Cutting ability of abrasive grains in the processing of billets of plastic materials with the applying of ultrasonic vibrations

A N Unyanin\textsuperscript{1,*} and A V Khazov\textsuperscript{2}

\textsuperscript{1}Faculty of Mechanical Engineering, Ulyanovsk State Technical University, Severniy Venets 32, Ulyanovsk, 432027, Russia
\textsuperscript{2}АО Ulyanovsk mechanical plant, Moskovskoe Shosse, 94, Ulyanovsk, 432008, Russia

\textsuperscript{*}a_un@mail.ru

Abstract. The research was carried out in order to identify the relationship between the intensity of sticking of the workpiece material particles on the abrasive grains (AZ) of the grinding wheel with the physical and mechanical properties of the grains and ultrasonic vibrations (UZK) used in the processing process. Numerical simulation of local temperatures during micro-cutting (scratching) of samples made of 3X3M3F steel with abrasive grains made of various materials, including with the imposition of a narrow band. The deformation of the bulk and the stresses resulting from this deformation acting on the connection of the bulk with grains from materials with different coefficients of linear expansion are calculated. It was found that with increasing difference in the coefficients of linear expansion of the materials of the billet and AZ, the stresses that contribute to the separation of the adhesive from the surface of the AZ increase. In the course of experimental studies, samples were micro-cut with single abrasive grains. We controlled the salting coefficient equal to the ratio of the area of nalip to the area of the blunting site at the gas station and the wear of grain. It was found that AZ from Elbor wear out and become salted to a lesser extent when grinding with the imposition of a narrow-gauge blank.

1. Introduction

When grinding workpieces made of plastic and adhesive-active materials, the loss of cutting capacity of the grinding wheel is mainly associated with salting its working surface. The reason for salting in most cases is the sticking of particles of the workpiece material on the abrasive grains (AZ). It was found [1] that the adhesion intensifies with an increase in the local temperature. The local temperature depends on various factors, including the thermophysical characteristics of the AZ material [2, 3]. Nalipes are retained on the grain surface due to mechanical and adhesive forces, and most firmly-in the cavity of the AZ submicroprofile [1]. After the AZ comes out of contact with the workpiece in the Linden and grain appear stresses that are a consequence of their cooling. To assess the strength of the joint of the nalip with AZ, it is necessary to evaluate these stresses. One of the ways to improve the efficiency of the grinding process is the use of ultrasonic vibrations (UZK). However, studies related to the assessment of stresses that occur in the non-tip and as when grinding with a narrow channel have not yet been performed.
2. Analytical research and discussion

After the as comes out of contact with the workpiece, residual deformations in the Linden give rise to forces acting from the side of the Linden on the surface of the cavity of the submicroprofile AZ.

Voltages $\sigma_{nT}$ at the site of contact of the nailip with AZ, the differences are proportional to $(\Delta\ell_n - \Delta\ell_{1T})$, where $\Delta\ell_n$ – the initial elastic deformation Nalepa in the cavity of submicro pores AZ, $m$; $\Delta\ell_{1T}$ – change in the deformation of the rivet during cooling to the temperature $T$, $m$: 

$$
\Delta\ell_{1T} = (\alpha - \alpha_{ag}) \cdot (T_n - T) \cdot d_s,
$$

where $\alpha$ and $\alpha_{ag}$ – coefficients of linear expansion of the material in the temperature range of the nailip and AZ respectively $T_n$ ... $T$, $K^{-1}$; $d_s$ – the average diameter of the cone, in the form of which the bulk is represented in the cavity of the grain; $T_n$ – the local temperature at which the adhesive interaction of the nailip with the grain occurred, $K$; $T$ – the temperature to which AZ and nailip cool down, $K$.

If $\Delta\ell_{1T} < \Delta\ell_n$, then after cooling down on the site of the contact of the nailip with the AZ, compressive stresses will act. When $\Delta\ell_{1T} > \Delta\ell_n$, at the site of contact with Nalepa AZ will be stress contributing to separation of the stick from the surface of AZ, and the probability of separation Nalepa will be higher. To get a larger value $\Delta\ell_{1T}$ and tensile stresses $\sigma_{nT}$ you should use as from materials whose linear expansion coefficients differ significantly from the linear expansion coefficients of the workpiece material.

Voltage value $\sigma_{nT}$ depends on the local temperature $T_n$, at which there was an interaction of the nailip with the grain. Local temperatures in the process of scratching the sample material with a single AZ were calculated using the method and software described in [3]. The method takes into account the change in the kinematics of micro-cutting with abrasive grains and the mechanical characteristics of the workpiece material when applying the UZK. It was modeled by applying a 22000 Hz narrow band with an amplitude of $A_y = 2$ microns (in the direction perpendicular to the surface to be treated) and different phases $\varphi$. Local temperatures were recorded in the contact zone of the AZ with the workpiece. The micro-cutting forces and the power of heat sources were calculated using the analytical dependencies obtained [3, 4, 5].

Numerical modeling of local temperatures and experimental studies were performed for AZ from normal electrocorundum (material № 1), zirconium electrocorundum: material № 2 made in Austria ($ZrO_2$ – 40%, $Al_2O_3$ – 60%), material № 3 – in JSC «Uralniash» ($ZrO_2$ – 39.6%, $Al_2O_3$ – 59.4%, $C$ – 0.49%), material № 4 also made in JSC «Uralniash» ($ZrO_2$ – 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 capacity and density), as well as a coefficient of friction in the contact zone with the sample.

Steel was used as the sample material 3X3M3F, having sufficiently high plastic properties and viscosity. When processing blanks made of this steel, the grinding wheel loses its cutting ability due to salting. In the process of modeling local temperatures were varied by the maximum depth of AZ implementation per sample material $a_z$, assuming it is equal to 3 and 6 microns. If the depth of implementation $a_z$ equal 3 microns, AZ performs plastic deformation of the workpiece material, at depth $a_z = 6$ microns AZ performs micro-cutting.

Without use and with the use of UZK the maximum temperatures are recorded when the sample is scratched by grains from the material № 4, having a minimum value of the coefficient of thermal conductivity, the minimum temperature – when scratching grains from Elbor (material № 5), having the maximum coefficient of thermal conductivity [5] and the minimum coefficient of friction on steel (table 1, 2).

We calculated the deformation of the adhesive and the stresses acting on the connection of the adhesive with grains from various abrasive materials (see table. 1, 2). The maximum difference with the linear expansion coefficient per Linden is the elbora expansion coefficient. Deformation Nalepa
located in the cavity of submicropores grain of this material, in the process of cooling is greater than its initial deformation, therefore contact area is Nalepa with AZ, any tension, contributing to the separation Nalepa from the surface of AZ. Electrocorundum, the coefficient of linear expansion of which is closest to the coefficient of the nalip material, provides compressive stresses at the contact site. Therefore, it is possible to predict a less intensive sticking of particles of the billet material on AZ from elbora in comparison with grains from other materials. The results obtained in the simulation without taking into account the narrow range are described in detail in [1].

**Table 1.** Results of modeling of local temperatures at the site of AZ contact with the sample and stresses $\sigma_{nT}$ in nalip: the numerator shows the results, obtained without applying the UZK, in the denominator – with UZK; depth of implementation of AZ in the sample material $a_z = 3$ microns; size of the blunting area on AZ – 20 microns

| Material number AZ | The average local temperature, K | Voltages $\sigma_{nT}$, MPa |
|--------------------|--------------------------------|-----------------------------|
| 1                  | 710 / 610                      | 380 / 720                   |
| 2                  | 750 / 650                      | 150 / 285                   |
| 3                  | 790 / 680                      | 110 / 210                   |
| 4                  | 790 / 680                      | 90 / 170                    |
| 5                  | 670 / 580                      | -60 / -30                   |

**Table 2.** Results of modeling of local temperatures at the site of AZ contact with the sample and stresses $\sigma_{nT}$ in nalip: the numerator shows the results obtained without applying the UZK, in the denominator – with UZK; depth of implementation of AZ in the sample material $a_z = 6$ microns; size of the blunting area on AZ – 20 microns

| Material number AZ | The average local temperature, K | Voltages $\sigma_{nT}$, MPa |
|--------------------|--------------------------------|-----------------------------|
| 1                  | 1250 / 1075                    | 60 / 115                    |
| 2                  | 1340 / 1150                    | -530 / -280                 |
| 3                  | 1380 / 1190                    | -580 / -310                 |
| 4                  | 1380 / 1190                    | -585 / -310                 |
| 5                  | 1150 / 1000                    | -650 / -340                 |

When applying UZK the local temperature in the AZ contact zone with the sample was 14% lower on average. With a decrease in temperature, the stress values to which Hooke's law applies increase to a greater extent than the modulus of elasticity, so when applying a narrow band, the initial elastic deformation the nalipe $\Delta \ell_0$ increases on average by 9%. Due to the lower temperature $T_n$ when applying UZK band the deformation of the adhesive during cooling $\Delta \ell_1$ changes to a lesser extent (by 14%). As a result, the voltage at the site of the contact of nalip with AZ was higher by 90%.

3. Experimental research and discussion

In the course of experimental studies, the sample was micro-cut with single abrasive grains from the above materials. Controlled the following parameters: area the nalipe of sample metal deposits on AZ $F_n$, $m^2$; the ratio of salting AZ $K_n$, equal to the ratio of the area of the nalipe $F_n$ to the area of the wear site on AZ, $m^2$; linear wear AZ $h_n$, $m$. Area $F_n$, the number of deposits and the size of the wear site on
the AZ were determined using a microscope PME. The depth of grain insertion into the sample \( a_z \) varied within 3 … 8 microns. If \( a_z = 3 \) microns AZ performs plastic deformation of the sample material, at large depths – micro-cutting. A device was used for superimposing the UZK on the workpiece, in which it was one of the links of the oscillatory system.

Maximum value \( K_z \) and \( h_i \) without superimposition and with the superimposition of UZK are obtained by scratching samples with grains of electrocorundum (material № 1), having a minimum hardness and heat resistance. AZ from Elbor wear out and are salted to a lesser extent than grains from other studied materials, without superimposition and with the superimposition of UZK are obtained by scratching samples with grains of electrocorundum.

Value of coefficient \( K_z \) correlated with voltage \( \sigma_{nT} \) in the n-aline. The Material AZ № 1 (electrocorundum normal), for which the maximum value is fixed \( K_z \), it also provides maximum values of compressive stresses during micro-cutting without overlapping and with the imposition of UZK. The Material № 5 (Elbor), on the site where the contact with the nip occurs voltages \( \sigma_{nT} \), helps to detach the adhesive from this surface, provides a minimum value \( K_z \). The coefficients of the clogging of AZ of zirconium corundum (materials № 2 – 4), like the stress values, they occupy an intermediate value. When applying the UZK coefficient of salting \( K_s \) was lower by 20 … 30\% (table 3), what is associated with a decrease in local temperature. On 19 … 26\% decreased and the wear of the grains (table 4).

### Table 3. Salting coefficient \( K_z \) (%) after 3000 AZ interactions with the billet (in the numerator – without overlapping, in the denominator – with UZK overlay)

| Material number AZ | The depth of penetration of AZ in the blank \( a_z = 3 \) microns | The depth of penetration of AZ in the blank \( a_z = 6 \) microns |
|-------------------|-----------------------------|-----------------------------|
| 1                 | 33 / 26                     | 54 / 41                     |
| 5                 | 12 / 8                      | 17 / 12                     |

### Table 4. AZ wear \( h_i \) (microns) after 3000 AZ interactions with the billet (in the numerator – without overlapping, in the denominator – with UZK overlay)

| Material number AZ | The depth of penetration of AZ in the blank \( a_z = 3 \) microns | The depth of penetration of AZ in the blank \( a_z = 6 \) microns |
|-------------------|-----------------------------|-----------------------------|
| 1                 | 47 / 38                     | 74 / 61                     |
| 5                 | 9 / 7                       | 15 / 11                     |

### 4. Main results and conclusions
1. Ranking completed AZ from various materials according to the criteria that characterize their wear and salting.
2. The relationship of grain salting intensity with linear expansion coefficients and thermophysical characteristics of AZ materials, which was revealed analytically, was confirmed.
3. Installed, what is UZK overlay on the workpiece leads to a decrease in local temperatures, the coefficient of salting and wear of abrasive grains.

### Acknowledgments
The research was carried out with the financial support of RFBR and the Government of the Ulyanovsk region in the framework of the scientific project № 19-48-730002.

### References
[1] Unyanin A N and Khazov A V 2020 *IOP Conf. Series: Materials Science and Engineering* Cutting ability of abrasive grains in the processing of billets of plastic materials 709 022054
[2] Evseev D G and Salnikov A N 2018 *Grinding Models. Theory and Experiment* (Moscow: FSUE Izvestiya) p 312

[3] Unyanin A N and Khusainov A S 2017 *MATEC Web of Conferences* The ultrasonic grinding process temperature field study Vol. 129

[4] Korchak S N 1974 *Performance of the grinding process of steel parts* (Moscow: Engineering) p 280

[5] Bokuchava G V 1984 *Tribology of grinding process* (Tbilisi: Sabchota Sakartvelo) p 238

[6] Abrasive and diamond processing of materials: Guide / edited by A. N. Reznikov. – M.: Engineering, p 391