EFFECTS OF ABRASIVE WATERJET PROCESS PARAMETERS TO MICROGEOMETRICAL QUALITY OF STAINLESS STEEL AISI 304

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Abstract: *The paper presents the experimental work of evaluation of process parameters of abrasive waterjet cutting. Full factorial design* 2^4 *was used as a statistical method to study effects of independent variable factors - pressure, J/T abbreviations, abrasive mass flow and traverse rate to impact to dependent variable roughness average* R_a *which is measured in three depths of samples. The data have been analyzed using ANOVA, in order to identify the variables that significantly affect the relationship between the taper and factors. The regression equations obtained from ANOVA gives the level quality Ra.*

Key words: *abrasive waterjet, full factorial design, process parameters, surface quality*

1. INTRODUCTION

Abrasive waterjet cutting is one of the most recently developed manufacturing technologies [5]. It uses a fine water and abrasive slurry jet to cut the materials by means of erosion. This cutting technology has various distinct advantages over the other cutting technologies, such as no thermal distortion on the work piece, high machining versatility to cut virtually any material, high flexibility to cut in any direction, and small cutting forces. [7] As a result, it is being increasingly used in the manufacturing industry. [1,2] However, many aspects of this technology have not yet been fully understood and its cutting capacity has limited its applications to relatively thin materials and where the requirements for the kerf quality are not high.[3,4] Therefore, it is necessary to identify the ling between the process parameters and their effects to surface quality of stainless steel. In this work the influence of process parameters (pressure, traverse speed, abrasive mass flow rate and J/T abbreviation) on the quality of abrasive waterjet cutting surfaces is analyzed by factorial design application. The analysis of variance is performed in order to identify which process parameters and

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their interaction variables significantly influence the cut quality in three various depth zones of 10 mm thick samples.

2. EXPERIMENTAL PROCEDURE

In order to optimise waterjet process production, Full Factorial Design for four independent variables was designed. The Experimental Design is based on [6, 9,11,12]. Full Factorial Design was used to obtain the combination of values that can optimise the response within the region of the four dimensional observation spaces, which allows one to design a minimal number of experimental runs. The variables are: Pressure, J/T abbreviation, Traverse speed, Abrasive mass flow rate were submitted for the analysis in the design. The variable of each constituent at levels –1, and +1 is given in Table 1.

Tab. 1 Coded factors on various levels

N.	Factors			Factor level	
	Variable	Terminology	Dimension	-1	+1
1	x_1	J/T abbreviation D_V/D_A	mm	0,1/1	0,14/1,2
2	x_2	Abrasive mass flow rate	$g.min^{-1}$	300	500
3	x_3	Pressure	MPa	200	350
4	x_4	Traverse rate	$mm.min^{-1}$	70	120

The selections of low and high levels for all these variables were based on random selection. A 2^4 is full factorial design with 2 replicates at the centre point, leading to the total number of 16 experiments.

Observations had been realized in a random order. The behaviour of the present system described by the following equation, which includes all interaction terms regardless of their significance:

$$\hat{y} = b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 \\ + b_{34}x_3x_4 + b_{123}x_1x_2x_3 + b_{134}x_1x_3x_4 + b_{234}x_2x_3x_4 + b_{1234}x_1x_2x_3x_4$$

Where y_{Ra} is predicted response roughness in upper erosion zone, x_1, x_2, x_3, x_4 are independent variables; b_0 is coefficient constant for offset term, b_1, b_2, b_3 are coefficient constant for linear effects and b_{12}, b_{21}, b_{31} are coefficient constant for interactions effects. The model evaluates the effect of each independent variable to a response. The variables studied were J/T abbreviation (0,1/1- 0,14/1,2), abrasive mass flow rate (300 - 500), pressure (200 - 350 MPa) and traverse rate (120 – 70 $mm.s^{-1}$).

2.2 EXPERIMENT REALIZATION

A two dimensional abrasive waterjet machine is used in this work with following specification: work table x-axix 2000 mm, y-axix 3000 mm, z-axis discrete motion, with maximum traverse rate. The high-pressure intensifier pump used is model from Ingersoll-Rand with maximum pressure 380 MPa and Autoline^{TM} cutting head from Ingersoll-Rand is used in this study. Abrasive machining conditions used in this study are listed in table.

Tab. 2 Experimental set-up

Variable parameters	Values	Constant parameters	Values
Pressure p [MPa]	200/350	Standoff	3 mm
Traverse rate v [mm.s^{-1}]	70/120	Mesh	80
Direction [°]	+180/-180	Abrasive material	Barton Garnet
J/T abbreviation D_v/D_A	0,14/1,2/0,1/1	Cutting head	Autoline™
Abrasive mass flow rate [g.min^{-1}]	200/500	Material thickness	10 mm
Target material: Stainless steel (AISI 304) Chemical properties: C 0,08; Mn 2,0; P 0,045; S 0,03; Si 1,0; Cr 18; Ni 8			
System characteristics			
Intensifier type	Double effect	Water pressure (max)	380 MPa
Intensifier power	kW	Intensification ratio	20:1
Oil pressure (max)	20 MPa	Accumulator volume	2 l
Number of cuts: 96 (16 experimental conditions with 6 replications)		Number of measurements: 288 (96 measurements in three depths h_1, h_5, h_9)	

The Mitutoyo Surftest 201 has been used for measure of surface roughness. The following picture illustrates roughness measuring method of samples measured in three different depths h_1 = 1 mm, h_5 = 5 mm, h_9 = 9 mm as is shown on figure.

3 RESULTS AND DISCUSSION

For simplified evaluation of measured data file graphic execution have been done (fig. 3.1, 3.2). Experimental graphic dependence that describes average roughness behaviour Ra at various factors combinations on sample depth h_1, h_2, h_3.

As can be seen from graphic interpretation average roughness shows week experimental dependence on change combinations of variable parameters in depth 1 mm. With increasing depth h_5 and h_9 average roughness strongly increases that is caused mainly by factor x_4 (traverse rate). The roughness significantly increases as the traverse rate increases. This observation agrees with results on aluminium, ceramics, metal-matrix composites, glass, and fiber-reinforced composites.

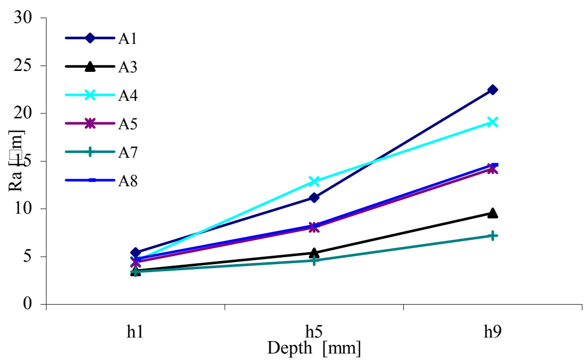

Fig. 1 Experimental dependence Ra on factors combinations and samples A and B depth

The increase in the number of impacting particles at lower traverse rates contributes to the improved surface finish. The additional particles serve to smooth the surface that forgoing particles generated.

Observations proved influence of orifice diameter on surface roughness. Figure 1 is graphical representation of factors change combination on average roughness measured in three various depths for samples set A and B where is proven influence of factor x_1. The description and evaluation influence of abrasive water jet cutting process parameters variables on Ra_{h1}, Ra_{h5}, Ra_{h9}, and the analysis of variance in this study has been used. Experimental data have been tested according Cochran´s test. The regression coefficients and equations obtained after analysis of variance gives the level of significance of variable parameters tested according Student's t-test. The regression coefficients and their significance are listed in table 3. Obtained regression coefficients that show no statistical significance have been rejected from the next process evaluation. The models, expressed by following equations, were generated by linear multiple regression of the data and is a function of the more significant variables:

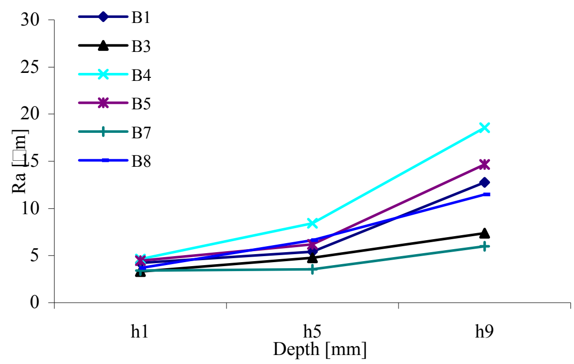

Fig. 2 Experimental dependence Ra on factors combinations and samples A and B depth

Regression equation for the variable Ra measured in 1 mm depth of sample.

$$\bar{y}_{Ra_{h1}} = 4{,}516 + 0{,}262x_1 - 0{,}185x_2 - 0{,}605x_3 + 0{,}489x_4 \qquad (1)$$

Regression equation for the variable Ra measured in 5 mm depth of sample.

$$\bar{y}_{Ra_{h5}} = 7{,}11 + 1{,}705x_1 - 1{,}089x_2 - 1{,}568x_3 + 2{,}24x_4 \qquad (2)$$

Regression equation for the variable Ra measured in the 9 mm depth of sample.

$$\bar{y}_{Ra_{h9}} = 12{,}07 + 3{,}263x_1 - 0{,}599x_2 - 4{,}255x_3 + 2{,}561x_4 \qquad (3)$$

where: y_{Ra} is the response, that is roughness of the surface and x_1, x_2, x_3, x_4 are coded values of the variables J/T abbreviation, abrasive mass flow rate, pressure and traverse rate. Regression model is containing four linear and interaction terms. Obtained regressions models, related the depth, induces that behaviour of water jet cutting is difficult process.

Material being machined by factor x_1 at level –1, samples set B, is characterised by lower surface roughness. In fact x_1 is J/T abbreviation, is change diameters of focus tube and diameter of water orifice. But it is assumed that the small diameter water orifice causes the speediest water jet and that causes the higher velocity of formed cutting tool. Thus abrasive water jet disposes higher energy concentrated to smallest area of the workpiece. Out of measured data result those roughness average values an asymmetry of the roughness values. Because the samples created for this purpose have been cut in two directions +180° and –180°. This phenomenon is may be caused probably due to feeding direction of solid phase and consequently distribution of abrasive particle in the water jet that confirms experiments of CHEN [13]. That phenomenon will be studied by special prepared experiment because the feeding direction of the abrasive to the mixing chamber was not perpendicular to the feed rate direction.

$$\bar{y}_{Ra_{h9}} = 12{,}07 + 3{,}263x_1 \qquad x_2 = x_3 = x_4 = 0; \qquad (4)$$

$$\bar{y}_{Ra_{h9}} = 12{,}07 - 0{,}599x_2 \qquad x_1 = x_3 = x_4 = 0; \qquad (5)$$

$$\bar{y}_{Ra_{h9}} = 12{,}07 - 4{,}255x_3 \qquad x_2 = x_1 = x_4 = 0; \qquad (6)$$

$$\bar{y}_{Ra_{h9}} = 12{,}07 + 2{,}561x_4 \qquad x_2 = x_3 = x_1 = 0; \qquad (7)$$

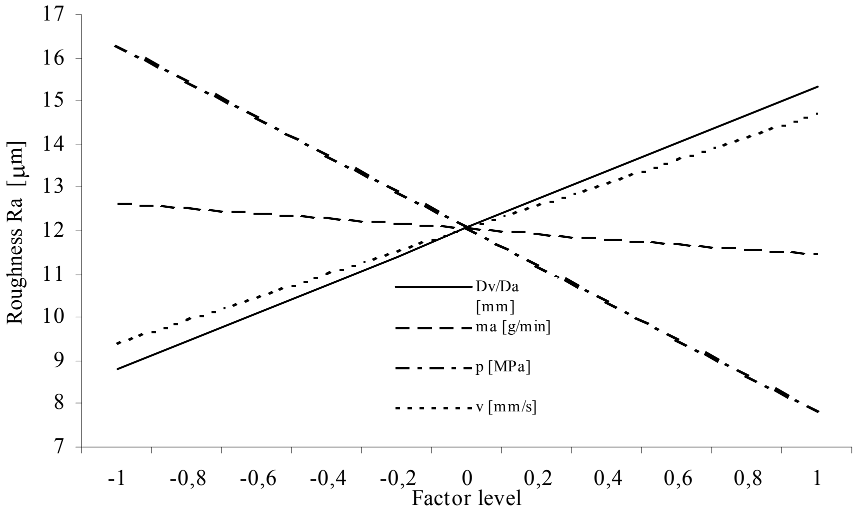

Fig. 3 Linear fit of factors influence to Ra in depth h = 9 mm

CONCLUSION

The problem analysed in these pages is the study of abrasive water jet cutting in terms micro cutting quality. The quality parameter average roughness has been measured. This analysis has pointed out that variable independent, pressure, abrasive mass flow rate, pressure and traverse rate influence the morphology of cutting surface. It has been found that influence of process parameters is variable related to different depth.

Evaluation has been carried according to design of experiments. Full factorial design has been used as a statistical method to study effects of selected process parameters. The pressure, abrasive mass flow rate, traverses rate and J/T abbreviation as independent variable, has been evaluated their significance and their impact to the taper as a dependent variable. Obtained regression equations after analysis of variance give the level quality as a function of the process parameters. It has been found that pressure, and traverse rate are important with the depth. It has been observed that dominant parameters influencing quality are - pressure and traverse rate. These factors directly determine quality of the tool – high-speed waterjet.

Experiment also proved an asymmetry of the roughness values due to the feeding direction of solid phase - abrasive at the entry of the mixing chamber. According theses results new experimental scheme will be created to continue of evaluation abrasive water jet machining.

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