ABRASIVE WATERJET PROCESS FACTORS INFLUENCE ON STAINLESS STEEL AISI 304 MACROGEOMETRICAL CUTTING QUALITY

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Abstract: *This study deals with abrasive waterjet process parameters influence to taper. 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.*

Keywords: *Abrasive waterjet, quality, design of experiments, process parameters*

1 INTRODUCTION

In current European conditions raising emphasis is posed to manufacturing processes quality with minimal environmental impact connected lower energetically and material consumption. Abrasive waterjet cutting represents these claims. Abrasive waterjet cutting technology and techniques are quickly gaining popularity as an economical alternative to traditional machining, molding and cutting methods.

The abrasive waterjet cutting technique is considered to be a flexible tool in the processing of a wide range of materials without wasting a time in tool changing and with minimal risk to occupational health and environment. [3,10,12] Most scientific papers concerning evaluation stainless steel macrogeometrical features of abrasive waterjet cutting are available [1,2,3,5], the object is to determine the final shape of the kerf walls, that is a function of the geometric characteristic of the abrasive waterjet tool and its quality process parameters. The taper geometry directly depends on the shape of the jet, which is not similar to shape of a fixed geometry tool. In fact, due to hydrodynamic characteristics of the jet, is geometry significantly influenced by pressure, water orifice diameter, and abrasive parameter and mixing parameter. These factors influence the qualitative characteristics of the tool, the speed, diameter kinetic energy of the stream. Through cutting parameters, created tool hits the workpiece the at upper erosion base, where erosion process begins. These facts confirm that abrasive waterjet cutting is a difficult process for classic experimental schemes.

2 EXPERIMENTAL PROCEDURES

To evaluate the cutting process of abrasive waterjet, the influence of selected process parameters (pressure, traverse speed, abrasive mass flow rate and J/T abbreviation) on the quality of abrasive waterjet cutting surfaces are analyzed by design of experiments application. The analysis of variance is performed in order to identify which selected process parameter and their interactions variables significantly influence the cutting quality of stainless steel that has been chosen as a target material because of its resistance to corrosion. [7,11]

In order to investigate the influence of abrasive waterjet process parameters on cutting quality, full factorial design for four independent variables has been designed. The variables are: pressure, J/T abbreviation, traverse speed, abrasive mass flow rate, which were submitted for the analysis in the design. The variable of each constituent at levels: –1, and +1 is given in table 1. [4,6,11]

Table 1. Coded factors at various levels

N	**Factors**		**Factor level**	
	Var.	**Terminology and dimension**	-1	+1
1	x_1	J/T abbreviation [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 experimental cuts have performed in a random sequence, in order to reduce the effect of any possible error. A 2^4 full factorial analysis has been used with *2* replicates at the center point, leading the total number of *16* experiments. Considering that the four levels of the x_1, x_2, x_2, x_4, and variables are *-1* and *1*, the designed matrix is 16-obsevations for dependent variable y_λ. [7]

According to experimental methodology each cut has been replicated three times; yielding total of *48* cuts. Specimens series A has been made with process parameter J/T at high level 0,14/1,2 (+1) and specimens series B with lowest level of J/T abbreviation. The smaller diameters of diamond orifice and focus tube produce water with higher speed of abrasive water jet. [5] Observations have been realized in a random order.

2.1 Experimental set up and measurement procedure

A two dimensional abrasive waterjet machine Wating, has been 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 250mm.s^{-1}. The high-pressure intensifier pump was used the Ingersoll-Rand model with maximum pressure 380 MPa. As a cutting an Autoline cutting head from Ingersoll-Rand head has been used.

A digital offset centerline digimatic calipers Mitutoyo 573-102-10 has been used to calculate the taper with 0,01 mm precision of measurement.

Table 2. Set up of experiments

Variable parameters	**Values**	**Constant parameters**	**Values**
Pressure p [MPa]	200/350	Standoff	3 mm
Traverse rate v [mm.s^{-1}]	70/120	Abrasive material Barton Garnet Mesh 80	
J/T abbreviation	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			
System characteristics			
Intensifier type	Double effect	Water pressure (max)	380 MPa
Intensifier power	50 kW	Intensification ratio	20:1
Oil pressure (max)	20 MPa	Accumulator volume	2 l

The measurement procedure consisted of measure variable dependents: width of upper erosion base y_{ueb} and width of lower erosion base y_{leb}. According to these measured data values the tapers $y_{\lambda I}$ has been calculated, from equation (1) for each group of samples, that is main typical macro geometrical feature of abrasive waterjet cutting.

$$cot\, g\lambda = \frac{|y_{ui} - y_{li}|}{2.h} \quad (1)$$

where: y_{ui} - width of sample upper erosion base of sample [mm], y_{li} - width of sample lower erosion base [mm], h - sample height [mm], λ - taper.

3 RESULTS AND DISCUSSION

Experimental graphic dependence describes the taper characteristics of 10 mm thick stainless steel. From the factor analysis, it is evident the influence of J/T abbreviation process parameter. The smaller is the diameter of water orifice, the higher the speed of water. This improves the macro geometrical quality characteristics of cutting surface. The diameter of cutting tool is crucial. This phenomenon is connected with energetically potential of the stream. But these characteristics dramatically change depending on the depth consequently on kinetic energy absorption by workpiece due to hydrodynamic friction of abrasive waterjet. Figure 1 shows the percentual proportion that was derived from regression coefficient of examined process parameters influence in upper erosion base and lower erosion base by factorial analysis.

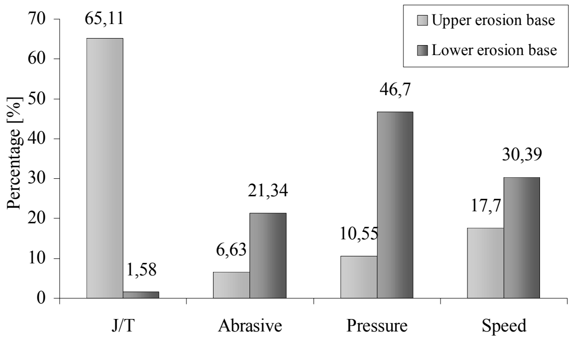


Fig. 1 Process parameters percentual proportion in UEB and LEB

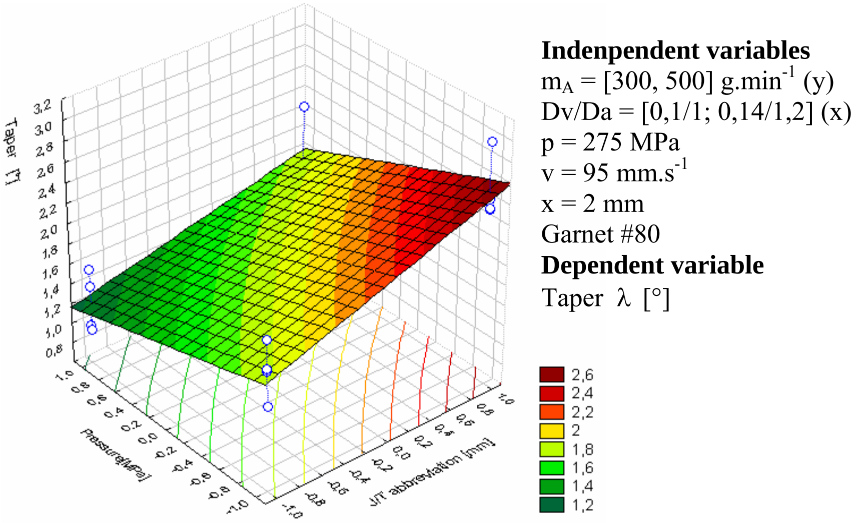
The results were analyzed using the analysis of variance as fitting to the experimental design used. Experimental data have been tested according Cochran's test. The regression coefficients and equations obtained after analysis of variance gives the level of significance of variable parameters tested according to Student's t-test. Obtained regression coefficients that show no statistical significance have been rejected from the next evaluation of the process. The model, expressed by following equation, was generated by multiple linear regressions of the data and is a function of the significant variables (2):

$$\bar{y}_{\lambda} = 1{,}82 + 0{,}3234x_1 - 0{,}1428x_2 - 0{,}333x_3 + 0{,}1607x_4 \qquad (2)$$

Where: y_{λ} is the response, that is kerf 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 contains four linear terms.

The model has been checked by several criteria. The fit of the model has been expressed by the coefficient of determination. R^2, which was found to be 0,9995 indicating that 99,95% of the variability in the response can be explained by the model. The value also indicated that only 0,05% of the total variation is not explained by the model. This shows that equation is suitable model for describing to describe the response of the taper. The value of adjusted determination coefficient adj = 0,9871 is very high to advocate for a high significance of the model.

The Figure 2 shows fitted surface of pressure and J/T abbreviation process parameters. Three-dimensional surface plot showing predicted macrogeometrical quality feature the taper as a function of independent variable – J/T abbreviation, pressure. The fitted function describes equation 3.



Indenpendent variables

m_A = [300, 500] g.min^{-1} (y)

Dv/Da = [0,1/1; 0,14/1,2] (x)

p = 275 MPa

v = 95 mm.s^{-1}

x = 2 mm

Garnet #80

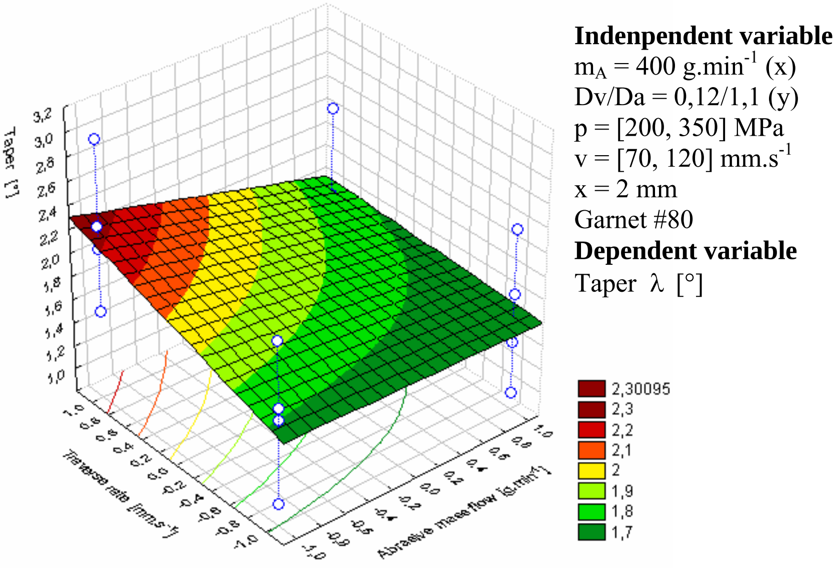
Dependent variable

Taper λ [°]

Fig. 2 3D surface plot for predicted the taper variable

$$\lambda = 1{,}82 + 0{,}3234.x - 0{,}1428.y \qquad (3)$$

An increase of the pressure, in general, improves surface quality. With pressure increase the abrasive increases water jet kinetic energy. [7] From fluid mechanics in the hydroabrasive cutting process, the primary factor is the water stream velocity and that velocity strongly depends on pressure and diameter of the diamond orifice and diameter of the focusing tube. The second and the most significant factor is J/T abbreviation that relates with size and active length of cutting tool. The impact of J/T abbreviation is shown on Figure 3.



Indenpendent variable
m_A = 400 g.min^{-1} (x)
Dv/Da = 0,12/1,1 (y)
p = [200, 350] MPa
v = [70, 120] mm.s^{-1}
x = 2 mm
Garnet #80
Dependent variable
Taper λ [°]

Fig. 3 3D surface plot for predicted the variable taper

$$\lambda = 1{,}82 - 0{,}333.y + 0{,}161.x \qquad (4)$$

The important fact is that J/T abbreviation with level –1 (0,1/1) creates more coherent stream. Therefore the surface quality improves with higher pressure and smaller diameter because an abrasive water jet disposes with higher energy concentrated to smaller area of the workpiece. The Figure 4 illustrates fitted three-dimensional surface plot of abrasive mass flow rate and traverse rate process parameters.

With an increase in the abrasive-mass flow rate, the quality of surface - taper characteristics improves. But according to planned level conditions that factor there is range of abrasive mass flow rate from 300 g.min^{-1} to 500 g.min^{-1}. From that mentioned reason high abrasive-mass flow rates influence to taper, is less significant. As the abrasive mass flow rate increases, speed of the abrasive water jet reduces. The higher the mass-flow rate, the higher the number of abrasive particles is that must share the kinetic energy of the water jet. It is assumed that at low values of the factor x_2, the particles do not collide one with another. They hit the material with a maximum velocity and maximum possible kinetic energy. The final result is that the abrasive mass flow rate has the less influence as hydrodynamics parameters, pressure and J/T abbreviation.

The traverse rate is more sensitive factor as abrasive mass flow rate. With an increasing speed of abrasive cutting head the taper increases. The smaller speed is, the longer abrasive waterjet remains at the upper erosion base location, and then the stream has the more time to erode the workpiece.

4 CONCLUSIONS

The quality parameter taper has been calculated according to measured experimental data the width of upper and lower erosion base. These data and calculated results have been analyzed using ANOVA, in order to identify the variables that significantly affect the relationship between the taper and process variables. The regressions equations obtained from analysis of variance gives the level quality as a function of different variables: pressure, traverse rate, abrasive feed rate and J/T abbreviation.

It has been observed that dominant parameters influencing macrogeometrical quality are hydrodynamic parameters - pressure and J/T abbreviation. These factors directly determine quality of the tool – high-speed waterjet. The effect of abrasive mass flow rate and feed rate are less noticeable. To improve process performance, it is obvious adjusting factors, which have the greatest effect.

REFERENCES

[1] ANNONI, M.; MONNO M. A lower limit for the feed rate in AWJ precision machining, BHR Group 2000 Jetting Technology, p. 285-295, ISBN 1 86058 253 2,

[2] ANNONI, M., MONNO, M., VERGARI A.: The macrogeometrical quality of the kerf in the awj process parameters selection, Politecnico di Milano - Dipartimento di Meccanica, Milano, Italy,

[3] BLAGODARNY, V, PAVLENKO, S, HLOCH S: Experimentálna metodika a hodnotenie experimentov vplyvu procesných parametrov vysokorýchlostného hydroabrazívneho prúdu na kvalitu obrobenej plochy a na hladinu akustického tlaku, In. *Zborník referátov VI. medzinárodná vedecká konferencia Nové trendy v prevádzke výrobnej techniky 2003, FVT TU Košice so sídlom v Prešove*, 2003 ISBN 80-8073-059-8 (s.185 – 191),

[4] BLAGODARNY, V., HLOCH, S., KMEC J. Plánovanie experimentov vplyvu technologických parametrov vodného lúča na kvalitu obrobenej plochy, 5. In. V*edecká konferencia s medzinárodnou účasťou: Informatika a algoritmy 2002*, ISBN 80-88941-21-0,

[5] BOHÁČIK, Ľ., VAGASKÁ, A. Určovanie hydrostatického tlaku reálnych kvapalín. In *Zborník referátov VI. medzinárodná vedecká konferencia Nové trendy v prevádzke výrobnej techniky 2003, FVT TU Košice so sídlom v Prešove*, 2003 ISBN 80-8073-059-8 (s.648-651),

[6] BLAHUŠ, P. *Faktorová analýza a její zobecnení.* SNTL Praha 1985, ISBN 04-028-85,

[7] BOHÁČIK, Ľ.; HLOCH S. *Mechanika tekutín a aerodynamika - základné teórie a cvičenia*. Fakulta výrobných technológií TU Košice s o sídlom v Prešove, 2003, s. 180. ISBN 80-8073-069-5,

[8] HANOUSEK, CHARAZMA: *Moderní metody zpracování dat.* Educa, Praha 1999, ISBN 80-85623-31-5,

[9] CHEN F.L., SIORES E.: *The effect of cutting jet variation on striation formation in abrasive water jet cutting*. Industrial Research Institute Swinburne, Swinburne University of Technology, PO Box 218, Melbourne, VIC 3122, Australia, Received 3 March 2000; accepted 10 January 2001, International Journal of Machine Tools & Manufacture 41 (2001) 1479–1486.

[10] RADVANSKÁ, A. Hodnotenie rizík technológie delenia vysokorýchlostným hydroabrazívnym prúdom kombinovanou bodovou metódou. In. *Zborník referátov VI. medzinárodná vedecká konferencia Nové trendy v prevádzke výrobnej techniky 2003, FVT TU Košice so sídlom v Prešove*, 2003 ISBN 80-8073-059-8,

[11] ŠEBEJ, P.: *Štatistika vybrané časti.* Informatech Košice ISBN 80-88941-04-0,

[12] LORKO, Martin - RADVANSKÁ, Agáta: Environmentalistika. Prešov : TU-FVT, 2001. 97 s. ISBN 80-7099-715-X.

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