CONTENTS AUTHORS

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SOFTWARE SOLUTION FOR ABRASIVE WATER JET MILLING PROCESS

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ABSTRACT
Abrasive Water Jet technology (AWJ) has some advantages as compared to other technologies, such as: no thermal distortion, high machining versatility and high flexibility. AWJ has proved to be an efficient technology for milling various engineering materials. The paper presents a mathematical model of the depth of milling and a software solution for calculating this depth. The software solution was tested afterwards through experimental research. The theoretical estimations proved to be in a good correlation with the experimental data.
Keywords: water jet, milling, software solution

1. INTRODUCTION
Abrasive Water Jet (AWJ) has various distinct advantages over the other 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).
Abrasive Water Jet (AWJ) technology is used in a routine manner in manufacturing industry to cut materials that are difficult to cut by other methods. AWJ technology is in a continuous development, using an abrasive jet, different parts can be milled (Susuzlu 2007). Milling parts using water jet cutting equipment can save time and money, eliminating an extra operation. Water jet milling is different from other classical milling techniques: process speed, 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.
To calculate the optimal value of process parameters has developed an original application software, named CAPAJETA. This software is used to calculate the feed rate for water jet cutting process a mathematical model enshrined in literature and in the calculation of feed rate for water jet milling process used the mathematical models described in this paper.
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2. ABRASIVE WATER JET MILLING PROCESS
The principle of the water jet milling process is to move the abrasive jet at a high speed so the abrasive jet does not pierce the full material thickness. When a part is processed we follow a 2D sketch with the abrasive jet, resulting a kerf equal to the abrasive jet. To mill 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.

Variab	Units	level				
P	Bar	1500	1905	2500	3094	3500
V	mm/min	500	1412	2750	4087	5000
Ma	Kg/min	0.32	0.4	0.53	0.6	0.8

Table 1. Experimental design

Figure 1. Experimental trails

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 type 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 80 mesh (180 µm on average) were selected.

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

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.

Mathematical model 4 shows the dependence of the depth of processing on the relative bending water pressure, feed rate and abrasive mass flow.

$$h(P,V,Ma) = c_1 + c_2 \cdot P + c_3 \cdot V + c_4 \cdot Ma + c_5 \cdot P \cdot V + \\ + c_6 \cdot P \cdot Ma + c_7 \cdot V \cdot Ma + c_8 \cdot P^2 + c_9 \cdot V^2 + c_{10} \cdot Ma^2 \qquad (4)$$

Where: h is the predicted response in real value, V is the feed rate, Ma is the abrasive flow, P is water pressure and c_{1-10} are the coefficients of the equation.
The coefficients of the equation were obtained by the multiple regression analysis of the experimental data, and are presented in table 2.

Table 2. The coefficients of the equation for Stainless Steel RVS 304

Coeficient	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}
Valoare	-1.928	2.558 xE-003	-1.447 xE-003	4.443	-4.981 xE-007	8.037 xE-004	-1.04 xE-003	-1.357 xE-007	4.309 xE-007	-2.711

The result of the ANOVA analysis shows that the "fit" of the model to the experimental data was significant at the 98% confidence level.

6. RESULTS AND DISCUTIONS

The parameter which has the strongest influence on the water jet milling process is the feed rate V, by increasing the feed rate the milling depth decreases.
The water pressure is another important parameter, by increasing water pressure the depth milling increases. Abrasive flow is another parameter of the process, by increasing the flow of abrasive milling the depth increases.

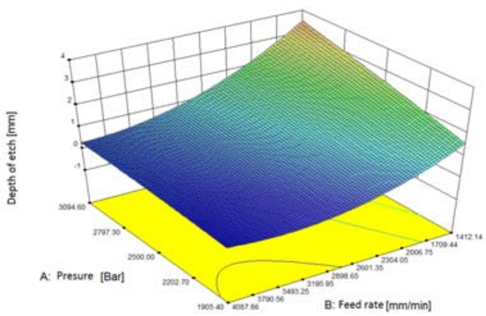

Figure 2. Variation of depth of mill as a function of feed rate and water pressure using a abrasive rate 0.55 kg/min

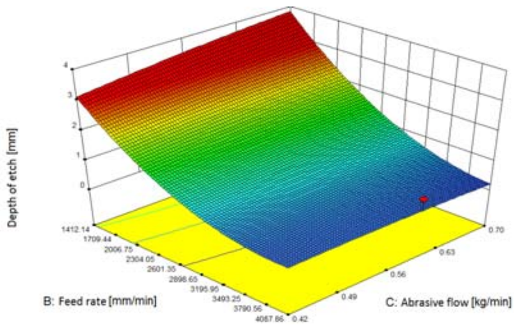

Figure 3. Variation of depth of mill as a function of feed rate and abrasive flow using a water pressure 3094 Bar

7. SOFTWARE SOLUTION

To calculate the optimal value of process parameters an original application software has been developed, named CAPAJETA. This software is used to calculate the feed rate for water jet cutting process a mathematical model enshrined in literature and in the calculation of feed rate for water jet milling process used the mathematical models described above.
Using the C programming language was developed this software application, CAPAJETA, whose interface is shown in figure 4.
For validating, this software was developed by processing three parts 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 (1.5 mm) with the proposed model was obtained almost 0.12 mm, 8.2%.
Therefore it may be that there is good agreement between results calculated using the program CAPAJETA and experimental results. Also, this program can be easily expanded for both a wider range of materials and a larger number of parameters.
This program can be used to provide the optimal parameters of the process, successful in industrial environments.

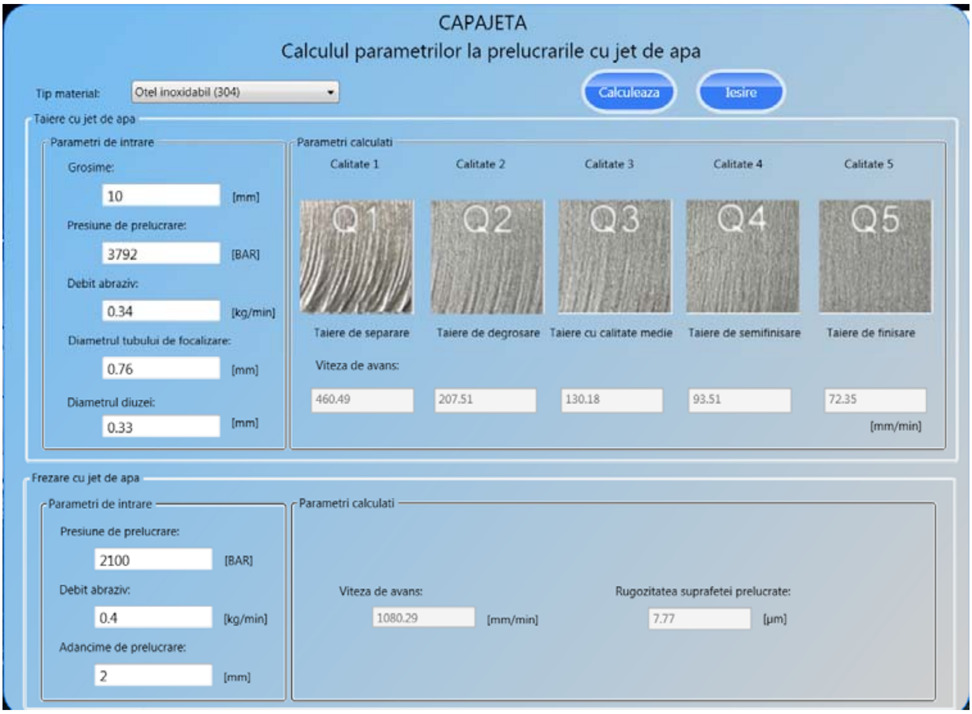

Figure 4. The interface of CAPAJETA software developed UTCN

8. CONCLUSIONS

This paper proposes to use the AWJ technology for milling different parts.

A mathematical model is proposed, that can be used for prediction of the depth of milling 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.

To calculate the optimal value of process parameters has developed an original application software, named CAPAJETA. This software is used to calculate the feed rate for water jet cutting process a mathematical model enshrined in literature and in the calculation of feed rate for water jet milling process used the mathematical models described above.

Therefore it may be that there is good agreement between results calculated using the program CAPAJETA and experimental results. Also, this program can be easily expanded for both a wider range of materials and a larger number of parameters.

The proposed software is considered to be suitable for industrial applications.

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