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A MODELING STUDY OF THE WJC ETCHING PROCESS OF STEEL AND STAINLESS STEEL MATERIALS

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Abstract: *Abrasive Water Jet Cutting technology has some advantages as compare to other technologies, such as: no thermal distortion, high machining versatility and high flexibility. WJC has proved to be an efficient technology for etching various engineering materials. The objective of the paper was to optimize the WJC parameters, in order to be suitable for etching process. An experimental investigation was undertaken, in order to study the influence of process's parameters: pressure, traverse feed rate and abrasive mass flow on the etching process. The paper presents a mathematical modeling of the depth of etching, using the abrasive water jet cutting process for etching onto steel and stainless steel. The mathematical models were tested after words by experimental research. The theoretical estimations proved to be in a good correlation with the experimental data.*
Key words: *water jet, etching, Response Surface Methodology*

1. INTRODUCTION

Abrasive waterjet cutting (AWJ) has various distinct advantages over the other cutting technologies, such as no thermal distortion, high machining versatility and small cutting forces, and has been proven to be an effective technology for processing various engineering materials (Farhad 2009).

AWJ technology proves to be in a continuous development, using an abrasive jet, different parts can be engraved and etched (Susuzlu 2007). Etching parts using water jet cutting equipment can save time and money, eliminating an extra operation. Water jet etching is different from other etching techniques: process speed, high depth, a good visibility, no thermal distortion, high machining versatility.

The purpose of the present paper is to establish an empirical model using Response Surface Methodology (RSM), which can be used for the study and prediction of processing depth and also to optimize it as a function of process parameters: feed rate, abrasive flow and water pressure.

2. ABRASIVE WATER JET ETCHING PROCESS

The principle of the etching process is to move the abrasive jet at a high speed so the abrasive jet does not pierce the full material thickness. When etching a part we follow a 2D sketch with the abrasive jet, resulting a kerf width equal with the abrasive jet. To etch a surface wider than the width of the abrasive jet, crossing the surface in several passes is required. The distance between crossings is equal with a half of abrasive jet diameter.

3. THEORETICAL FORMULATION

The RSM is a collection of statistical and mathematical techniques used to examine the relationship between one or more response variables and a set of quantitative experimental variables. RSM postulates a model of the form (Nuran 2007):

$$y(x) = f(x) + e \qquad (1)$$

Where: *y(x)* is the unknown function of interest, *f(x)* is a known polynomial function of *x*, and å is random error which is assumed to be normally distributed with mean zero and variance ε^2. The individual errors, ei, at each observation are also assumed to be independent and identically distributed. The polynomial function, *f(x)*, used to approximate *y(x)* is typically a low order polynomial which in this paper is assumed to be quadratic, Eq. (2) (Nuran 2007).

$$y = \beta_0 + \sum_{i=1}^{k}\beta_i x_i + \sum_{i=1}^{k}\beta_{ii} x_i^2 + \sum_{i}\sum_{j>i}\beta_{ij} x_i x_j \qquad (2)$$

The parameters, *βo*, *βi*, *βii* and *βij*, of the polynomial in Eq. (2) are determined through least squares regression which minimizes the sum of the squares of the deviations of the predicted values *y*, from the actual values, *y(**x**)*. The coefficients of Eq. (2) used to fit the model can be found using the least square regression given by Eq. (3):

$$\beta = [X'X]^{-1}X'y \qquad (3)$$

Where: *X* is the design matrix of sample data points, *X'* is its transpose, and *y* is a column vector containing the values of the response at each sample point.

4. EXPERIMENTAL DESIGN

Design of experiment is a technique for setting an efficient point parameter.A well designed series of experiments can substantially reduce the total number of experiments. In this paper a central composite design (CCD) with three factors was used. (Lazarescu 2008).The water pressure (*P*), abrasive flow (*Ma*) and feed rate (*V*) are independent variables and their values are in the table 1.

Variables	Units	level				
P	Bar	1500	1905.4	2500	3094.6	3500
V	mm/min	500	1412.14	2750	4087.86	5000
Ma	Kg/min	0.32	0.4	0.53	0.6	0.8

Tab. 1. Experimental design

Planning an experiment using this method resulted in 20 trials and the material used for this was Stainless Steel RVS 304.

The experiments were conducted on a waterjet system Technocut tipe Milestone. The waterjet cutting equipment consists of a high output pump, cutting head, three axis positioning system and a CNC controller.

The cutting head is consisted of a 0.254 mm diameter saphire oriffice that transforms the high pressure water into a collimated jet, an abrasive mixing chamber, an abrasive intel tube and a 76.2 mm long carbide waterjet nozzle of 1.016 mm in diameter. Industry type abrasive granets with a mesh size of 80mesh (180μm on average) were selected.

Fig. 2. Experimental trails

With the help of Design Expert Software the analysis of the proposed model for the experimental data, and calculation of its coefficients, were carried out.

5. MATHEMATICAL MODEL

Mathematical model 4 shows the dependence of the depth of processing on the relative bending water pressure, feed rate and abrasive mass flow. The coefficients of the equation were obtained by the multiple regression analysis of the experimental data:

$$\begin{aligned} h &= -1.92 + 0.0025 \times P - 0.0015 \times V + 4.443 \times M \\ &- 4.98E - 7 \times P \times V + 0.0008 \times P \times Ma - 0.001 \times V \times Ma \\ &- 1.35E - 7 \times P^2 - 4.3E - 7 \times V^2 - 2.711 \times Ma^2 \end{aligned} \tag{4}$$

Where: *h* is the predicted response in real value, *V* is the feed rate, *Ma* is the abrasive flow and *P* is water pressure.

The closer the value of R2 is to a unit, the better the empirical model fits the actual data. Multiple regression analysis results were R=0.89 of the quadratic model, indicating a good degree of correlation between the experimental values and the predicted values obtained from the model. Statistical testing of the empirical model has been done with the Fisher's statistical test for Analysis Of Variance – ANOVA. Table 2 shows the ANOVA test applied to the individual coefficients in the model, to test their significance.

Source	*Sum of Square*	*Degree of Freedom*	*Mean Squares*	*F Value*	*P Value*
Model	*28.04*	*9*	*3.12*	*7.89*	*0.0017*
P	*2.44*	*1*	*2.44*	*6.18*	*0.032*
V	*11.5*	*1*	*11.5*	*29.13*	*0.0003*
Ma	*0.18*	*1*	*0.18*	*0.45*	*0.5116*
PxV	*1.33*	*1*	*1.33*	*3.36*	*0.0965*
PxMa	*0.11*	*1*	*0.11*	*0.29*	*0.6105*
VxMa	*0.12*	*1*	*0.12*	*0.30*	*0.5950*
P^2	*0.081*	*1*	*0.081*	*0.20*	*0.6608*
V^2	*9.51*	*1*	*9.51*	*24.09*	*0.0006*
Ma^2	*0.040*	*1*	*0.040*	*0.10*	*0.75*
Residual	*4.25*	*10*	*0.43*		
Total	*36.77*	*19*			

Tab. 2. Analysis of variance (ANOVA) for quadratic model

The F-value is the ratio of the mean square due to regression to the mean square due to residual. The model F-value of 7.89 implies that the model is significant. The calculated F-value of the model should be greater than the tabulated value for a good model. F-value is compared to the tabulated value $F_{\alpha}(v_1, v_2)$, where v_1 represents the degree of freedom of the model and v_2 is the degree of freedom of the residual. In our case, for a reliance threshold of 0.01, we find $F_{0.01}(9.10) = 9.1$.Therefore the calculated F-value is greater than the tabulated value and the null hypothesis is rejected. Values of "Prob > F" less than 0.05 indicate that the model terms are significant.In this case: *P*(water pressure), *V*(feed rate), *PxV*, V^2 are significant model terms. The other terms with values of "Prob > F" more 0.05 are not significant.

6. REZULTS AND DISCUTION

The parameter which has the strongest influence on the process of etching is the feed rate *V*, by increasing feed rate the etching depth decrease.

The water pressure processing is another important parameter, by increasing water pressure the depth engraving increases.Abrasive flow is another parameter of the process, by increasing the flow of abrasive etching depth increases.

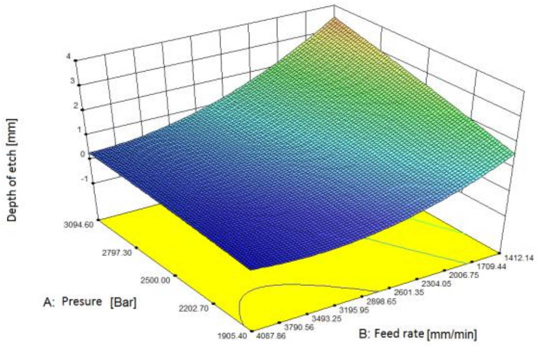

Fig. 3. Variation of depth of etch as a function of feed rate and water pressure using a abrasive rate 0.55 kg/min

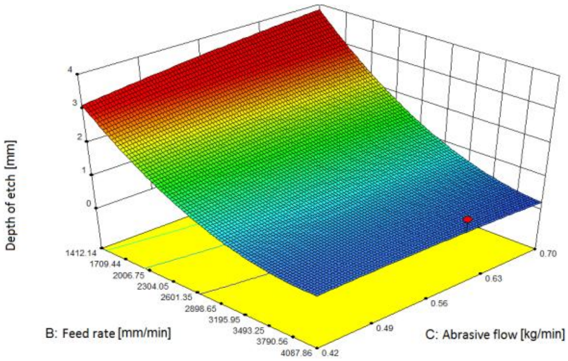

Fig. 4. Variation of deept of etch as a function of feed rate and abrasive flow using a water pressure 3094 Bar

For validating, the mathematical model was developed by processing part of Fig.3 as feed rate *V* was calculated for the depth of processing rates *h:* 0.5, 1 ,1.5 mm water pressure *P* 2100 Bar and abrasive flow rate 0.53 kg / min. The feed rate calculating using the proposal model was 2250, 1830 and 1200 mm/min. Maximum difference between depth processing and depth calculated with the proposed model was obtained almost 0.03 mm, 2.2%.

7. CONCLUSIONS

This paper proposes to use the AWJ technology for engraving and etching different parts.

A mathematical model is proposed, that can be used for prediction of the depth of etching as a function of the feed rate, water pressure and abrasive flow. The result of the ANOVA analysis shows that the "fit" of the model to the experimental data was significant at the 98% confidence level.

The proposed mathematical model is considered to be suitable for industrial applications.

8. REFERENCES

Farhad K, Hamid K, (2009) *Modeling and Optimization of Abrasive Waterjet Parameters using Regression Analysis,* World Academy of Science, Engineering and Technology

Lazarescu L, (2008). *FEM- Simulation and response surface methodology for analysis and prediction of cross section distortion in tube bending processes* International Conference, Debrecen, Hungary

Nuran Bradley. (2007). *The response surface metodology,* Indiana University South Bend

Susuzlu T, Hoogstrate A, (2007) *Initial research on the ultra-high pressure waterjet up to 700MPa,* Journal of Materials Processing Technology 149 (2004) 30–3

Shanmugam D, Masood H, (2007). *An investigation of characteristics in abrasive waterjet cutting of layered composites,* Jurnal of materials processing technology 2008