

MACHINING OF BLANKS AND ASSEMBLY

Fracture Behavior of Workpiece Surface Material during Abrasive Finishing under Fabrication or Repair Conditions

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Abstract—This paper addresses the key features of the abrasive surface finishing process and presents mathematical models for forces acting on a workpiece surface being machined with abrasive grains. It is shown that, at the specified working and force parameters of the machining of a workpiece with surfaces of abrasive grains of a lap plate, the surface fracture of the metallic workpiece being machined is more brittle at small cutting depths. This helps intensify the chip formation process and achieve required workpiece surface quality.

Keywords: abrasive finishing, force interaction, lap plate, abrasive grains, process intensification

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INTRODUCTION

One component of comprehensive research into the operation of abrasive grains on a lap plate is determination of force dependences. According to previous studies concerned with a model of an abrasive grain [1–3], each of its protrusions can be regarded on a small scale as a grain top, having appropriate dimensions and the shape of a truncated regular pyramid with a square base (Fig. 1).

In connection with this, the set of forces generated during microcutting can be exemplified by the interaction between a single protrusion of an abrasive particle with the surface of the workpiece being machined, in accordance with previously reported results [1–3].

Moving at velocity V along the surface being machined, a protrusion of an abrasive grain (Fig. 1) removes a layer of the material of thickness a_z (cut

thickness). As a result of shear deformation in the *OAGB* plane, this layer transforms into microcutting chips. While moving in the direction of the velocity V , the abrasive grain microprotrusion overcomes the tangential component P_z of the cutting force. Penetration of the microprotrusion into the surface being machined is ensured by the cutting force component P_y , which defines the compression directions in the shear plane and under the *OAGB* area.

MATERIALS AND METHODS

It is reasonable to assume in a first approximation that, in the case of surface material removal at small cutting depths, $a_z(h_d) \geq 0.002\text{--}0.03$ mm, the stress state in the region around the cut follows the same general rules as in the case of microcutting with the top of an abrasive particle during grinding. In determining

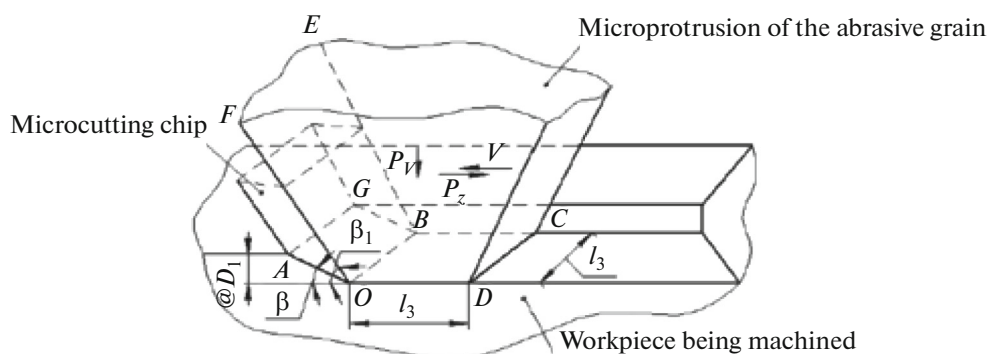


Fig. 1. Schematic illustrating the motion of an abrasive grain relative to the workpiece surface being machined.

Unlike in the case of microcutting with grains during grinding, where the grain tops have considerable blunting areas, abrasive finishing is characterized by a uniform normal stress distribution along the length of the blunting area as a consequence of its small size, and the normal stress σ can be taken to be equal to that under point O . We then have [1–3]

$$\sigma \approx \sigma_0 = 1.5\tau_s. \quad (1)$$

It follows from geometric relations:

$$\begin{aligned} P_s &= \tau_s f_{av} = \tau_s OA \left(\frac{l'_m + L'_m}{2} \right) \\ &= \frac{\tau_s h_d (l'_m \sin \beta_1 + h_d \tan \gamma)}{\sin^2 \beta_1}. \end{aligned} \quad (2)$$

Previous results [1–5, 7] demonstrate that, in the case of abrasive finishing, the parameters of the wear area of abrasive grains vary in the range $l_m = l'_m = 3–20 \mu\text{m}$, depending on machining conditions.

The normal force P_N (Fig. 2) can be found as follows:

$$P_N = \sigma f_{av} = \frac{\sigma h_d (l'_m \sin \beta_1 + h_d \tan \gamma)}{\sin^2 \beta_1}. \quad (3)$$

Since it follows from Eq. (1) that $\sigma \approx \sigma_0 = 1.5\tau_s$, we obtain

$$P_N = \frac{1.5\tau_s h_d (l'_m \sin \beta_1 + h_d \tan \gamma)}{\sin^2 \beta_1}. \quad (4)$$

The resultant force R_s can be found using the following relation:

$$R_s = \sqrt{P_s^2 + P_N^2} = \frac{2.55\tau_s h_d (l'_m \sin \beta_1 + h_d \tan \gamma)}{\sin^2 \beta_1}. \quad (5)$$

From R_s and the angle β between the cut line and the direction of the resultant cutting force R_s , we can find the cutting force components:

$$P_{ys} = R_s \sin \beta = \frac{2.55\tau_s h_d (l'_m \sin \beta_1 + h_d \tan \gamma) \sin \beta}{\sin^2 \beta_1}, \quad (6)$$

$$P_{zs} = R_s \cos \beta = \frac{2.55\tau_s h_d (l'_m \sin \beta_1 + h_d \tan \gamma) \cos \beta}{\sin^2 \beta_1}. \quad (7)$$

With allowance for the normal stresses involved and the size of the friction area, f_{fr} , the friction force components in the friction area can be found as

$$P_{yfr} = \sigma f_{fr} = 1.5\tau_s l'_m l'_m;$$

$$P_{zfr} = \mu P_{yfr} = 1.5\mu\tau_s l'_m l'_m,$$

where μ is the coefficient of external friction between the abrasive and the metal.

Taking into account the relations for the component forces, we obtain the tangential and radial components of the resultant cutting force R :

$$\begin{aligned} P_y &= P_{ys} + P_{yfr} \\ &= \frac{2.55\tau_s h_d (l'_m \sin \beta_1 + h_d \tan \gamma) \sin \beta}{\sin^2 \beta_1} \\ &\quad + 1.5\tau_s l'_m l'_m; \end{aligned} \quad (8)$$

$$\begin{aligned} P_z &= P_{zs} + P_{zfr} \\ &= \frac{2.55\tau_s h_d (l'_m \sin \beta_1 + h_d \tan \gamma) \cos \beta}{\sin^2 \beta_1} \\ &\quad + 1.5\tau_s l'_m l'_m. \end{aligned} \quad (9)$$

According to previously reported results [5, 6], in the case of cutting with the tops of abrasive grains the shear angle β_1 is given by

$$\tan \beta_1 = \frac{\cos \gamma + 0.05\eta_{mc}}{0.9\eta_{mc} - \sin \gamma}, \quad (10)$$

where γ is the front angle of the cutting edge of the grains and η_{mc} is the shrinkage coefficient of the microcutting chips: the ratio of the chip thickness a_{mc} to the cut thickness h_d .

In the case of microcutting with the tops of abrasive grains, the front angle γ is commonly taken to be from -45° to -55° in accordance with previous results [4, 6]. According to electron microscopy data [1, 2], the front angles of the cutting edges of microprotrusions fall in roughly the same range.

Chip shrinkage can be determined experimentally by measurements on a large number of chips produced by microcutting with single abrasive grains. According to previous studies [4, 6], the chip shrinkage coefficient ranges from 1.1 to 1.8.

As shown earlier [1–5], chip shrinkage in the case of microcutting at small depths ($h_d \leq 0.002–0.03 \text{ mm}$) is smaller, falling in the relatively narrow range $\eta_{mc} = 1.1–1.8$. The small chip shrinkage is consistent with the near-unity chip formation coefficients K_c obtained in previous studies [1, 2] and confirms that, in the case of abrasive finishing, the surface fracture of the metallic workpiece being machined is more brittle in comparison with microcutting of the workpiece surface with the abrasive grain top in the case of grinding.

Calculation using Eq. (10) at an average chip shrinkage coefficient $\eta_{mc} = 1.14$ and $\gamma = -50^\circ$ gives $\beta_1 = 23^\circ$. Previous results demonstrate that, at limiting chip shrinkage coefficients and γ angles, the shear angle lies in the range $\beta_1 = 19^\circ–26^\circ$.

The angle β can be found from the relation

$$\frac{P_N}{P_s} = \tan(\beta_1 + \beta) = 1.5.$$

We obtain $\beta_1 + \beta = 56^\circ 18'$. Since $\beta_1 = 23^\circ$, we have $\beta = 33^\circ 18'$.

The parameters τ_s and μ can be approximately determined using analytical relations, a particular blunting area size, and experimentally determined P_y and P_z . Equations (8) and (9) should then be solved simultaneously by dividing P_z by P_y because both contain the parameter τ_s and the coefficient of friction μ influences only the tangential component of the cutting force.

In the case of grinding, residual stress τ_s depends on machining conditions and the properties of the material being machined. This stress results from plastic deformation of the metal during grinding, which is accompanied by a nonuniform intragranular shear of some parts of a crystallite relative to others.

Solving Eqs. (8) and (9), we obtain

$$\tau_s = \frac{P_y \sin^2 \beta_1}{2.55 h_d (l'_m \sin \beta_1 + h_d \tan \gamma) \sin \beta + 1.5 l'_m \sin^2 \beta_1} \quad (11)$$

Substituting the geometric and force parameters in Eq. (11), we find that, in the case of abrasive finishing, the plastic shear stress varies in the range $\tau_s = 3550$ – 4550 MPa (355 – 455 kgf/mm²), depending on machining conditions ($\mu = 0.26$ – 0.29), unlike in the case of grinding, where $\tau_s = 2000$ – 3000 MPa. The shear stress calculated using experimental data is several times that in the case of microcutting with abrasive grain tops during grinding. The higher shear stress in the case of abrasive finishing points to an increased shear resistance of the material, which can be accounted for by the more brittle fracture behavior of the material [7–9].

DISCUSSION

Investigation of the fracture behavior of a material during abrasive finishing has shown that the material removal process takes place at a higher plastic shear stress. This can be accounted for by the more brittle fracture behavior of the material when it is dispersed.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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