OPTIMIZING ABRASIVE WATERJET CUTTING FOR SPECIAL MATERIALS.
CASE STUDY: CUTTING AUSTENITIC STAINLESS STEELS

Ion - Aurel PERIANU, Aurel-Valentin BÎRDEANU, Ion MITELEA

a Mechanical Engineering Faculty, „Politehnica” University of Timisoara, Mihai Viteazul no.1, 300222, Timisoara, Romania
b National R&D Institute for Welding and Material Testing – ISIM, Bv. Mihai Viteazul no.30, 300222 Timisoara, Romania

perianu.ion.aurel@gmail.com; valentin@isim.ro; ion.mitelea@mec.upt.ro

Abstract

Present day preoccupations regarding abrasive waterjet cutting of hard to process materials focuses on obtaining specific technologic data for different material thicknesses and on activities regarding the optimization of the cutting process with technical and economic aspects. This paper presents an optimization method for abrasive waterjet cutting process of austenitic stainless steel based on using factorial experiments. The main influence factors are: cutting speed, water jet pressure, abrasive flow rate and the distance between the focusing tube and the surface of the material to be cut. The objective functions monitored refers to the depth of penetration, geometry and quality of cuts. Carrying out the preliminary experiment allowed the exploration of a large technologic domain depending on the allocated levels for the influence factors having as results different geometries and quality for cuts. The tests carried out with optimum working parameters have consisted as the central point of the whole factorial experiment which led to obtaining an experimental model for the objective function determined by the influence factors analyzed. The highest effects for the objective functions analyzed are given by the cutting speed, water jet pressure and the interaction between the two. The instruments used for the factorial experiment can be applied also to other materials in order to further optimize abrasive waterjet cutting technologies.

Keywords: waterjet cutting, factorial experiment method, optimization

1. INTRODUCTION

Stainless steels with austenitic microstructure due to high ductility and toughness characteristics, are known as materials which are difficult / hard to cut by machining or processes alike [1,2].

The present paper presents the results obtained from abrasive waterjet processing of stainless steel materials EN 1.4306 (ASTM 304L; JIS SUS 304L). The main purpose was, that by carrying out a full factorial experiment, using various experimentally tested technological regimes and values identified by scientific literature [3,4], to determine the process parameters influence onto the processed surfaces quality, the kerf geometry and to determine pairs of parameters that would ensure an optimal quality along with high productivity for practical applications.

The main criteria taken into consideration for evaluating processed surfaces targeted the quality of the process surface and the process productivity. The methodology used for optimizing the process parameters was based on the factorial experiments method [2,5,6] and had technical and economic consideration.

An analysis of abrasive waterjet processing on stainless steel parts was made considering the material processed and its thickness, which was 20 mm. The chemical composition of the material tested experimentally was as follows: 0.06%C; 19.19%Cr; 8.29%Ni; 1.75%Mn; 0.63%Si; 0.028%P; 0.024%S; 0.08%Mo, the rest being Fe.
Evaluation of processed surfaces was done taking into account the influence onto the quality of cutting surfaces and their geometry.

2. EXPERIMENTAL CONDITIONS

The workstation used for accomplishing the experimental program is presented in figure 1 and consists of the following elements:

1 – device for moving the cutting head on the Oz axis
2 – adjustable abrasive feeder: 50 – 600 g/min
3 – abrasive waterjet cutting head
4 – longitudinal displacement system
5 – transversal displacement system
6 – abrasive tank
7 – cantilever system (transversal girder)
8 – cutting grill
9 – cutting reservoir fitted with waterjet damping system and scrapers for removing used abrasive and waste debris.

The abrasive material used for processing was type GMA 80 Mesh (abrasive particles size ranged between 150 and 300 µm, with a density of 2300 kg/m³).

The base material used for the cutting operations was a EN 1.4306 stainless steel plate with 20 mm in thickness.

In order to design the experimental trials of the abrasive waterjet cutting process of austenitic stainless steel, the following process parameters were selected as influence factors (IF):
- \( x_1 \) = water pressure;
- \( x_2 \) = abrasive flow;
- \( x_3 \) = cutting speed;
- \( x_4 \) = nozzle standoff.

As for objective functions (OF) characteristics were chosen for the cut geometry (kerf size at surface, kerf size at the bottom of the cut, processed surface roughness) and also the processing productivity. Kerf size at the surface of material was noted with \( Y_1 \), kerf size at the bottom of material was noted with \( Y_2 \), average roughness (Ra) of the cut was noted with \( Y_3 \) and \( Y_4 \) for productivity respectively.

Table 1 presents the program matrix for the full factorial experiment FFE \( 2^4 \times 3 \) for the stainless steel material EN 1.4306.

The kerf sizes were measured using an optical laboratory microscope, Carl Zeiss.

Because the roughness values present a high variation for the cut surfaces the roughness measurements were taken in the superior area of the cut, in the middle area and respectively for the inferior area of the cut.

On the other hand, taking into consideration the fact that usually for all the existing quality classes of abrasive waterjet cutting of thick metallic materials, relatively high values for roughness at the inferior side of
the kerf are accepted, it was chosen as an objective function (OF) the average roughness (Ra) in the median zone of the kerf. The productivity was calculated as the volume of material processed in the time unit. The roughness values were measured using a roughness measuring device type Mitutoyo SJ – 201 P. The experimental design and the processing of the measured and calculated data was done by using specialized software for statistical modelling – STATGRAPHICS.

Table 1 Program matrix for the full factorial experiment FFE $2^3+3$ – stainless steel

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The surface aspect for EN 1.4306 stainless steel part is presented in figure 2 after the experimental trials displayed in table 1 were carried out.

Fig. 2 Surface aspect of the material used for the experimental program
Three additional trials were done (in the central point of the experimental domain) respectively cuts 17 – 19, in order to increase the precision of the statistical experimental modelling. The acquired data did also permit to check the repeatability of the trials with results that did demonstrate the fact that productivity and cut quality was maintained for the three trials. One observation could be made regarding the bottom side of kerf 17 which was sandblasted due to interactions between the abrasive waterjet recoil and the bottom side of the material that overlapped with the cutting direction and supporting cutting grill element. The sandblasted area of cut 17 and also the rest of the bottom side of the material cut may be observed in figure 3.

3. RESULTS AND DISCUSSION

The processing results obtained permitted significant information to be gathered regarding the IF and their interactions importance against the studied OF, i.e. the graphical representations from figures 4 ÷ 12 for the: surface width (kerf) (Ls), base width (Lb), productivity and average roughness (Ra) in the median area of the kerf.

3.1. Surface width (Ls)

From the Pareto diagram for Ls it may be observed the fact that for the investigated experimental domain, the factors with high influence over the value of Ls are: nozzle standoff, abrasive flow and cutting speed. Also there are no important interactions between the factors and the water pressure has an insignificant influence over the value of Ls. Thus in order to obtain a minimum value for the kerf it is necessary that the values referring to abrasive flow and nozzle standoff parameters to be set at low values and the cutting speed should be set on the highest value according to the application at hand.
The experimental work and the consequent processing of the obtained data did allow obtaining the experimental mathematical model presented in (1) which was verified by subsequent trials in the experimental domain and by comparing the projected values with the measured ones.

\[ L_s = 0.785279 - 0.001015 \cdot TS + 0.00033 \cdot AF - 0.000001875 \cdot WP + 0.10325 \cdot NS \]  

(1)

Where:  
- \( L_s \) = surface width  
- \( TS \) = travel speed (cutting speed)  
- \( AF \) = abrasive flow  
- \( WP \) = water pressure  
- \( NS \) = nozzle standoff

3.2. Kerf size on the lower side (\( L_b \))

From the Pareto diagram for \( L_b \), presented in figure 7, one can observe the following that there are strong interactions between the studied IF while first degree level of influence has low impact onto the \( L_b \) variation in the investigated experimental domain. This could be related to an existing local extreme for the \( L_b \) variation, according to the 3-D Estimated Response Surface (ERS) presented in figure 8 and hence a lack of linear variation of \( L_b \) in the investigated experimental domain. Nevertheless, the obtained data, could be used to determine pairs of IF values in order to obtain a required \( L_b \) value and hence to minimize the parallelism displacement.
3.3. **Productivity**

From the Pareto diagram for productivity, presented in figure 9, one can observe the main influence over its calculated values is due to the travel speed and that there are no important interactions between the studied IF. Since the productivity was approximated by means of using Ls and Lb values, this fact could be explained by rather small variations of Ls and Lb respectively, in the investigated domain, and the influence of the travel speed values against Ls. Consequently, in order to obtain high productivity in the investigated experimental domain high travel speeds can be used, as shown in figure 10.

3.4. **Average roughness (Ra)**

From the Pareto diagram for Ra in the medium zone of the cutting kerf, one can observe the main influence over the measured values is due to the travel speed, abrasive flow and that there is a relatively low interaction between the two IF. The direction of the influence, for the investigated experimental domain, of the two IF could be correlated with other experimental data regarding abrasive waterjet cutting of metallic materials: the increased travel speed leads to higher values of Ra and that higher abrasive flows lead to lower Ra respectively. The Ra variation showed a good linear variation in the experimental domain and consequently an experimental model for its variation was determined and verified by subsequent experimental trials. Furthermore, the determined ERS’s could be used to determine pairs of process parameters values for a required Ra of the kerf surfaces.

4. **CONCLUSIONS**

The methodology employed based on using factorial experiments allows the optimization of abrasive waterjet cutting process of EN 1.4306 stainless steel, with a basis in response surface representations obtained from which necessary data may be extracted for cutting regimes usable in industrial applications.
Combinations between the levels of influence factors used for analysis determine significant modification of performances obtained for objective functions that characterize the geometry and quality of cuts. Factorial experiments method used in this paper may be used also for optimizing abrasive waterjet cutting of other materials regardless of their type and nature.

For the specific case presented (EN 1.4306 stainless steel, 20 mm thick) the following may be specified:
- for all cuts, regardless of the technological combination of parameters used for carrying out the tests the width of surface kerfs was higher than the width in the central of the kerfs which also in their turn had higher values than the width of bottom kerfs;
- nozzle standoff has influence over the width at the surface of the material;
- for Lb the investigated experimental domain included a local extreme and thus high interactions between the studied influence factors (IF);
- overall, the best quality was achieved for cut no. 7 which represents a technological combination between high water pressure, high abrasive flow rate, slow cutting speed and a nozzle standoff of 1 mm;
- the data and experimental variation models obtained can be used for determining pairs of parameters which will ensure a simultaneous optimization of more OF according to specific industrial requirements.

ACKNOWLEDGEMENTS:

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LITERATURE

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