DETERMINATION OF MATERIAL PROPERTIES FROM THE AWJ CUTTING SURFACE CHARACTERISTICS

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Abstract

Abrasive water jet cutting process induces some typical characteristics (striations) on the cut surfaces. Introducing a new method of investigation of these features we prepared an original procedure that enables us to determine some material properties from the striations’ shapes. The paper is aimed at explanation of the method and its confirmation through experiments. Experimental results are widely analysed and discussed.

1. INTRODUCTION

Research results presented in this paper are products of the continuous process focused on the improvement of abrasive water jet cutting. The efficiency and quality of the process can be evaluated in several methods. One of the first ones is the method prepared by Hashish (1989), who identified two basic zones in which the cutting wear or the deformation wear are the predominant processes of material disintegration and removal. The zones correspond with impact of abrasive particles at shallow angles and large angles respectively. By impacts at shallow angles the shear stress of material prevails and the process of material disintegration is similar to micromachining. By impacts at large angles, of course, the material flow stress prevails due to excessive plastic deformation. Another method for quality determination was presented by Urbánek (1996), who submitted the evaluation of the efficiency and quality of abrasive water jet cutting through measurement of the height of the so-called “nose” - the uncut part of material at the end of cut. Our method, presented by Hlaváč et al. (2007a, b), is based on measurement of the tangents to the striations at the jet outlet from material.

2. THEORETICAL BACKGROUND

Our fundamental equations used for evaluation of the cutting parameters were derived and presented by Hlaváč (2001). They were replenished by introduction of five zones of quality observable on cutting walls in the case of the highest possible traverse rate that enables penetration of the jet through the whole thickness of material and its parting. The basic equations describing either limit depth of penetration of the jet into the material for given traverse rate or the limit traverse rate for given material thickness are presented as follows:

\[
h_{\text{lim}} = \frac{C_p S}{8 (v_p + a_n)^{1/2}} \sqrt{\frac{2 \rho_j p_j^2 e^{-2\xi/L}}{p_j \rho_m \alpha^2 e^{-2\xi/L} + \sigma p_i}} (1 - \alpha_i^2)
\]

(1)
Two material properties are explicit in equations (1) and (2) – there are material density and strength. Two more properties are inherent in variable $\alpha_e$. They are material hardness and grain size. Therefore, we tried to find out some relationship between these individual material properties and quality of cutting walls evaluated through tangent to striation declination angle.

3. EXPERIMENTAL PROCEDURE

Our experimental work was based on cutting of materials with different properties upon the same abrasive water jet conditions. The water pressure was 380 MPa, water nozzle diameter 0.25 mm, abrasive Australian garnet 80 mesh, abrasive flow rate $350 \text{ g.min}^{-1}$, focusing tube diameter 1.02 mm, stand-off distance 2 mm, traverse rate 100 mm.min$^{-1}$. The samples were plates 10 mm thick and impinging jet axis was perpendicular to the upper plate surface. We measured the angle of declination between the tangent to the striation at the jet outlet from material and the impinging jet axis (see Hlaváč et al. 2007b). As the mentioned angle is our valutational parameter, we tried to compare values measured for various materials with significant material properties inherently included in equations (1) and (2). The results of comparison can see in Fig. 1 through 4 (the values of material properties were transformed into values comparable with angles for better visual comparison using appropriate factors).

![Fig. 1. Comparison of the trend of material strength with the one of the respective angles of declination for selected steels. No direct correspondence between trends can be observed.](image-url)
Fig. 2. Comparison of the trend of grain size with the one of the respective angles of declination for selected steels. There is no direct correspondence between trends.

Fig. 3. Comparison of the trend of material hardness with the one of the respective angles of declination for selected steels. No strong correspondence between trends can be observed.
Fig. 4. Comparison of the trend of material density with the one of the respective angles of declination for selected steels. Completely no correspondence between trends is evident.

Analysing comparisons presented in Fig. 1 through 4 we can conclude that there are no evident direct relations between individual selected material properties and respective declination angles measured for striations on the cutting walls. Therefore, we tried to choose any other suitable parameters for material behaviour description through combination of the basic ones (density, strength, grain size and hardness).

The quality of the cutting process is deteriorated with increase of each of selected parameters and the worse quality corresponds to the larger angle of declination, hence we tried to compare the trends of the products that combine few material properties with the trend of the angle of declination. These comparisons are presented in Fig. 5 through 9.

4. DISCUSSION

The correlations between measured angles of declination (our valuational parameter) and respective significant material properties that we had selected (tensile strength, grain size, hardness or density) were very week or none, as it is presented in the previous paragraph. Therefore we tried to prepare some combinations of material properties to obtain better description of material response to jet impact. These parameters are products of either two or three significant material properties. The comparison of trends for the material properties combinations for selected materials and respective trend of the declination angle are presented in Fig. 5 through 9.

The combinations of two material parameters, like product of strength and grain size (Fig. 5), product of strength and hardness (Fig. 6) or product of grain size and hardness (Fig. 7), did not yield trends similar to the trend of the angle of deviation.

Combinations with density were not tested, because values of densities are very similar and, therefore, trends of the results of products with densities are almost identical with the trends without densities. Nevertheless, we tried to test the product of three parameters – strength, grain size and hardness. The result was quite surprising for us, because the trend of this combination parameter...
seems to be almost the same as the trend of the angle of declination (see Fig. 8). Combination of all four material properties into the product also yields the trend very well corresponding to the one of the angle of declination (Fig. 9).

**Fig. 5.** Comparison of the trend of the product of material strength and grain size with the one of the respective angles of declination for selected steels. No correspondence is evident.

**Fig. 6.** Comparison of the trend of the product of material strength and hardness with the one of the respective angles of declination for selected steels. There is no evident correspondence there.
Fig. 7. Comparison of the trend of the product of material grain size and hardness with the one of the respective angles of declination for selected steels. A week correspondence is seen.

Fig. 8. Comparison of the trend of the product of material strength, grain size and hardness with the one of the angles of declination – the trends are almost identical.
Fig. 9. Comparison of the trend of the product of material strength, grain size, hardness and density with the one of the angles of declination – the trends are very similar.

The results of our preliminary tests are very promising for future mapping of material behaviour under abrasive water jet impact. The product of material strength, grain size and hardness seems to be an appropriate parameter for evaluation of the machinability of materials by abrasive water jets. The parameter created by the product of all considered material properties also needs to be investigated in more detail and for larger scale of materials. Both parameters can be used for determination of cutting efficiency of abrasive water jetting and prediction of the cutting wall quality. The database of materials with characteristics enabling prediction and control of cutting efficiency and quality could be much easily prepared with the support of these parameters.

5. CONCLUSIONS

The linkage of material properties and quality characteristics of the abrasive water cutting was investigated and the following results were designated:
♦ there is no direct linkage between material strength and abrasive water jet cutting ability;
♦ there is no direct linkage between material hardness and abrasive water jet cutting ability;
♦ there is no direct linkage between material density and abrasive water jet cutting ability;
♦ there is no direct linkage between material grain size and abrasive water jet cutting ability;
♦ combinations of two material properties also do not show any direct linkage to abrasive water jet cutting ability;
♦ the combination (product) of three material properties (strength, hardness, grain size) embody the direct linkage to the abrasive water jet cutting ability;
♦ the product all four considered material properties (inherent in our equations) yields also a promising linkage to the abrasive water jet cutting ability.
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LIST OF USED SYMBOLS

\( \alpha_e \) coefficient of loss of liquid jet velocity in the interaction with material determined from parameters of experimental cut…[-]

\( \theta \) angle of deflection of the tangent to the actual trajectory of flow in the plane of cut at the depth \( h \) below the surface of material from the original axis of jet above the material…[rad or °]

\( \theta_{lim} \) limit angle of deflection of the tangent to the actual trajectory of flow in the plane of cut at the jet exit from the material from the original axis of jet above the material by the limit cut…[rad or °]

\( \rho_j \) the density of abrasive jet (conversion to homogeneous environment)…[kg.m\(^3\)]

\( \rho_m \) density of material being machined…[kg.m\(^3\)]

\( \sigma \) strength of material being machined…[Pa]

\( \xi_j \) attenuation coefficient of abrasive jet in the environment between the focusing tube orifice and the material surface…[m\(^{-1}\)]

\( a_n \) mean size of abrasive particles formed in the mixing process…[m] or the limit traverse rate of the cutting process…[m.s\(^{-1}\)]

\( C_d \) coefficient that modifies the jet performance in relation to the changing content of abrasive below so-called saturation level (above this level, the jet performance increases no more)…[-]

\( d_o \) water nozzle diameter…[m]

\( h \) actual depth of cut…[m]

\( h_{lim} \) limit depth of cut at the given traverse rate (maximum cut-through depth )…[m]

\( H \) material thickness…[m]

\( L \) stand-off distance (distance between the material surface and the exit orifice of the focusing tube)…[m]

\( p_j \) pressure obtained from Bernoulli's equation for liquid with density and velocity of abrasive jet…[Pa]

\( S_p \) ratio between the amount of non-damaged grains (i.e. not containing defects) and the total amount of grains in the supplied abrasive material…[-]

\( v_p \) traverse rate of jet trace on the material surface…[m.s\(^{-1}\)]

\( V_p \) traverse rate of jet trace on the material surface calculated for the thickness \( H \)…[m.s\(^{-1}\)]

REFERENCES


