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REGRESSION ANALYSIS OF THE SURFACE ROUGHNESS IN ABRASIVE WATER JET CUTTING

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ABSTRACT
The abrasive water jet (AWJ) cutting technique is one of the most rapidly improving technological methods of cutting materials. In this paper a mathematical model for analysis and prediction of surface roughness during AWJ cutting of aluminium plate is developed based on experimental observations. Dependent variable in the model is average surface roughness, while independent variables are depth of cut in cutting process, traverse speed and abrasive mass flow rate. To evaluate results, analysis of variance (ANOVA) method is performed. Obtained regression model results suggest that regression modelling can be useful tool for analysing surface roughness in abrasive water jet cutting process.
Keywords: abrasive water jet cutting, surface roughness, cutting parameters, regression analysis

1. INTRODUCTION
In abrasive water jet cutting, water is pumped to a very high pressure (typically up to 380 MPa) using intensifier technology and is allowed to expel through a sapphire nozzle of diameter 0.25–0.4 mm to form a water jet with high velocity. A thin, high velocity water jet accelerates abrasive particles that are directed through an abrasive water jet nozzle at the material to be cut. Advantages of abrasive water jet cutting include the ability to cut almost all materials, no thermal distortion, and high flexibility, small cutting forces and being environmentally friendly. The abrasive water jet has been investigated since the end of seventies of the twentieth century. Many researchers have been dealing with this topic and one of the first models and experiments in the branch was performed in [1]. The mechanism and rate of material removal during AWJ cutting depends both on the type of abrasive and on a range of process parameters. A great deal of research has been done to improve the cutting performance and enhance the cutting capacity of AWJ cutting technique, including studies of the mechanism of the AWJ cutting process and modeling of process control and optimization [2, 3]. The surface quality is one of the most specified customer requirements and the major indicator of surface quality on machined parts is surface roughness. The surface roughness is mainly result of various controllable or uncontrollable process parameters and it is harder to attain and track than physical dimensions are. A considerable number of studies have investigated effects of process parameters on the surface quality, and the fact that traverse speed has great effect on the surface roughness at the bottom of the cut [4] and with same traverse speed the sample surface roughness has small variablity at lower abrasive mass flow rate [5]. Thus, it is necessary to have a deeper knowledge about the

optimum operation conditions, which will assure a good surface roughness. For this reason, in the present study regression analysis including an analysis of variance (ANOVA) has been applied for prediction of surface roughness in abrasive water jet cutting of aluminum plates.

2. EXPERIMENTAL SETUP

The experiments are conducted on a NC 3015 EB abrasive water jet cutting system with a KMT Streamline ™ SL-V 50 ultra-high pressure pump capable of providing maximum water pressure of 413.7 MPa. Cutting is performed on aluminum plates of thicknesses 15 mm and 30 mm. The constant process parameters (orifice diameter, focusing tube diameter, water jet pressure, abrasive type and size) are shown in table 1.

Table 1. Constant parameters and their values.

Constant parameters	Orifice diameter	Focusing tube diameter	Water jet pressure	Abrasive type	Abrasive size (grit no)
Value	0.20 mm	0.762 mm	350 MPa	GMT garnet	80 mesh

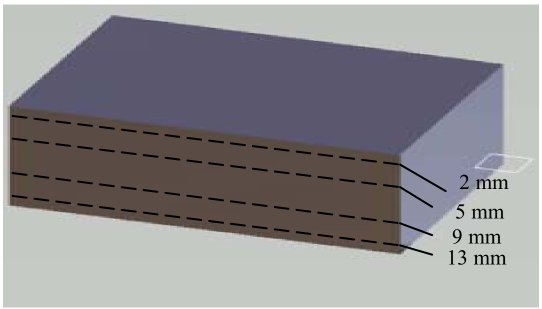
Two variable process parameters (traverse speed and abrasive mass flow rate) are selected for the present study, as shown in table 2.

Table 2. Variable parameters and their values.

Variable parameters	Traverse speed mm/min	Abrasive mass flow rate g/min
Material thickness 15 mm	77, 100, 139, 250, 350	100, 130, 200, 250, 320
Material thickness 30 mm	37, 49, 69, 109, 130	240, 285, 320, 350, 390

The observed parameter is the surface roughness. Sample surface roughness (with a cutoff of 0.8 mm) on the cut surface is measured in terms of the average roughness *Ra*, using the Surf-Test Mitutoyo stylus instrument; see Figure1. The measurement of surface roughness is performed in the Laboratory for Cutting Technologies-LaTOOS, Faculty of Mechanical Engineering in Sarajevo. Average surface roughness (*Ra*) measurements are made at different depth of the cut surface as shown in Figure 2.

Figure 1. The samples with linear cuts prepared for the measurement of surface roughness (left), and the measurement of surface roughness (right).



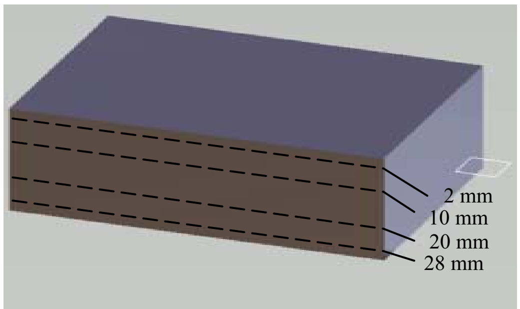


Figure 2. Schematic view of the cut where surface roughness is measured: the sample of 15 mm (left) and the sample of 30 mm thickness (right).

3. REGRESSION ANALYSIS AND DISCUSSIONS

Results of the measurements of the surface roughness (SR) for the abrasive mass flow rate AMFR=320 g/min and material thickness MT=15 mm are shown in table 3, while SR values for the AMFR=390 g/min and MT=30 mm are shown in table 4.

Table 3. SR for AMFR=320 g/min; MT=15 mm

Traverse speed	Depth of measurement			
[mm/min]	2 mm	5 mm	9 mm	13 mm
77	3,20	3,40	3,13	3,30
100	3,24	3,83	3,47	3,79
139	3,12	3,35	3,56	3,81
250	3,89	4,22	4,33	5,72
350	4,07	4,27	4,87	N/A

Table 4. SR for AMFR=390 g/min; MT=30 mm

Traverse speed	Depth of measurement			
[mm/min]	2 mm	10 mm	20 mm	28 mm
37	3,10	3,27	3,48	3,56
49	2,79	3,01	3,18	3,50
69	3,20	3,57	3,79	3,86
109	3,06	3,24	3,47	6,32
130	3,22	3,37	N/A	N/A

Results of the measurements of the surface roughness (SR) for traverse speed TS=77 mm/min and material thickness MT=15 mm are shown in table 5, while surface roughness (SR) values for the TS=37 mm/min and MT=30 mm are depicted in table 6.

Table 5. SR for TS=77 mm/min; MT=15 mm

AMFR	Depth of measurement			
(g/min)	2 mm	5 mm	9 mm	13 mm
100	4,20	4,64	4,50	5,80
130	4,46	4,44	4,59	6,10
200	3,72	3,80	3,98	4,56
250	3,62	4,10	3,85	3,92
320	3,66	3,96	4,08	3,89

Table 6. SR for TS=37 mm/min; MT=30 mm

AMFR	Depth of measurement			
(g/min)	2 mm	10 mm	20 mm	28 mm
240	3,51	3,55	3,59	3,78
285	3,45	3,50	3,30	3,63
320	3,15	3,05	2,95	3,11
350	2,73	2,95	3,10	3,20
390	2,56	2,78	2,99	3,10

Results outputs with respect to data given in table 3, table 4, table 5 and table 6 are depicted in table 7, table 8, table 9 and table 10 respectively.

Table 7. Results with respect to data given in Table 3.

	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	5,659	2,829	19,772	0,000	
Residual	16	2,290	0,143			
Total	18	7,948				
	Coefficients	*Stan. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2,425	0,248	9,795	0,000	1,900	2,949
TS	0,005	0,001	5,777	0,000	0,003	0,007
Depth	0,070	0,022	3,243	0,005	0,024	0,116

Table 8. Results with respect to data given in Table 4.

	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	4,463	2,231	6,413	0,010	
Residual	15	5,219	0,348			
Total	17	9,682				
	Coefficients	*Stan. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2,230	0,427	5,219	0,000	1,319	3,141
TS	0,008	0,004	1,890	0,078	-0,001	0,017
Depth	0,048	0,014	3,330	0,005	0,017	0,079

Table 9. Results with respect to data given in Table 5.

	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	5,183	2,591	14,938	0,000	
Residual	17	2,949	0,173			
Total	19	8,131				
	Coefficients	*Stan. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4,752	0,300	15,862	0,000	4,120	5,384
AMFR	-0,005	0,001	-4,309	0,000	-0,007	-0,003
Depth	0,076	0,022	3,363	0,004	0,028	0,123

Figure 3, figure 4, figure 5 and figure 6 present graphs of residuals versus predicted surface roughness. These graphs show no pattern and that constant error variance condition is satisfied for all values of explanatory variables, with emphasis on circled values shown at figure 3 and figure 4. These values are above three standard deviations from the corresponding mean value. Error terms approximately follow normal distribution with the mean value equals zero.

Table 10. Results with respect to data given in Table 6.

	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	1,743	0,872	43,541	0,000	
Residual	17	0,340	0,020			
Total	19	2,084				
	Coefficients	*Stan. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4,763	0,202	23,548	0,000	4,336	5,189
AMFR	-0,005	0,001	-8,822	0,000	-0,007	-0,004
Depth	0,010	0,003	3,042	0,007	0,003	0,017

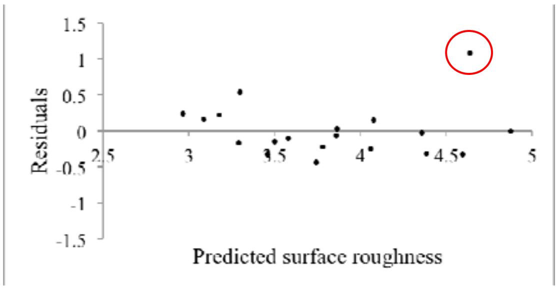


Figure 3. AMFR=320 g/min; MT=15 mm

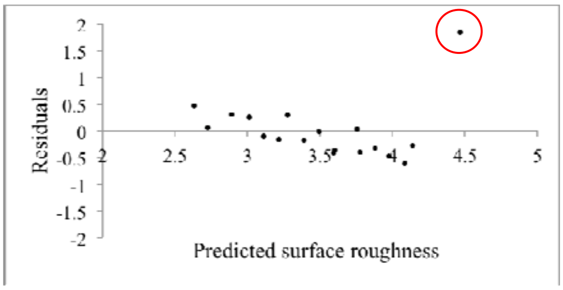


Figure 4. AMFR=390 g/min; MT=30 mm

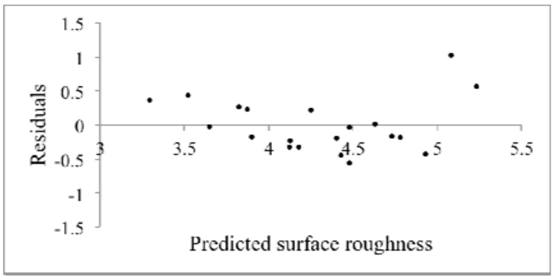


Figure 5. TS=77 mm/min; MT=15 mm

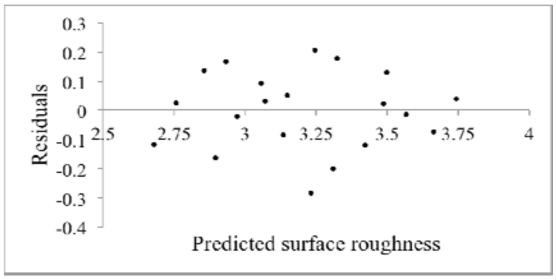


Figure 6. TS=37 mm/min; MT=30 mm

4. CONCLUSION

Surface roughness as results of experiments of cutting of aluminum plates of different thickness of 15 mm and 30 mm using abrasive water jet cutting process are presented. Multiple regression analysis appears to be acceptable approach to develop model to predict surface roughness as independent variable with respect to depth of cut in cutting process, traverse speed and abrasive mass flow rate as independent variables. Future work might include testing of cutting of plates made from different materials as well as influence of other cutting parameters on performances of the cutting process.

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