Examination of average surface roughness in waterjet cutting

R. Horváth[1], Á. Drégelyi-Kiss[1], J. Lukács[1]

[1] Institute of Materials and Manufacturing Sciences, Óbuda University, Donát Bánki Faculty of Mechanical and Safety Engineering, Népszinház str. 8., Budapest, 1081 Hungary

Abstract. Waterjet cutting is a non-conventional cutting technology. Important criteria of the cut surface are geometric accuracy and surface roughness. The aim of this paper is to provide predictive models to estimate average surface roughness (*Ra*), taking into account significant effects. Full factorial design of experiments were used in the waterjet cutting tests. The input parameters were plate thickness (mm), grain mass (g/min), and feed rate (mm/min). The quality of the waterjet cut surface depends on the thickness of the cut plate to a great extent (due to the bending of the waterjet or the pressure decrease, etc.), therefore surface roughness was measured in three places along the thickness of the plate and so three predictive models were constructed.

Keywords: waterjet cutting; average surface roughness; design of experiment; phenomenological model

1 Introduction

In the last decade non-conventional cutting technologies have spread considerably. Waterjet cutting is a cold cutting technology where water and abrasive grains mixed together can cut complicated contours. Waterjet cutting requires a high metal removal rate, which is provided by high pressure water flowing through a thin nozzle at high speed. The great advantage of waterjet cutting is that it does not use or produce substances dangerous for the environment. It is also important that waterjet cutting does not change the properties of cut surface (especially for metals) because there is no heat involved.

Jegaraj and Babu [1] invesigated abrasive waterjet (AWJ) cutting technology. Their paper reported the experimental studies carried out to investigate the influence of orifice and focusing tube bore variation on the performance of abrasive waterjets in cutting 6063-T6 aluminum alloy. The performance was assessed in terms of different parameters such as depth of cut, kerf width and surface roughness. The study made use of Taguchi's design of experiments and analysis of variance (ANOVA) to analyze the performance of AWJs in cutting. Their experimental data was used to build empirical models. They found that surface roughness is greatly influenced by focusing tube size, traverse rate and waterjet pressure.

Valíček et al [2] studied the system of cutting tool, material and final surface topography and optimization of their parameters under waterjet technolgy.

Srinivasu and Babu [3] developed an artificial neural network (ANN) based model for the prediction of depth of cut which uses the diameter of focusing nozzle along with the controllable process parameters such as water pressure, abrasive flow rate and jet traverse rate.

The work of Patel and Tandon [4] explored a thermally enhanced abrasive water jet machining (TEAWJM) process to improve the machining capabilities of a conventional abrasive water jet machine by heating the work by an external heat source. The experimental data of cutting parameters at critical temperatures of hard-to-machine metals Inconel 718, Titanium (Ti6Al4V) and mild Steel (MS-A36) (ductile in nature) with full factorial design of experiments (DOE) was presented.

Some results of aluminium alloy abrasive waterjet cutting experiments for the investigation of cutting kerf geometry were summarized by Maros [5].

The accuracy of abrasive waterjet cutting mainly depends on the form of cutting gap. It is very difficult to keep in hand the taper of the gap and produce almost parallel cut surfaces. There are a lot of parameters having an effect on the gap. Some results of research related to the taper of the cutting kerf carried out on Ti6Al4V alloy are explained by Maros [6].

In this article the surface roughness of waterjet cut surfaces were investigated in the case of a steel workpiece. For the waterjet cutting tets a full factorial design of experiment (DOE) was used. The main goal was to construct an empirical model in which the average surface roughness (*Ra*) can be easily estimated in the entire length of cutting.

2 Materials and methods

The waterjet machine used was a Byjet 4022 having a 4020 × 2010 mm workspace and the water pressure was 4000 bar. The abrasive grains used were so-called Supreme Garnet sand, the grain size was 0.125 – 0.40 mm and grain hardness was 7.0 – 7.5 Mohs. The workpiece material in the cutting experiments was S355 steel.

The average surface roughness (*Ra*) was measured with a Surftest SJ301 (Mitutoyo) surface roughnes tester. A full factorial design of experiments (3^3) was used for the cutting tests in which there were three independent input parameters: thicnkess of plate, mm; volume of grains, g/min; and feed rate, mm/min.

The aim of the investigation is to construct an empirical modell with which the avereage surface roughness (*Ra*) can be easlily estimated. The model is of the following form:

$$Y = e^{c_0 + c_1 \cdot X_1 + c_2 \cdot X_2 + c_3 \cdot X_3} \qquad (1)$$

where Y is the response function; X_1, X_2, X_3 are the input parameters; c_0, c_1, c_2, c_3 are empirical constants.

2.1 The determination of experimental runs

From the full factorial design of experiments (3^3) come the 27 experimental runs (Table 1). The values of the three independent input parameters are the following:

thickness of the plate: 15–25–35 mm; the volume of grains: 300–350–400 g/min; feed rate: minimum value, middle value, maximum value. (The values of feed rate depend on the thickness of the plate.)

Table 1. The experimental runs

Experimental run	Thickness, t, mm	Grain volume, g, g/min	Feed rate	Feed rate, v_f, mm/min
1	15	300	minimum value	50
2	15	300	middle value	75
3	15	300	maximum value	100
4	15	350	minimum value	50
5	15	350	middle value	75
6	15	350	maximum value	100
7	15	400	minimum value	50
8	15	400	middle value	75
9	15	400	maximum value	100
10	25	300	minimum value	22
11	25	300	middle value	33
12	25	300	maximum value	44
13	25	350	minimum value	22
14	25	350	middle value	33

Experimental run	**Thickness, *t*, mm**	**Grain volume, *g*, g/min**	**Feed rate**	**Feed rate, v_f, mm/min**
15	25	350	maximum value	44
16	25	400	minimum value	22
17	25	400	middle value	33
18	25	400	maximum value	45
19	35	300	minimum value	13
20	35	300	middle value	19
21	35	300	maximum value	25
22	35	350	minimum value	13
23	35	350	middle value	19
24	35	350	maximum value	25
25	35	400	minimum value	13
26	35	400	middle value	19
27	35	400	maximum value	25

3 Results

Surface roughness greatly depends on the depth of cut therefore the average sufrace roughness parameter (*Ra*) was measured in three places (entry place – 1, middle place – 2 and exit place – 3). The measured places are shown in Fig. 1. Each measurement of surface roughness was carried out twice.

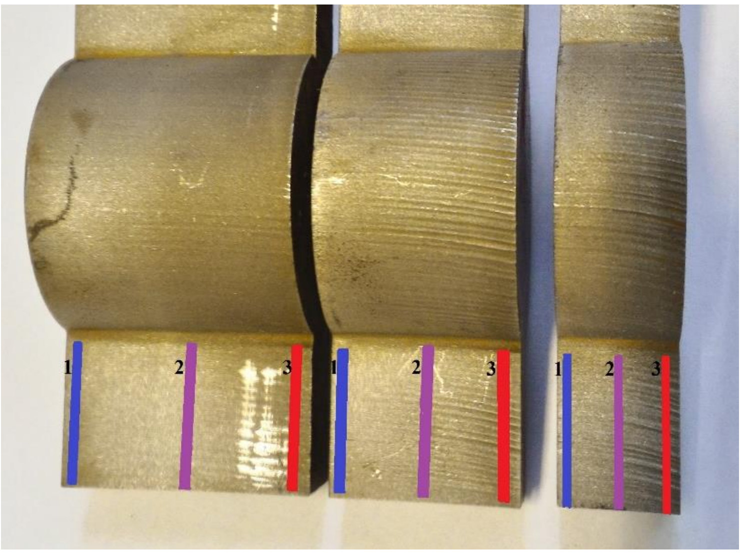

Fig. 1. The places of surface roughness measurement

3.1 The construction of an Empirical model to caculate average surface roughness (*Ra*)

The predictive model to estimate the average surface roughness (based on eq. 1) is the following:

$$Ra = e^{c_0 + 0.019t - 0.0028g + 0.012v_f} \qquad (2)$$

where t is the thickness of the plate, mm; g is the volume of grains, g/min; v_f is the feed rate, mm/min, and c_0 is the constant which depends on the measurement location.

The values of c_0 are as follows (based on Fig. 1):

1. measurement location: 1.491; 2. measurement location: 1.813; 3. measurement location: 2.421.

The graphical representation of eq. (2) is shown in Fig. 2.

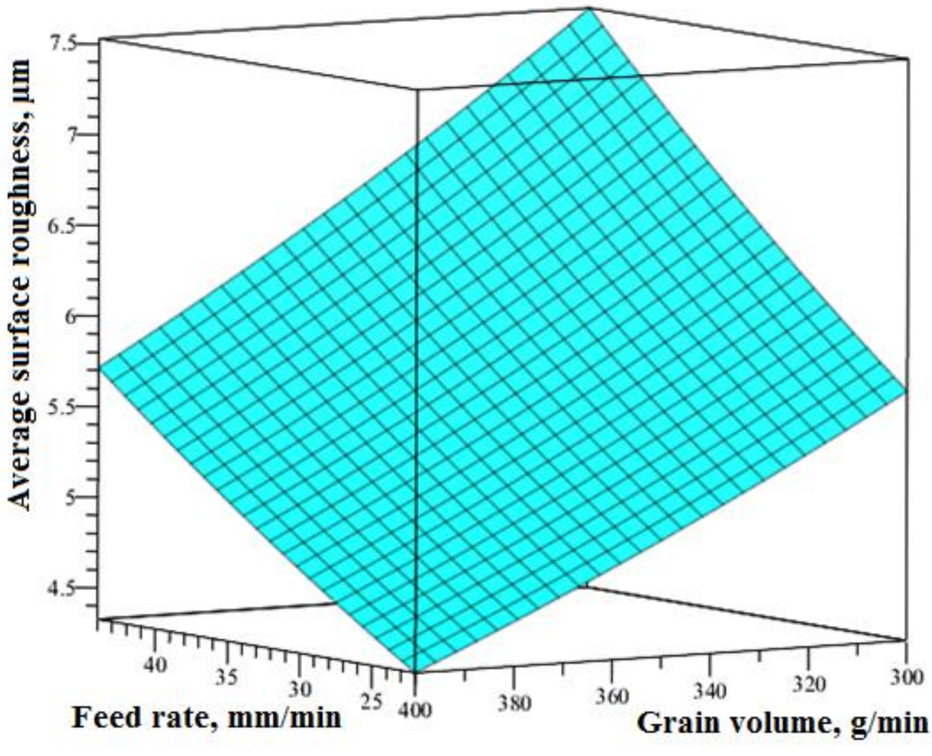

Fig. 2. The values of average surface roughness plotted against the feed rate and grain volume in measurement location 2 (the middle; t = 25 mm)

3.2 The investigation of residuals

Fig. 3 shows the difference of the measured and calculated values of average surface roughness on histograms. The histograms show that the accuracy of the empirical model slightly degrades as a function of depth of cut.

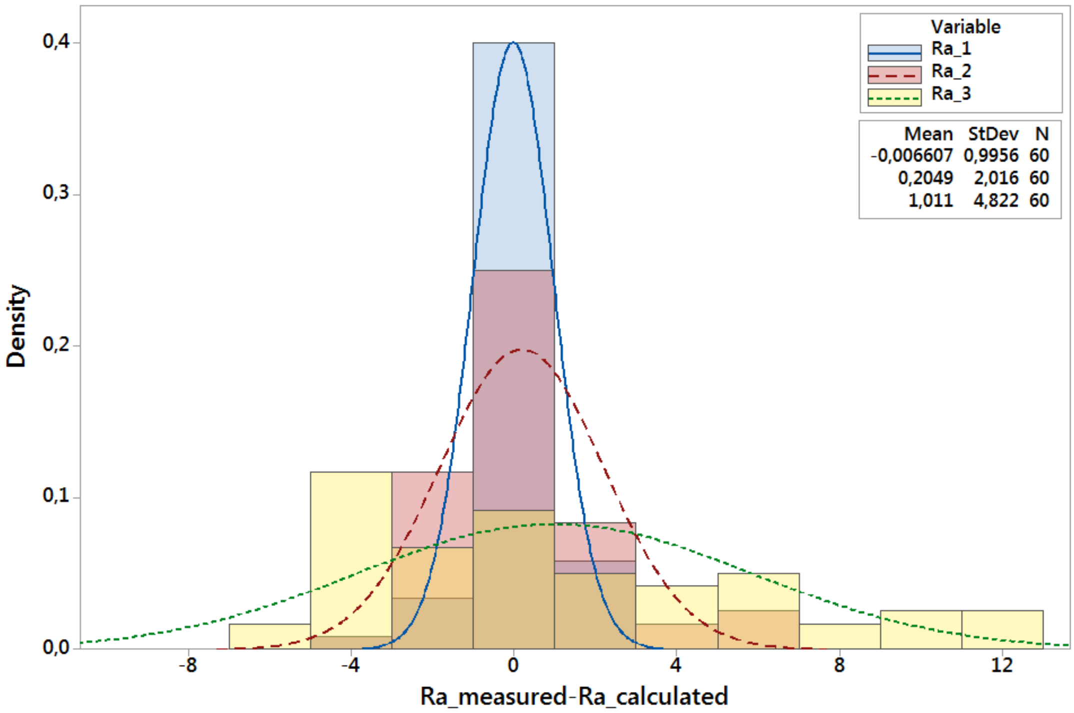

Fig. 3. The error of eq. (2) shown on histograms (in each measurement location)

4 Conclusions

In this article the surface roughness attainable with waterjet cutting was examined. A full factorial Design of Experiments was used and an empirical model was constructed to estimate average surface roughness. Our investigations have shown that:

- Our model predicts average surface roughness at the desired accuracy.
- The accuracy of the model slightly degrades as a function of depth of cut.
- The errors of the model follow normal distribution.

Acknowledgement

SUPPORTED BY THE ÚNKP-16-4/I. NEW NATIONAL EXCELLENCE PROGRAM OF THE MINISTRY OF HUMAN CAPACITIES

References

[1] Jegaraj, J. J. R., Babu, N. R.: A soft computing approach for controlling the quality of cut with abrasive waterjet cutting system experiencing orifice and focusing tube wear, *Journal of Materials Processing Technology* 185, 217-227, 2007

[2] Valíček, J., Harničárová, M., Kušnerová, M., Grznárik, R., Zavadil, J.: *Proposition of a Solution for the Setting of the Abrasive Waterjet Cutting Technology*, Measurement Science Review, 13, No. 5, , 279-285, 2013

[3] Srinivasu, D. S., Babu, N. R.: A neuro-genetic approach for selection of process parameters in abrasive waterjet cutting considering variation in diameter of focusing nozzle, *Applied Soft Computing*, 8, 809-819, 2008

[4] Patel, D., Tandon, P.: Experimental investigations of thermally enhanced abrasive water jet machining of hard-to-machine metals, *CIRP Journal of Manufacturing Science and Technology*, 10, 92-101, 2015

[5] Maros, Zs.: Taper of cut at abrasive waterjet cutting of an aluminium alloy, *Journal of Production Processes and Systems*, 6, 55-60, 2012

[6] Maros, Zs.: Energy approach of the taper at abrasive waterjet cutting, *Production Processes and Systems*, 6, 89-96, 2013