is less worn. This is another reason for the less intense sticking of metal on AG from elbor. The values of the coefficient of salinity are correlated with the stresses $\sigma_{elT}$ in the excrescence. Material AG № 1 (normal electrocorund), for which the maximum value of $K_z$ is fixed, provides among the tested materials and the maximum values of compressive stresses. Material № 5 (elbor), at the site of contact which the excrescence any tension $\sigma_{elT}$, contributing to the separation the excrescence from the surface, has the minimum value of $K_z$. Zirconium electrocorund (materials № 2 - 4) have almost the same values of tensile stresses (at AG = 6 microns these stresses are in the range of $\sigma_{elT} = 532 ... 585$ MPa). The coefficient of salinization of AG from these materials, as well as the stress values, occupy an intermediate position between AG from elbor and normal electrocorund. Less intensively metal sample adheres to the gas station of zirconium electrocorund № 2, which may be due to lower values of local temperature (among zirconium electrocorund) when scratching grains from this material.

Between the recorded values of $K_z$ and $h_u$ there is a correlation: the more $h_u$, the more $K_z$. One of the reasons for the increase in $K_z$ with increasing wear as the number of interactions increases is the increase in local temperatures with an increase in the area of blunting on AG. At the same time, with an increase in $K_z$, the process of adhesion wear of grains intensifies. Since the wear of AG. IS studied more fully than the process of salting, the established relationship of these parameters makes it possible to predict the $K_z$, based on the values of AG wear.

4. Key findings and conclusions
1. Numerical simulation of local temperature in the scratching (microreserve) samples of steel 3KH3M3F abrasive grains of various materials.
2. The dependences for the calculation of the initial elastic strain hardening at the bottom of submicropores AG; deformation the excrescence in the process of cooling it with the grain; tension at the site of contact the excrescence with AG after cooling.
3. It is established that with the increase in the difference of the coefficients of linear expansion of the billet materials and AG, the stresses that contribute to the separation of the excrescence from the surface of AG, which allows to predict a lower intensity of the sticking of the billet material on AG.
4. Experimental studies, during which micro-cutting of samples with single abrasive grains was carried out, showed that AG from elbor, which has the maximum value of the thermal conductivity coefficient and the maximum difference between the linear expansion coefficients and the material of the excrescence, are less worn and salted.
5. As a result, AG was ranked from various materials according to the criteria characterizing their wear and salting. Confirmed identified analytically the relationship between the intensity of brining of grain with a coefficient of linear expansion and thermal characteristics of the materials AG.

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