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DETERMINATION OF METAL PARAMETERS FROM ABRASIVE WATER JET STRIATIONS

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Summary: *The procedure aimed at determination of some significant metal parameters from the striations left on the walls of the kerf after material cutting was tested. It is based on measurement of the angle between jet axis at the outflow from material and the impinging jet axis. No direct relationships were found out for individual properties, but combination of the most important material parameters – strength, hardness and grain size – seems to be the proper one for description of material resistance to abrasive water jet cutting.*

1. Introduction

Material cutting by abrasive water jet is studied at our university both theoretically and experimentally. Striations at the cutting walls are the typical marks corresponding to both the jet parameters and cut material properties. Therefore, there is some possibility, for abrasive water jet with definite parameters, to find out the relationship between a particular material property and the quantity describing quality of cutting walls. This problem became the topic of thesis especially aimed at material properties determination from cutting wall quality. Simultaneously, the work is a subsequent one to the previous theoretical and experimental work published by Hlaváč (1998, 2001). The surface quality of the cutting walls can be determined particularly from the angle ϑ between the actual jet axis in the depth h inside material and the axis of jet impinging on the cut material. The instantaneous jet axis in the depth h is supposed to be equal to the tangent to striation curve – the tracks leaved on the walls of the cutting kerf by abrasive water jet. The angle, further called "deviation angle" is measured according to the experimental procedure presented in paper Hlaváč et al. (2007). Results are compared with material properties recognized from tables, material schedules or tests performed on samples prepared from experimental metals.

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2. Theoretical principles

The model describing dependence of the depth of cut on basic abrasive water jet parameters and material properties derived from energy and momentum conservation laws was firstly presented in the complex form by Hlaváč (1998). In 2001 it was completed by a relationship describing dependence of cutting wall quality on the limit thickness of material cut at given traverse speed or for limit traverse speed for given thickness of material (Hlaváč, 2001). Usually, there is not reasonable to cut material at the maximum traverse speed possible with given jet parameters and material properties. Analogical condition is valid for cutting of the maximum possible material thickness by respective traverse speed. Therefore, the equations for calculation of limit thickness of material which may be cut with given traverse speed and/or for calculation of limit traverse speed for the given (limit) material thickness were supplied by an auxiliary coefficient C_Q for determination of the parameters applicable for required quality of cut (Hlaváč, 2001).

$$h_Q = C_Q \frac{C_5\, S_p\, \pi\, d_o \sqrt{2\rho_j p_j^3\, e^{-5\xi_j L}}\,(1-\alpha_e^2)}{8\,(v_P + v_{Pmin})^{1,5}\left(p_j \rho_m \alpha_e^2\, e^{-2\xi_j L} + \sigma\rho_j\right)} \tag{1}$$

$$v_{PQ} = C_Q \left[\frac{C_5\, S_p\, \pi\, d_o \sqrt{2\rho_j p_j^3\, e^{-5\xi_j L}}\,(1-\alpha_e^2)}{8\,H\left(p_j \rho_m \alpha_e^2\, e^{-2\xi_j L} + \sigma\rho_j\right)}\right]^{\frac{2}{3}} - C_Q v_{Pmin} \tag{2}$$

Later the equations (1) and (2) were supplied by another one describing dependence of the actual jet axis declination from the initial one (the declination angle). The actual jet axis is supposed to be parallel to the tangent to the actual main line of the kerf head curve. This curve is expected to have the same character as the respective striation lines left on the cutting walls. This theoretical consideration lead to the theoretical and experimental approach aimed at determination of the surface wall quality through measurement and/or calculation of the actual "declination angle" in the depth *h*. The respective equation (3)

$$\vartheta = -\vartheta_{lim}\left(\frac{h}{h_{lim}}\right)^{1.5} \tag{3}$$

enables us to allocate measured quality represented by "declination angle" ϑ, jet parameters and material properties.

3. Experimental procedure

Experiments with metal samples were performed in the Laboratory of Liquid Jet at the VŠB - Technical University of Ostrava. The pump with pressures up to 415 MPa and maximum flow rate 1.9 liters per minute is used for pressurization of water and cutting is performed on the x-y table with working area 2 x 1 m^2. The following basic parameters characterized water jet:

- water pressure inside pump 400 MPa
- water nozzle diameter 0.25 mm
- focusing tube diameter 1.02 mm
- focusing tube length 76 mm

- abrasive mass flow rate 350 g.min^{-1}
- stand-off distance 2 mm
- traverse speed 100 mm.min^{-1}
- impact angle (angle between jet axis and normal to the sample surface at intersection point of jet axis with sample surface) 0 rad
- sample thickness 10 mm
- sample length 60 mm

Six steel samples were tested. Five of them were marked according to the ČSN norm by a five-figure code - 11523, 12050, 14220, 15142 and 17246. The sixth one was equivalent to the steel 19437 marked 1.2436. The photos of the cutting walls were taken and the angles were measured according to our method presented in (Hlaváč et al., 2007). The absolute average values of "declination angles" measured at the jet outlet from the sample (at the depth equal to sample thickness) are presented in Table 1.

Tab. 1: Steel parameters and respective outlet "declination angles" of abrasive water jet.

MT	TS	YM	D	H	G	AV DA
	MPa	GPa	kg.m^{-3}	HB	μm	°
Steel 11523	538	206	7850	126	22.5	10.1
Steel 12050	553	221	7870	173	25.0	16.7
Steel 14220	711	206	7850	239	10.0	11.6
Steel 15142	746	216	7850	186	16.5	16.1
Steel 17246	574	219	7900	131	27.5	14.0
Steel 19437	716	218	7600	241	16.5	20.4

Table legend: MT - material type, TS - tensile strength, YM - Young modulus, D - density, H - hardness, G - average grain size, AV DA - absolute value of declination angle

Simultaneously, selected parameters of metals were found out in tables and material schedules or determined by tests of material in several laboratories. Unfortunately, the uncertainties of the results are quite high and, therefore, the results have still rather preliminary character. The comparison was performed for steel samples' properties and respective outlet "declination angles" measured for definite abrasive water jet parameters within the limits of accuracy of setting parameters and homogeneity of material or abrasive feeding. The results are summarizes in the Tab. 1 and the Fig. 1 (the angles are presented in absolute values).

4. Discussion

Comparison of values presented in Fig. 1 shows no direct relationship between particular material properties and respective outlet "declination angle" being our parameter of material quality evaluation. It was concluded from the previous experimental results that the worse the material cuts the greater is the absolute value of the outlet "declination angle" (for the same thickness of the sample and equivalent parameters of jet and cutting). Therefore, it was expected that any direct relationship between respective material property and material cutability should approve through the values of the "declination angle". No such a relationship was observed, however.

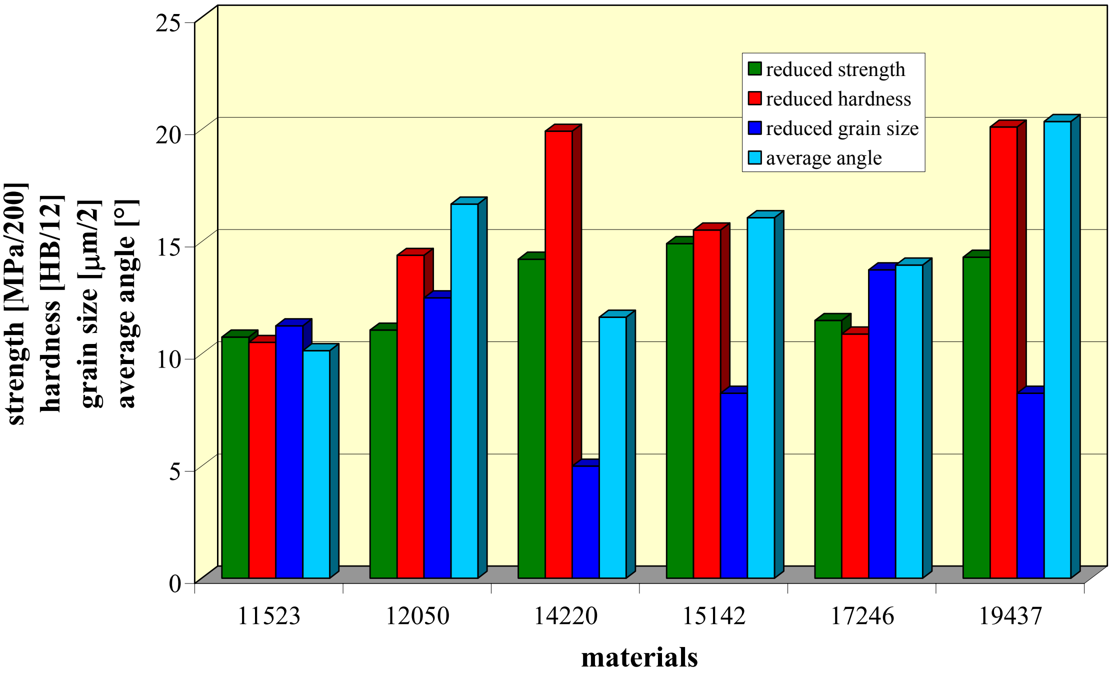

Fig. 1. Comparison of trends of selected material properties and respective absolute values of the outlet "declination angles" for tested steels.

Nevertheless, it can be observed even on walls of samples presented in Fig. 2 that there are certain intervals of "declination angles" closely related to each quality zone on the wall surface – the considered five zones are related to the limit depth or limit traverse speed and their definition was presented by Hlaváč (2001). Therefore, some pairs combined of presented material properties were compared with the "declination angles". Unfortunately, no direct relationship appeared again.

Fig. 2. Typical walls of samples cut by abrasive water jet – the quality is decreasing with the increasing depth (thickness) of cut-through material.

Finally, the product of the most significant properties – strength, hardness and grain size – was prepared and its trend was compared with the one of measured absolute values of the outlet "declination angles" for tested steel samples. The result of this comparison is evident from the Fig. 3. The trends are almost identical for selected group of steels.

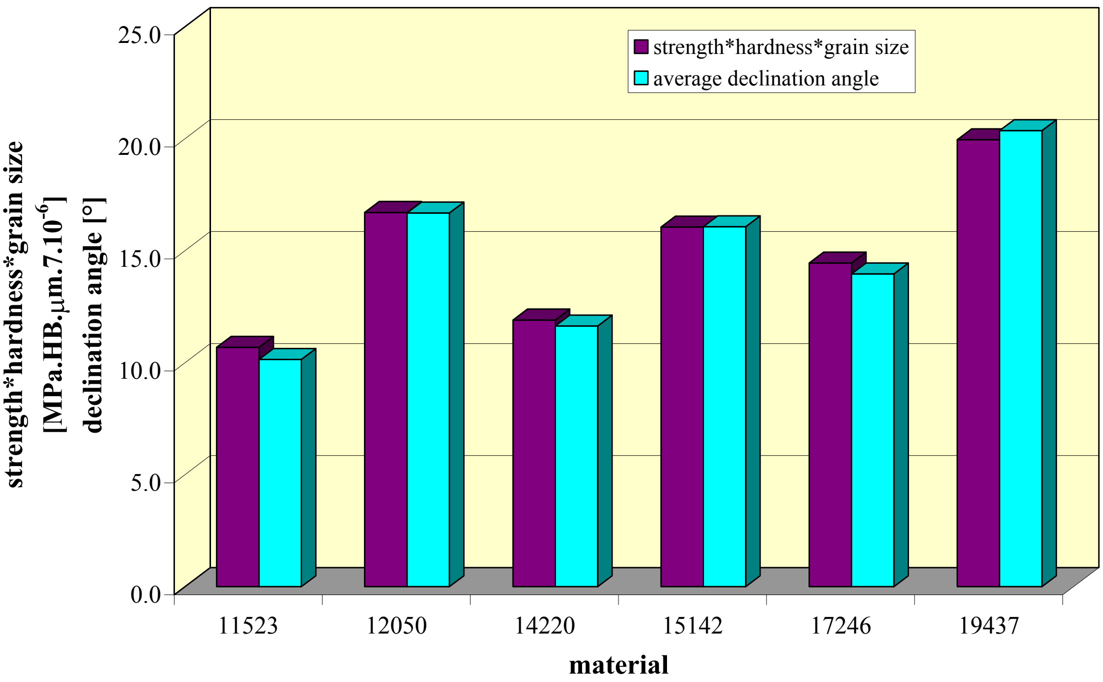

Fig. 3. Trends of the product of the material strength, hardness and grain size and respective outlet "declination angles" produced by abrasive water jet under identical conditions.

5. Conclusions

Up-to-date results confirm our assumption that there is some potentiality to determine certain material parameters or their combinations from striation characteristics of the abrasive water jet cutting. There are especially the ones with the most important influence to the cutting process. Nevertheless, the up-to-date procedure enables to determine only certain combination of parameters, not the individual ones. The quality of wall surface after cutting process can be evaluated by angle between the tangent to the striation curve and the impinging jet axis in the respective depth of jet penetration into cut material. This value of the declination angle can be used for both the determination of surface quality and evaluation of parameter characterizing machinability of the investigated material by abrasive water jet.

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Nomenclature

α_e coefficient of abrasive water jet velocity loss in the interaction with material determined from experiment…[-]

ϑ angle between impinging jet axis and tangent to the striation curve in depth h…[°]

ϑ_{lim} absolute value of the angle between impinging jet axis and the tangent to the striation curve in the depth h_{lim}…[°]

ρ_j density of abrasive water jet…[kg.m^{-3}]

ρ_M material density…[kg.m^{-3}]

σ material strength…[Pa]

ξ_j attenuation coefficient of abrasive water jet for the medium between the focusing tube and the material surface…[m^{-1}]

a_n mean size of abrasive particles inside jet…[m]

C_5 coefficient of the jet performance in relation to the changing content of abrasive below so-called saturation level…[-]

d_o diameter of water nozzle…[m]

h depth of cut…[m]

h_{lim} limit depth of cut for given traverse speed…[m]

H material thickness…[m]

L stand-off distance…[m]

p_j pressure of abrasive water jet…[Pa]

S_P non-damaged to the total number of grains ratio in the supplied abrasive material…[-]

v_P traverse speed of jet trace on the material surface…[m.s^{-1}]

v_{Plim} limit traverse speed of cutting (the amount is equal to a_n, i.e. $v_{Plim} = a_n$)…[m.s^{-1}]

V_P traverse speed of jet trace on the material surface for thickness H…[m.s^{-1}]