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Determination of Energy Parameters for Liquid Blasting

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Abstract

This research aimed to search for the best conditions for finishing processing of details by streams of compressed air. The main peculiarity of such a method is that abrasive dust doesn't go through the nozzles that may cause their severe wear out and breakdown, it joins the streams of compressed air beyond the nozzle section effusing to the container with abrasive slurry and surfaces being worked upon. Finishing processing makes it possible to get a mat surface that reduces surface roughness, corrects surface defects, conceals its irregular forms, moreover this processing is used for descaling after thermal processing, oxide coating removing for metal plating, corrosion and paint removal, making it have a good state. This method showed that it did not require increasing the quantity of the abrasive material and its extraction from the container where the processing takes place, except the case of its wear out in the form of crushing. At the same time joining the streams of compressed air beyond the nozzle section abrasive grains have less kinetic energy for cutting process than in case they went through the nozzle.

Keywords: Liquid blasting, abrasive grain, cutting stress, shear plane, G-ratio

References

V_0 – speed of abrasive grain;

P_z - tangential component of cutting force;

P_y - radial component of cutting force;
β - angle between shear plane of the metal and the abrasive grain moving direction;
τ - shear stress of the plane;
$в$ - length of cut;
L - conditional shear plane length of the material;
x and y - position of the intersection point of conditional shear plane *OA* with work surface *BA*;
a − thickness of cut, m;
α - angle of when abrasive grain enters work material;
$K_ш = P_z / P_y$ - G-ratio;
ψ - conditional angle of friction of abrasive grain and work material;
γ - negative-rake angle of abrasive grain;
τ_{max} - maximum shear stress;
σ - conditional stress of cutting action

1. Introduction

First liquid blasting was applied for workpiece descaling, and surface finish of details including the ones with an irregular shape (Provolotskiy, 1989). It was also used for surface roughness reduction, production of the surface without machine working marks, work hardening for fatigue strength increasing, production of surfaces with high capillary quality, wear out resistance increasing and adherence to coatings and paints, tool life increasing, machine working marks removal, derusting, surface cleaning etc (Novikov and Yakimov, 2002). The objective of this research is theoretical justification of productivity improvement of conditions of finishing processing of composite surfaces by compressed air with abrasive slurry injected. In this work a theoretical analysis of chip forming conditions while single abrasive grain cutting was made and energy parameters of liquid blasting were determined

Research Main Objective and Tasks

Liquid blasting is based on the effect of shock impulsive operation of a stream of loose abrasive material against a workpiece surface that causes finest microsection formation and work material removal. To determine optimal conditions of the blasting, it is necessary to know the law of interaction process between abrasive grains and the material being worked upon and first of all the principles of blasting energy datum formation. Therefore, the objective of this research is theoretical analysis of chip forming conditions while single abrasive grain cutting action and determination of liquid blasting energy parameters.

Method of Study

The theoretical study was conducted with the help of methods based upon the main statements of theory of material cutting, strength of materials, physics, mathematical analysis, mathematical statistics and mathematical modeling.

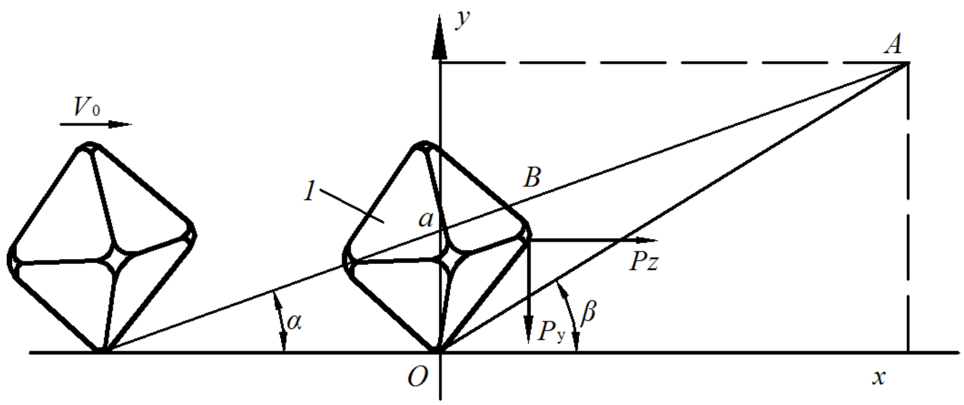
2. Work Summary

To solve the assigned task we will use a theoretical approach to the process of cutting action with variable thickness of cut described in the work (Novikov and Yakimov, 2003), figure 1. Let us assume that the abrasive grain moving with the speed V_0 to the worked material subjects it to tangential P_z and radial P_y components of cutting force which cause periodic damage (shear) of the material along the line of the conditional shear plane inclined at angle β to the grain moving direction. To locate the position of the conditional shear plane we will find shear stress τ of this plane:

$$\tau = \frac{P_z \cdot \cos\beta - P_y \cdot \sin\beta}{в \cdot L}, \tag{1}$$

where $в$ is length of cut, m; L =*OA* is conditional shear plane length of the material, m.

Figure 1: Diagram of chip forming process while single abrasive grain 1 cutting.



Length L can be found on the basis of two trigonometric equations which follow from fig. 1:

$$\begin{cases} y = a + tg\alpha \cdot x, \\ y = tg\beta \cdot x, \end{cases} \tag{2}$$

where x and y - the position of the intersection point of conditional shear plane *OA* with surface *BA* to be worked upon; a is thickness of cut, m; α is angle of entry of the abrasive grain to the material being worked upon.

After solving simultaneous equations (2), we get

$$x = \frac{a}{(tg\beta - tg\alpha)}, \tag{3}$$

$$L = \frac{x}{\cos\beta} = \frac{a}{\cos\beta \cdot (tg\beta - tg\alpha)}. \tag{4}$$

Rearranging the dependence (1), with dependence (4), we get

$$\tau = \frac{P_y \cdot \cos\beta \cdot (tg\beta - tg\alpha)}{в \cdot a} \cdot (K_ш \cdot \cos\beta - \sin\beta), \tag{5}$$

where $K_ш = P_z / P_y$ is G-ratio determined on the basis of the dependence (Novikov and Yakimov, 2002): $K_ш = ctg(\psi + \gamma)$; ψ − conditional angle of friction of abrasive grain and work material; γ − negative-rake angle of abrasive grain.

Denoting $\psi + \gamma = \psi_1$ and considering $K_ш = ctg\psi_1$, the dependence (5) will be:

$$\tau = \frac{P_y}{2 \cdot в \cdot a \cdot \sin\psi_1 \cdot \cos\alpha} \cdot [\sin(2\beta - \alpha + \psi_1) - \sin(\alpha + \psi_1)]. \tag{6}$$

Maximum shear stress $\tau_{\max}$ which determines the position of the conditional shear plane of the worked material will be reached in case $\sin(2\beta - \alpha + \psi_1) = 1$. Thus,

$$\beta = \frac{\pi}{4} + \frac{\alpha - \psi_1}{2}. \tag{7}$$

We can see that the more the angle of entry of the abrasive grain to the work material α is and the less $\psi_1 = \psi + \gamma$, the more the conditional angle of shear of work material β is, i.e. the less the conditional angle of friction of abrasive grain and work material ψ (or friction factor f) and the negative-rake angle of abrasive grain γ are.

Substituting the dependence (7) into (6), it is possible to find maximum shear stress $\tau_{\max}$:

$$\tau_{\max} = \frac{P_y}{в \cdot a \cdot \sin\psi_1 \cdot \cos\alpha} \cdot \sin^2\left(\frac{\pi}{4} - \frac{\alpha}{2} - \frac{\psi_1}{2}\right). \quad (8)$$

The shear of work material in the conditional plane *OA* will be realized under the condition of maximum shear stress $\tau_{\max}$ reaching the ultimate shear strength of work material $\tau_{сдв}$. Thus, considering $\tau_{\max} = \tau_{сдв}$, it is possible to find radial component of cutting force P_y using the dependence (8):

$$P_y = 2 \cdot a \cdot в \cdot \tau_{сдв} \cdot \sin\psi_1 \cdot \cos\alpha \cdot \frac{1}{\left[1 - \sin\left(\alpha + \psi_1\right)\right]}. \quad (9)$$

Tangential component of cutting force P_z will be

$$P_z = P_y \cdot K_ш = P_y \cdot ctg\psi_1 = 2 \cdot a \cdot в \cdot \tau_{сдв} \cdot \cos\psi_1 \cdot \cos\alpha \cdot \frac{1}{\left[1 - \sin(\alpha + \psi_1)\right]}. \quad (10)$$

If the tangential component of cutting force is $P_z = a \cdot в \cdot \sigma$, the conditional stress of cutting action σ will be

$$\sigma = \cos\psi_1 \cdot \cos\alpha \cdot \frac{2}{\left[1 - \sin\left(\alpha + \psi_1\right)\right]}.$$

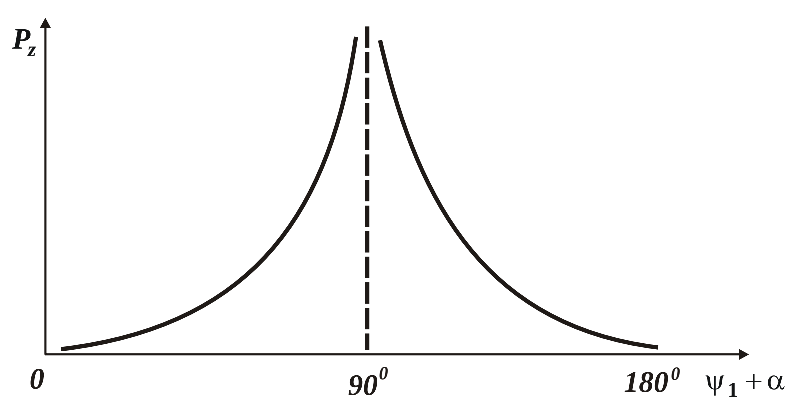
In accordance with the dependence (10) tangential component of cutting force P_z has ambiguous behavior with the increase of angles ψ_1 and α. On the one part, due to the numerator P_z decreases with the increase of angles ψ_1 and α, on the other part, due to the denominator P_z increases. Therefore, there are extremal dependencies of the tangential component of cutting force P_z on angles ψ_1 and α. To find the extremum of function P_z we will subject the dependence (10) to the required extremum condition $\left(P_z\right)'_\alpha = 0$. Thus, we receive

$$\alpha = 90^0 - \psi_1. \quad (11)$$

Substituting the dependence (11) into (10), we can see that function P_z becomes infinite in the point of extremum, fig. 2, due to the fact that the shear angle β, determined in dependence (7), is equal to angle α. According to fig. 1, the conditional shear plane *OA* does not meet the work surface *BA* and, as a result, there is no chip formation process, but only elasto-plastic deformation of the work material. Thus, to decrease tangential component of cutting force P_z it is required to meet two conditions:

$$\psi_1 + \alpha < 90^0; \; 90^0 < \psi_1 + \alpha < 180^0. \quad (12)$$

Figure 2: Dependence of P_z on angle $\psi_1 + \alpha$.



In the first case both angle ψ_1 and angle α should be decreased. In the second case (with a larger value of angle $\psi_1 \to 90^0$) angle α should be increased $\alpha \to 90^0$. Angle $\psi_1 = \psi + \gamma$ can take values close to 90^0 due to relatively large negative-rake angle of the abrasive grain γ=45−60^0. Thus, the first case can be realized only with very small values of the angle $\alpha \to 0$. The second case, which can be fulfilled with higher values of the angle α, seems to be more realizable.

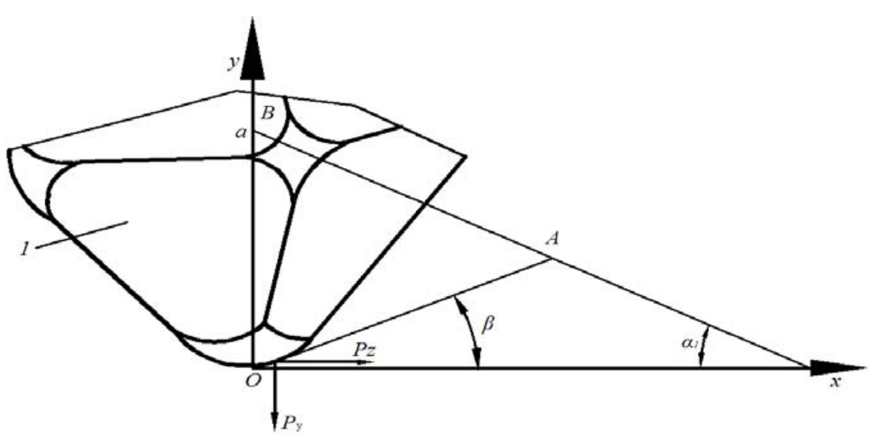
3. Results and Discussion

Therefore, it can be seen that the value of angle α may vary over a wide range $0<\alpha<90^0$. It indicates that liquid hydro rotary blasting (grinding) of small elements under 3 g and of irregular space form can be effectively applied (Andilakhay, A.A. 1983). In this case abrasive treatment of elements by submerged jets (Andilakhay, 2006) scheme is realized; in accordance with it there can be moments of collision of moving work elements and abrasive grains determined by the angle $0<\alpha<90^0$. Since the abrasive grain form resembles a globe form, angle $\psi_1+\alpha>90^0$ and nearly in all the cases abrasive grain and work material interaction will cause chip formation process, as stated above. Due to it expenditure of energy during blasting are less than in case of plastic deformation of metals without chip formation process. Thus, it is ascertained that liquid blasting can be effectively realized with both fixed angle of entry of the abrasive grain to the work material α and not fixed angle α, e.g. in case of abrasive treatment of elements by submerged jets (Andilakhay, 2006).

It should be noted that this condition is true if a globe-shaped cutting element with negative-rake angle is used. If we deal with a positive rake angle, the conditional angle ψ_1 will take small values and the change of angle α should be limited in this case. Angle α should be relatively small, otherwise angle $\psi_1+\alpha \to 90^0$ and chip formation process (and therefore cutting process) cannot be realized since $\alpha \to \beta$. The work material will be subjected only to plasto-elastic deformation without chip formation process and as mentioned above it will increase force P_z and energy intensity during blasting. It proves that a globe form for abrasive grain is the most optimal form for cutting element used during abrasive blasting by submerged jets with the following value changing range for angle α: $0<\alpha<90^0$.

The determination of parameters of force intensity for cutting process by abrasive grain when it stops contacting with work material, i.e. for cutting process with cut thickness decreasing is of some interest too. Let us assume that initial thickness of the cut is a (fig. 3) and it decreases under the law $a - tg\alpha_1 \cdot x$ with the grain moving along axes *ox*, where α_1 − angle when abrasive grain stops its contact with the work material.

Figure 3: Chip formation process scheme for cutting process with cut thickness decreasing



It can be seen that forces P_z and P_y will cause work material shear along the line of conditional shear plane $OA=L$ inclined to the grain moving direction at shear angle β. Shear stress τ for this plane can be determined with the help of the above-mentioned dependence (1), the conditional shear length $OA=L$ can be found on the basis of two trigonometric equations which follow from fig. 3:

$$\begin{cases} y = a - tg\alpha_1 \cdot x, \\ y = tg\beta \cdot x, \end{cases} \tag{13}$$

where x and y − the position of the intersection point of conditional shear plane OA with work surface BA.

Thus,

$$x = \frac{a}{\left(tg\beta + tg\alpha_1\right)}, \tag{14}$$

$$L = \frac{x}{\cos\beta} = \frac{a}{\cos\beta \cdot \left(tg\beta + tg\alpha_1\right)}. \tag{15}$$

Substituting the dependence (15) into (1) taking into consideration $K_ш = ctg\left(\psi + \gamma\right) = ctg\psi_1$, we will have

$$\tau = \frac{P_y}{2 \cdot в \cdot a \cdot \sin\psi_1 \cdot \cos\alpha_1} \cdot \left[\sin\left(2\beta - \alpha_1 + \psi_1\right) - \sin\left(\alpha_1 - \psi_1\right)\right]. \tag{16}$$

Maximum shear stress $\tau_{\max}$ which determines the position of conditional shear plane of work material can be reached under the condition $\sin\left(2\beta + \alpha_1 + \psi_1\right) = 1$. Thus, the work material conditional shear angle β can be found

$$\beta = \frac{\pi}{4} - \frac{\left(\alpha_1 + \psi_1\right)}{2}. \tag{17}$$

Comparing dependence (17) with a similar dependence (7), it can be noticed that in the first case the conditional shear angle β of work material is less.

Substituting dependence (17) into dependence (16), we can find maximum shear stress $\tau_{\max}$:

$$\tau_{\max} = \frac{P_y}{2 \cdot в \cdot a \cdot \sin\psi_1 \cdot \cos\alpha_1} \cdot \left[1 + \sin\left(\alpha_1 + \psi_1\right)\right]. \tag{18}$$

Considering $\tau_{\max} = \tau_{сдв}$, dependence (18) is followed by the dependence for radial component of cutting force determination P_y:

$$P_y = 2 \cdot a \cdot в \cdot \tau_{сдв} \cdot \sin\psi_1 \cdot \cos\alpha_1 \cdot \frac{1}{\left[1 + \sin\left(\alpha_1 + \psi_1\right)\right]}. \tag{19}$$

Therefore, tangential component of cutting force P_z and conditional stress of cutting action σ are equal

$$P_z = P_y \cdot K_ш = P_y \cdot ctg\psi_1 = 2 \cdot a \cdot в \cdot \tau_{сдв} \cdot \cos\psi_1 \cdot \cos\alpha_1 \cdot \frac{1}{\left[1 + \sin\left(\alpha_1 + \psi_1\right)\right]}, \tag{20}$$

$$\sigma = \frac{P_z}{a \cdot в} = \cos\psi_1 \cdot \cos\alpha_1 \cdot \frac{2}{\left[1 + \sin\left(\alpha_1 + \psi_1\right)\right]}. \tag{21}$$

In comparison with similar dependences (9) and (10), dependences (19) and (20) take finite values under condition $\sin\left(\alpha_1 + \psi_1\right) = 1$. This proves that the force intensity for cutting process at the moment when abrasive grain stops its contact with the work material is less than at the moment when abrasive grain enters the material to be worked.

4. Conclusions

The outcomes were used when creating ornamental surfaces for the details of irregular space form made of different kinds of metals and alloys and rounding their sharp corners, when oxide coating removing for metal plating, when descaling and flash removing with abrasive dust propelled by compressed air with abrasive slurry injected. Due to the applied processing method it is possible to avoid wear out of nozzles as abrasive grains join the streams of compressed air beyond them.

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