CRITERION C –BASED EVALUATION OF THE TOPOGRAPHY OF ABRASIVE WATERJET-PRODUCED SURFACES

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In the contribution we present the utilization of criterion C for the evaluation of topography of metallic materials surfaces generated by the abrasive waterjet. The criterion C provides a realistic picture of the proportion of waviness (low-frequency irregularities) to the total number of surface irregularities. The critical value of parameter $C_c = 0.66$ was determined experimentally for metallic materials. This value differentiates the surface into two morphologically different zones. The first zone, which is there in the upper part of the cut, is characterised by the absence of conspicuous striations, and thus is considered to be of good quality. The other zone is characterised by conspicuous striations and thus is taken as a zone of poor-quality. The parameter C can also be used in the classification of materials by machinability.

Keywords

abrasive waterjet, surface roughness, optical measurement

1. Introduction

The economic efficiency of operation of production systems for water stream cutting, and subsequently their competitive ability from the point of view of production technology are conditioned mainly by cutting performance and cut wall quality. To measure accurately the quality of cut it is necessary to have an objective method and a parameter of quality of the cut at disposal. The abrasive waterjet (AWJ) cutting of materials is a technology where a tool is not a solid tool but it is a mechanically flexible hydroabrasive stream (mixture of water, air and abrasive), and thus according to the magnitude of resistance to penetration, it causes the curvature of cutting trace; a change in the AWJ trajectory in the given material occurs with the increasing depth of the cut. The greater are the depth of cut and the resistance to penetration being dependent especially on material properties, the greater is the curvature of trajectory of the cutting front. The analysis of the surface and the evaluation of striations formed are of great importance not only to the description and definition of geometric parameters, waviness/roughness, but also to the understanding of a mechanism of material removal. To the prediction of both a change in AWJ trajectory for the given material and the final roughness of surface and also to the prediction of the achieving of greater depths of cut by maintaining optimal technological factors in the automated machining process, it is thus very important to analyse the shape of AWJ trajectory and to describe it analytically. The contribution analyses the results of measurements carried out by using the contactless shadow optical method, the procedure of processing the results, the analysis and interpretation. A method of distinguishing the zone of good quality from the zone of poor quality is proposed here on the basis of critical parameter Cc based on the evaluation of geometric irregularities of AWJ produced surfaces. The submitted contribution is a continuation and extension of the contribution already published [Valicek 2007].

2. Related and previous works

A surface produced by the AWJ technology is characterised by duality. The upper part of the cut is rather smooth (according to [Hashish 1984] the cutting zone h_c) and from a certain depth, the striated zone (deformation h_d) occurs. This is caused by the fact that the jet loses its kinetic energy, which leads to a change in the mechanism of material removal, namely from the prevailing cutting mechanism of removal to the deformation one. According to Hashish, the depth of cutting mechanism of material removal h_c (good-quality zone) can be calculated by the following empirical relation:

$$h_c = \frac{\frac{v_a}{C_k} d_a}{\left(\frac{\pi\, \rho_p\, v_p\, d_a^2}{14\, m_a}\right)^{\frac{2}{5}} + \frac{v_e}{C_k}}, \qquad (1)$$

where:
- v_a – movement speed of abrasive particles, [m.s⁻¹]
- C_k – coefficient of characteristic speed, [1]
- d_a – focusing tube diameter, [m]
- ρ_p – abrasive material density, [kg.m⁻³]
- v_p – traverse speed of cutting head, [m.s⁻¹]
- m_a – abrasive mass flow rate, [kg.s⁻¹]
- v_e – critical speed of abrasive particles. [m.s⁻¹]

According to this author, the depth of deformation mechanism of material removal $\boldsymbol{h_d}$ [Hashish 1984] can be calculated in a similar way. The above-mentioned relations are very complicated, because the process of AWJ cutting is affected by many parameters and factors. This calculation cannot include all factors influencing cutting, and that is why the calculated value may differ from the real value by even more than 50% [Palenikova 2005]. This relation is empirically valid, namely for metallic materials [Stoic 2007].

2. Related and previous works

Test samples of AISI 309, CSN 11503, CSN 13116, CSN422712 and CSN 11375 materials were experimentally measured. The size of the samples was 20x20x8 mm. The samples that are presented in this article were produced on a machine PTV–37-60 Pump under constant conditions, see Tab. 1. The observed factor was the traverse speed of cutting head; different speeds, namely 200, 150, 100 and 50 mm.min^{-1}, formed the walls of the sample. The surface of the sample is illuminated by a laser at the angle of 10° – 20°; a beam of the laser passes through a collimator directing the beam so that the beam may illuminate the whole surface of the sample being measured, Fig. 1. By this illumination, the distribution of light and shadow areas is formed. This light-shadow distribution is scanned using a CCD camera connected to a PC with a signal processing program. In the course of experiment, a laser diode of 3 mW/650 nm output was used. The shadow visualization effect, which changes depending on surface reflectivity, also depends on the angle of illumination. At a suitable angle of illumination, elevations and depressions in the surface topography related to the typical AWJ waviness and also to the course of the cutting process itself can be easily seen. In our case, the angle of illumination was 15°. A change in light intensity distribution was detected by a CCD camera having a resolution of 1090 x 1370 pixels. The assembly used in measurements is shown in Fig. 2.

Table 1. Experimental set up

Technological factors	symbol	unit	value
liquid pressure	p	MPa	300
water nozzle diameter	d_o	mm	0.25
focusing tube diameter	d_a	mm	0.8
focusing tube length	l_a	mm	76
abrasive mass flow rate	m_a	g.min^{-1}	250
nozzle-surface distance	L	mm	2
material thickness	h	mm	8
traverse speed	v_p	mm.min^{-1}	50, 100, 150, 200
abrasive size	–	MESH	80
abrasive material	–	–	Barton garnet

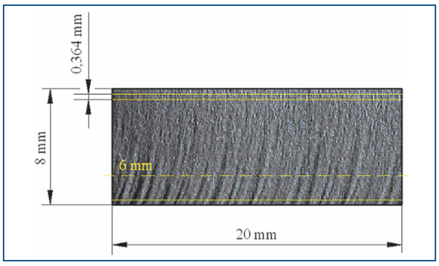

Figure 1. *Illustration of measuring lines on a sample of AISI 309 material*

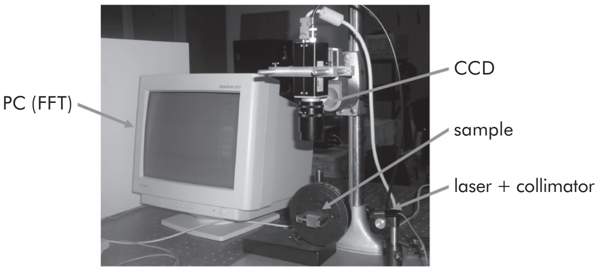

Figure 2. *Photograph of assembly for measurements by the optical shadow method*

Summarised values were directly averaged and statistically processed along the whole length of cut wall l_p. Considering the specific features of surfaces being processed, each line was averaged by summing 20 lines to secure better statistical evaluation in the direction along the AWJ stream trajectory.

3. Results and discussion

The acquired signals were transformed using a Fast Fourier Transform to amplitude-frequency spectra. In these amplitude-frequency spectra, a band filtration was performed, i.e. division of amplitude-frequency spectrum into six frequency bands, see Tab. 2. The frequency bands chosen like that simulated a "cut-off" of contact profilometer for decomposing the surface topography into its specific subcomponents. The division of amplitude-frequency spectrum into six frequency bands is graphically illustrated in Fig. 3.

Table 2. Division of amplitude-frequency spectrum into frequency bands.

	RMS(1)	*RMS*(**2**)	*RMS*(3)	*RMS*(4)	*RMS*(5)	*RMS*(6)	*RMS*
f [mm^{-1}]	0 to 2.5	2.5 to 5	5 to 10	10 to 15	15 to 20	20 to 25	0 to 25

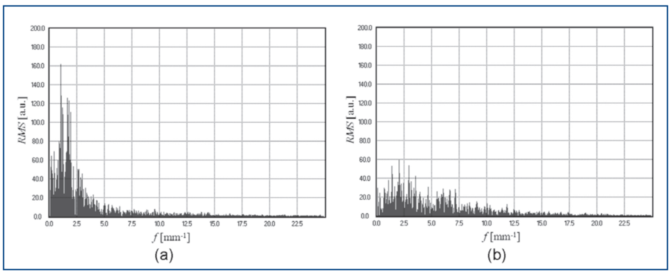

Figure 3. *Amplitude-frequency spectra of studied surfaces obtained from one representative measuring line at the depth of 6 mm below the surface (v = 200 mm.min^{-1} (a), v = 50 mm.min^{-1} (b)).*

On the basis of measured data, three graphs of *RMS* behaviour versus the depth *h* were constructed. For illustration, in Fig.4 a graph is plotted showing all measured values for specific frequency bands of one cut through the sample of CSN 17251 material.

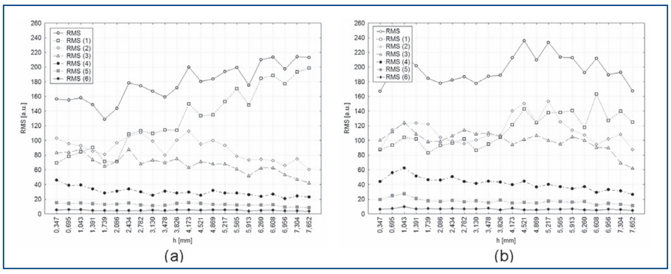

Figure 4. *Dependence of RMS on the depth of cut h for AISI 309 material (v = 200 mm.min^{-1} (a), v = 50 mm.min^{-1} (b)*

In Fig. 4 we can see that the behaviours of high-frequency irregularities (*RMS*(2) to *RMS*(6)) are almost constant at all depths of cut. On the contrary, the behaviours of low-frequency irregularities *RMS* (1) grow with the depth, and thus the overall irregularity of surface *RMS* increases as well. This is caused by the fact that with the increasing depth of cut *h* the kinetic energy of the jet diminishes and thus surface irregularities grow, i.e. their amplitudes grow and spatial frequencies diminish.

4. C criterion utilization for the evaluation of surface topography

The criterion C was presented in [Valicek 2007] as follows:

$$C = \frac{RMS(1)}{RMS} \quad (2)$$

This parameter is a constant for the given horizontal measuring line. The ***C*** value is thus a ratio of *RMS* (1) value – (waviness zone) to the total ***RMS*** value measured along each measuring line, see relation (2). It is necessary to distinguish the parameter C, which is a constant for the given measuring line, from the function c, which is a distribution function of values (C_1 – C_{22}) in relation to the depth *h*:

$$c = f(C_1 - C_{22}, h) \quad (3)$$

In Fig. 5a the dependence of *RMS* on *h* is given for the CSN 17 251 material at the traverse speed of cutting head of 200 mm.min^{-1}. Fig. 5b illustrates the dependence of *RMS* on *h* for the same material at the traverse speed of 50 mm.min^{-1}.

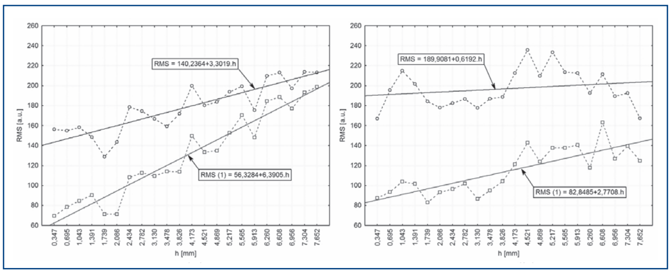

Figure 5. *Dependence of RMS on the depth h for AISI 309 material (v = 200 mm.min^{-1} (a), v = 50 mm.min^{-1} (b)).*

The dependence of behaviour of parameter C on the depth *h* is illustrated in Fig. 6 for the CSN 17 251 material and the traverse speeds v_p = 200 mm.min^{-1} and v_p = 50 mm.min^{-1}; regression equations are presented as well. In the case of this ratio (2), there are two extreme values. If C approximates to zero, surface roughness dominates over waviness. If C is near 1, surface waviness dominates over roughness. The measurements prove that the values of real surfaces move in the interval of 0.4 ÷ 0.95.

The main objective is to utilise the quantitative criterion C to assess whether the good quality (cutting) zone or poor quality (deformation) zone is involved. In Tab. 3 five materials measured by the optical shadow method are stated in the first column. In the second column, two traverse speeds v_p, namely 200 and 50 mm.min^{-1} for each material are given. In the third column, calculated predictive values of h_c according to [Hashish 1984] (1) are there. In the fourth column distribution functions c obtained according to (3) are provided.

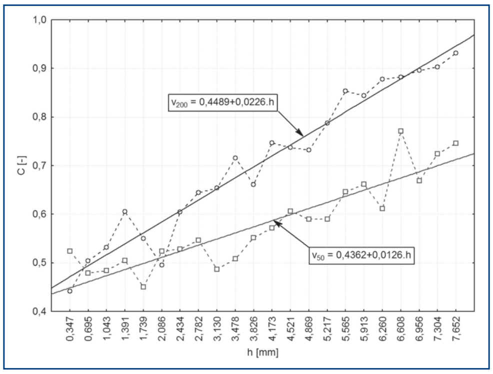

Figure 6. *Dependence of parameter C on the depth h for AISI 309 material.*

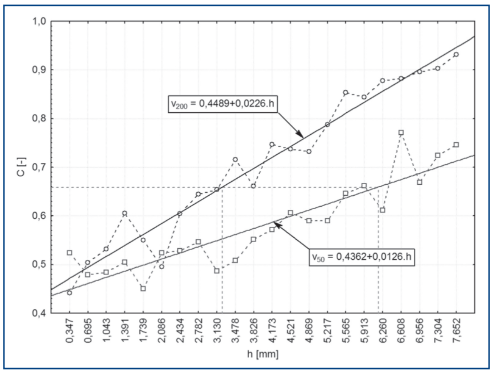

Figure 7. *Dependence of parameter C on the depth h for AISI 309 material with the marked value of C_c = 0.66.*

Table 3. Calculation of critical depth h_c and determination of critical quantitative parameter C_c.

	1	2	3	4	5
	Material	v_p	h_c	C	C_c
1	ČSN 17251	200	2.7	c_{200} = 0.065.*h* + 0.4489	0.6244
		50	3.6	c_{50} = 0.0361.*h* + 0.4362	0.5662
2	ČSN 11503	200	2.8	c_{200} = 0.0719.*h* + 0.4621	0.6634
		50	3.6	c_{50} = 0.0268.*h* + 0.5843	0.6808
3	ČSN 13116	200	2.6	c_{200} = 0.0719.*h* + 0.4621	0.6490
		50	3.5	c_{50} = 0.0268.*h* + 0.5843	0.6781
4	ČSN 422712	200	2.9	c_{200} = 0.0719.*h* + 0.4621	0.6697
		50	3.8	c_{50} = 0.0268.*h* + 0.5843	0.6861
5	ČSN 11375	200	3.0	c_{200} = 0.0719.*h* + 0.4621	0.6778
		50	3.8	c_{50} = 0.0268.*h* + 0.5843	0.6861
					ϕ 0.66

In the fifth column there are calculated values of critical quantitative parameter C_c; they are the critical values for the given material at the given traverse speed v_p. These values were acquired by inserting the calculated value of h_c into the distribution function c. On the basis of low fluctuation of critical quantitative parameter C_c, we determined the average value, C_c = 0.66. This value divides the surface topography into two zones. If the parameter C is smaller than its critical value C_c, then the zone is of good quality (cutting zone), if the parameter C is greater, the zone is of poor quality (deformation zone).

As opposed to Hashish, who determined the depth h_c on the basis of input factors influencing the quality of cut formed, the critical quantitative criterion C_c = 0.66 was experimentally defined in the area of problems concerned. By this criterion, we distinguish the good quality zone (C_c < 0.66) from the poor quality zone (C_c > 0.66). In Fig. 7 the practical utilization of this parameter can be seen; for the given type of material we demonstrate there the maximum cutting depth, which can be attained at a change in traverse speed, at which the required quality of the surface can be achieved.

5. Conclusions

On the basis of criterion C, which was already presented in the contribution [Valicek 2007], we determined experimentally the critical value of this parameter C_c. This value differentiates unambiguously the zone without conspicuous striations from the zone with conspicuous striations. By means of this parameter we are able to distinguish the good-quality zone of cut from the poor-quality zone, which is mainly of importance to the satisfaction of needs of buyers of cut materials. The parameter C_c represents the reference value for metallic materials. We obtained the critical value C_c for materials given in Tab. 3 by means of the calculation of relation (1). By identifying the surface topography we acquired data, analysed and interpreted the data and also proposed the reference parameter usable in materials classification. We expect that this parameter will be applied more generally to the prediction of surface topography in relation to changes in technological factors that affect it.

Acknowledgements

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