JOURNAL OF SCIENCE
SAKARYA UNIVERSITY

Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University |

http://www.saujs.sakarya.edu.tr/

Title: A Modeling Study on Surface Roughness of Spinneret Mold Sections Machined By WEDM

Authors: Erdoğan Kanca, Volkan Cem Taşkın, Ali Günen

Recieved: 2018-05-30 00:37:31

Revised: 2018-10-11 12:50:50

Accepted: 2018-10-23 09:27:12

Article Type: Research Article

Volume: 23

Issue: 1

Month: February

Year: 2019

Pages: 85-93

How to cite
Erdoğan Kanca, Volkan Cem Taşkın, Ali Günen; (2019), A Modeling Study on Surface Roughness of Spinneret Mold Sections Machined By WEDM. Sakarya University Journal of Science, 23(1), 85-93, DOI: 10.16984/saufenbilder.428457
Access link
http://www.saujs.sakarya.edu.tr/issue/38708/428457

Sakarya University Journal of Science 23(1), 85-93, 2019

A Modeling Study on Surface Roughness of Spinneret Mold Sections Machined By WEDM

Erdoğan Kanca[*1] Volkan C. Taşkın[1], Ali Günen[2]

ABSTRACT

The Wire Electrical Discharge Machining (Wire EDM) is widely used in the cutting of Bulk Continuous Filament (BCF) spinneret molds. Because of the low surface roughness of the spinneret molds obtained by the Wire EDM method, it ensures that the polypropylene material has a steady flow, volume and cross-sectional shape. Since the yarn extruded from the sections on the BCF acquire a number of physical and visual properties surface roughness of these molds have a great of importance. In this context, a new model was developed to predict the surface quality of spinneret mold sections, AISI 431 martensitic stainless steel, machined using Wire EDM by Analysis of variance (ANOVA). Machining parameters such as voltage, current, pulse time and wire feed rate were used as independent input variables and surface roughness was used as dependent output parameters. Contribution of input variables into the output variable determined by means of analysis of variance. Developed mathematical model estimations have been found to be in good agreement with the measured ones. The parameters with the most effect on surface roughness are listed as voltage, current, pulse, and feed, respectively. It is predicted that the steel used in spinneret mold can be machined more economically and practically by using the empirical formula obtained from this study.

Keywords: Wire EDM, Surface Quality, ANOVA

1. INTRODUCTION

BCF (Bulk Continuous Filament) yarns are manufactured by means of extruding polymer through spinneret molds. Stability of yarn flow and yarn quality are determined directly by surface quality of spinneret mold sections. Holes with different sections are machined on spinnerets by means of wire electrical discharge machining (Wire EDM).

Wire EDM is based on electric discharges between wire electrode and workpiece body so that it is a non-contact machining process. Consequently material removal is not dependent upon material hardness [1]. Wire EDM is the best choice for most of the machining operations because of its ability to produce intricate shapes with good dimensional accuracy and surface roughness.

Performance measures of Wire EDM processes are classified as material removal rate, dimensional accuracy and surface quality. Analytical and statistical methods are used to determine useful parameters for optimal machining performances [2].

[*] Corresponding Author

[1] Iskenderun Technical University/Mechanical Engineering Department, Hatay, Turkey
[2] Iskenderun Technical University/ Metallurgy and Materials Engineering Department, Hatay, Turkey

Discharge current, pulse duration and pulse frequency are found to be Most affecting factors material removal rate by Scott et al. on the other hand they found that wire speed, wire tension and dielectric flow rate have least effect on MRR [3]. An approach for determining parameters setting based on Taguchi design method and ANOVA proposed by Liao et al. it is conclude that MRR is influenced easily by feed rate and pulse on time [4]. Similar results have been reported by Rozenek et al and Huang and Liao [5], [6]. Hsue et al presented a systematic analysis for MRR in corner cutting by Wire EDM and they formulated the MRR of geometrical cutting [7].

Lots of research tried to improve dimensional accuracy of Wire EDM by using different approaches. Firouzabadi et al. have investigated errors of small radius convex and concave successive cutting (two roughing and one finishing). They have found that roughing is the most influential stage of Wire EDM cutting and in can be better by optimization of process parameters [8]. Sanchez et al. also concluded that errors produced by previous cuts must be considered during optimization of corner radius [9]. Chen et al. have achieved to reduce corner radius error 50% by optimization of control factors [10].

Surface roughness is a very important performance parameter for Wire EDM as well as other machining processes. Durairaj et al. have used multi

objective optimization technique grey relational theory to get optimum values of gap voltage, wire feed, pulse on time and, pulse off time for machining of Stainless Steel (SS304) to get minimum surface roughness and the results have been validated with experimental results [11]. In another study, Pulse-on time, pulse-off time, peak current, spark gap voltage, wire feed rate, and wire tension have been selected as input variables of optimization of surface roughness of Inconel 718. Mathematical models have been developed by using surface response methodology and surface roughness was predicted with error less than 5% [12]. As a result of a study on Wire EDM of titanium alloy pulse off time has been determined as the most significant parameter on material removal rate, surface roughness and kerf with [13].

There are a vast amount of papers on effects of cutting parameters of Wire EDM on dimensional accuracy and surface quality. But, a little of them about Wire EDM machining of martensitic stainless steel, which is material of spinnerets. In this study effects of Wire EDM cutting parameters (voltage, current, pulse time and wire feed rate) on surface roughness of spinneret material, which is 1.4057 stainless steel, will be studied.

2. MATERIALS AND METHOD

2.1. Experimental

Because of high pressure and high temperature conditions, DIN X17CrNi16-2 (1.4057) martensitic stainless steel (AISI 431) is used for spinneret mold applications. Blocks with 35x10x5 mm dimensions made from AISI 431 was prepared for Wire EDM cutting operations. Required and chemical composition of the material according to the standard and chemical analysis of the used specimen are given in Table 1. The used cutting pattern for this experiment is shown in Figure 1.

Table 1. Chemical composition of (wt. %) AISI 431 martensitic stainless steel used in the experimental studies

	%C	%Si	%Mn	%Cr	%Ni
Standard	0.12-0.22	1.00 (max)	1.50 (max)	15-17	1.50-2.50
Chemical Analysis	0.172	0.274	0.482	15.4	2.11

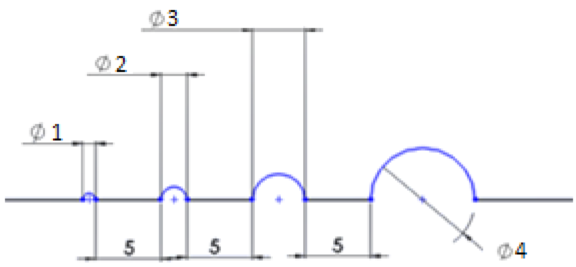

Figure 1. Cutting pattern used for experiments

During experimental cutting cupper plated brass wire with 0.25 mm thickness used on SPM EZ20S EDM machine tool. Used cutting parameters during experiments are listed in Table 2. The used specimens marked by cold stamping is shown in Figure 2.

Table 2. Cutting parameters

Parameters	**Used Values**
Voltage (V)	38, 44, 50
Current (A)	7, 9, 11
Pulse On Time (µs)	1, 2, 3
Feed Rate (m/min)	3, 4, 5

Figure 2. Marked and cut sample specimens

Surface roughness values were measured with respect to JIS 01- 0.25x5 standard as shown in Figure 3. Three measurements were applied for each experiment and mean values were recorded.

2.2. ANOVA

During ANOVA analysis the total sum of squares was calculated by adding the sum of the squares of residual random error into the sum of sum of squares of individual factors. Corresponding sum of squares of the factors were divided by associated degrees freedom to calculate mean squares of the factors. Then, null hypothesis was tested for individual factors to evaluate the effect or significance at a particular probability level of them. For this, the ratio of mean squares of factors to the mean squares of the residual error, i.e. F-statistic, was calculated and compared to the tabulated F-values related to Fisher distribution. Number of degrees of freedom of the individual factors, number of degrees of freedom of residual error and the probability level affects the F-values [14]. Degree of contribution (ρ %) of each significant factor in model was also determined according to computed value of F distribution. The ratio of F-value of each factor to the sum of computed F values give the degree of contribution of each significant factor. The q% values in Table 3. Define the degree of contribution of each independent factor to the measured dependent parameter.

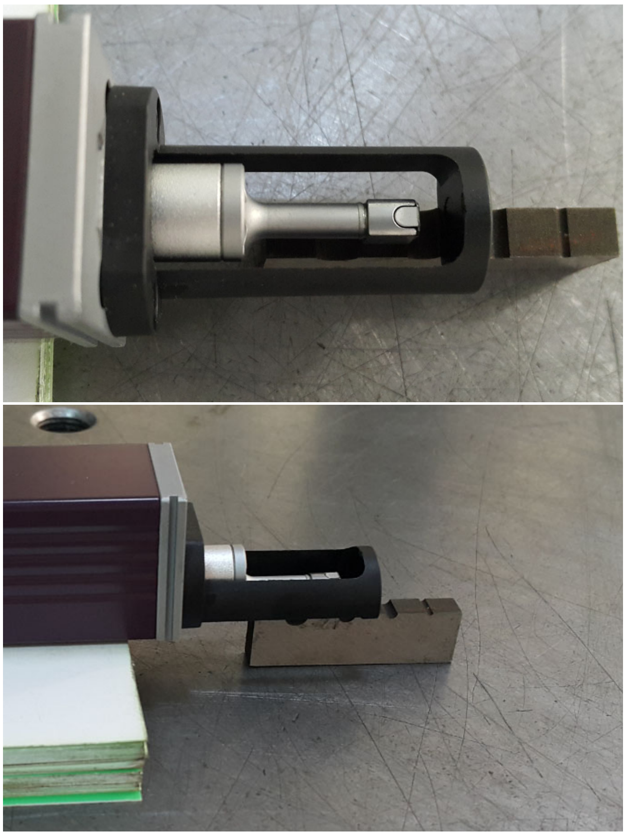

Figure 3. Measurement of surface roughness

The test results listed in Table 4 were analyzed to find out the variation in the surface roughness depending on the cutting parameters i.e. voltage, current, pulse and feed rate. Analysis of variances (ANOVA) have been performed by using a commercial statistical software (Design-Expert 7.0.3). Cubic regression model was determined as the best fitted among others by comparing estimations with measured values.

Table 3. Results of ANOVA

Independent Parameters	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**P value**	**ρ% (% effect on model)**
Model	16	2.53				
A-Voltage	1	0.66	0.66	31.6	< 0.0001	25.8
B-Current	1	0.49	0.49	23.4	0.0003	19.1
C-Pulse	1	0.11	0.11	5.25	0.0394	4.3
D-Feed	1	1.57E-03	1.57E-03	0.075	0.7886	0.1
AB	1	0.062	0.062	2.97	0.1082	2.4
AC	1	0.05	0.05	2.4	0.1455	2.0
AD	1	0.17	0.17	8.01	0.0142	6.5
BC	1	0.011	0.011	0.54	0.4767	0.4
BD	1	9.03E-05	9.03E-05	4.31E-03	0.9486	0.0
CD	1	1.02E-03	1.02E-03	0.049	0.8284	0.0
A^2	1	0.14	0.14	6.9	0.0209	5.6
BCD	1	0.25	0.25	11.73	0.0045	9.6
A^2C	1	0.11	0.11	5.27	0.0389	4.3
A^2D	1	0.016	0.016	0.75	0.4007	0.6
AB^2	1	0.47	0.47	22.51	0.0004	18.3

Table 4. Predicted and measured surface roughness values with respect to independent variables

Voltage (V)	**Current (Ω)**	**Pulse On Time (µs)**	**Feed Rate (m/min)**	**Surface Roughness**		**% Error**
				Predicted (µm)	**Measured (µm)**	
44	9	2	4	3.035	3.047	0,48
44	9	2	3	3.063	3.013	-1,65
44	9	2	5	3.007	2.957	-1.70
44	9	3	4	2.687	2.687	0.00
44	7	2	4	2.783	2.797	0.049
44	11	2	4	3.112	3.110	-0.06
38	9	2	4	3.404	3.410	0.18
38	7	1	3	2.878	2.987	3.64
38	7	1	5	2.665	2.617	-1.85
38	7	3	3	2.966	2.817	-5.30
38	7	3	5	2.290	2.370	3.38
38	11	1	3	3.282	3.123	-5.08
38	11	1	5	2.565	3.187	19.51
38	11	3	3	2.981	3.177	6.16
38	11	3	5	2.791	2.660	-4.93
50	9	2	4	2.254	2.260	0.27
50	7	1	3	2.316	2.203	-5.11
50	7	1	5	2.513	2.557	1.71
50	7	3	3	2.628	2.773	5.24
50	7	3	5	2.361	2.277	-3.70
50	11	1	3	2.970	3.130	5.11
50	11	1	5	2.662	2.567	-3.71
50	11	3	3	2.892	2.697	-7.24
50	11	3	5	3.112	3.243	-4.05

3. RESULTS AND DISCUSSIONS

A statistical analysis was performed to determine the statistically significant dependent parameters and interactions of them on roughness.

Results of ANOVA are given in Table 3. The F value in the table provides an information of the degree of contribution of the independent parameters to the measured dependent parameter (roughness). If the F is high, the contribution of the factors to that particular response is high. P values are related with the significance of independent parameters on the dependent parameter. P values smaller than 0.05 means that related parameter is statistically significant on result.

A regression model in reduced cubic polynomial form is built as a result of ANOVA. The coefficients of terms of the model equation are listed in Table 5.

Table 5. Regression coefficients of model equation

Coefficient	Factor
-98.512	Constant
2.83989	* Voltage
17.70618	* Current
20.58278	* Pulse
-4.73774	* Feed
-0.38086	* Voltage * Current
-0.86624	* Voltage * Pulse
+0.24745	* Voltage * Feed
-0.23450	* Current * Pulse
-0.12506	* Current * Feed
-0.54944	* Pulse * Feed
-0.015138	* Voltage^2
-0.96548	* Current$^{\wedge 2}$
+0.061938	* Current * Pulse * Feed
9.95E-03	* Voltage^2 * Pulse
-2,62E-03	* Voltage^2 * Feed
+0.021448	* Voltage * Current^2

Evaluation of regression model by comparing predictions versus measured values is given by Figure 4. and Table 4. Figure 4 depicts actual values of the experiment results versus the predicted ones. The points on the graph shows a uniform distribution in a region close to the 45° line which represents the perfect fit. In addition actual and corresponding predicted values of surface roughness values and % error are listed in Table 4. Maximum absolute % error in this table is 19.51 % and the rest of the errors are less than 7 %.

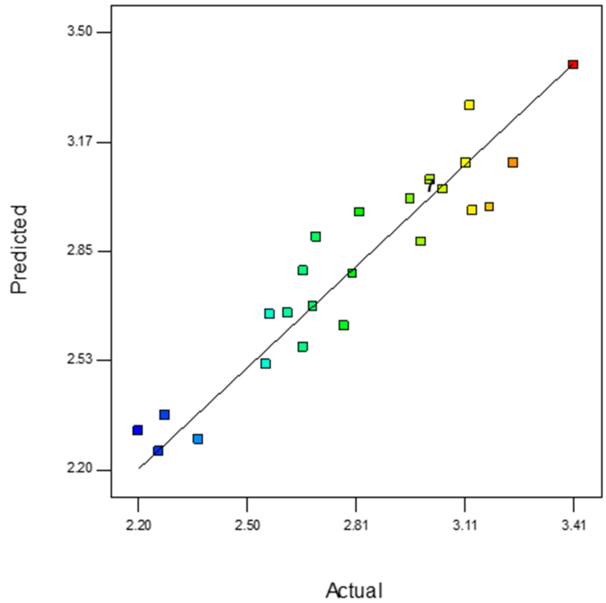

Figure 4. Evaluation of model estimations

It is seen that from the Table 3. the most significant variables are voltage, current and pulse on time. In addition interactions of factors i.e. multiplication of them, which have significant effect on the result (surface roughness value) are, voltage*pulse on time, voltage^2, current*pulse on time* feed, voltage^2*pulse on time, voltage*current^2. The findings revealed by ANOVA are compatible with literature [2], [15], [16]. Developed model have four basic variables so that it can be represented by only a surface in a five dimensional hyperspace. Consequently the model depicted in three dimensional space by keeping constant two of the variables and constructing the model graph in three dimensions or contour graphs for changing values of remaining two variables. Three dimensional graphs of 6 combinations the variables are presented in Figures 5 to 10. It must be noted that the graphs are valid just for stated values of the constant factors. The graphs are varied for the changing values the constant factors.

Effects of voltage and current on surface roughness for constant values of pulse on time at

2 µs and feed rate at 4 m/min is depicted in Figure 5. Increase in current have a positive effect up to about 10 A. After this value it decreases slightly. On the other hand surface roughness decreases with increase of voltage.

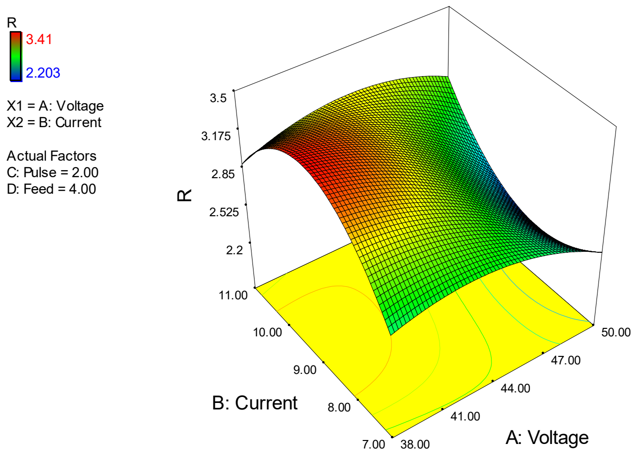

Figure 5. 3d plot of change of surface roughness with current and voltage for constant values of pulse on time =2 µs and feed = 4 m/min.

Pulse on time have almost no effect on surface roughness for constant values of current at 9 A and feed rate at 4 m/min as seen in Figure 6. Increase in voltage causes decrease of roughness values in similar manner with Figure 5 but in this case the rise is quite steep.

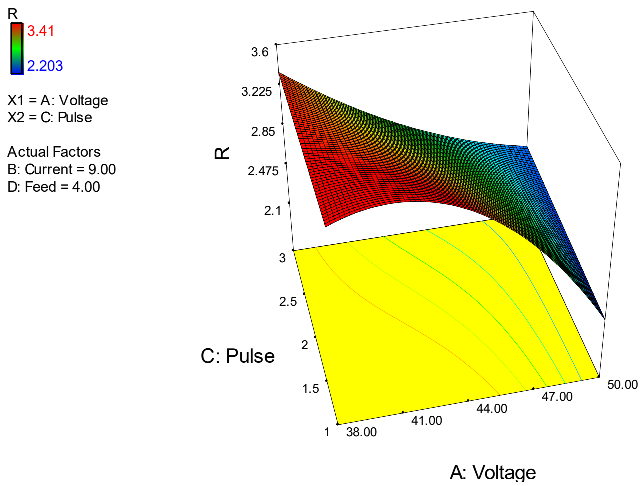

Figure 6. 3d plot of change of surface roughness with pulse on time and voltage for constant values of current = 9 A and feed = 4 m/min.

Change in surface roughness voltage and feed rate for the constant values at current value of 9 A and pulse on time of 2 µs is shown in Figure 7. As in Figures 5 and 6. roughness have sharp rise with increase in voltage. Increase in feed rate have a negative effect on roughness for lower values of voltage although it have almost no effect on roughness for higher voltages.

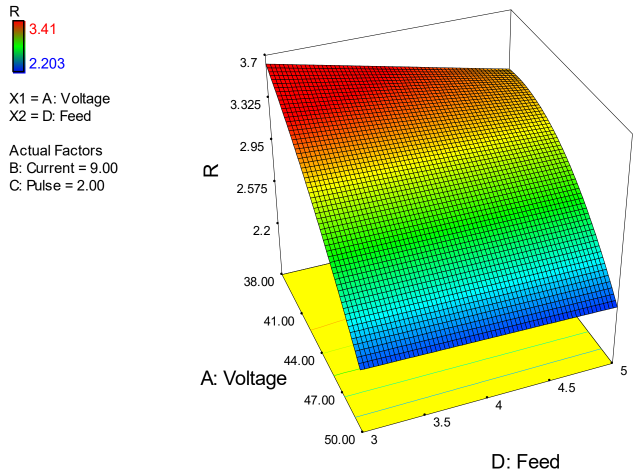

Figure 7. 3d plot of change of surface roughness with feed and voltage for constant values of current =9 A and pulse on time = 2 µs.

Figure 8. shows change in surface roughness with respect to current and feed rate for voltage of 44 V and pulse on time of 2 µs. As being compatible with Figure 5. roughness increases with increase in current. Similar with Figure 7. roughness values decreases slightly with increase in feed rate.

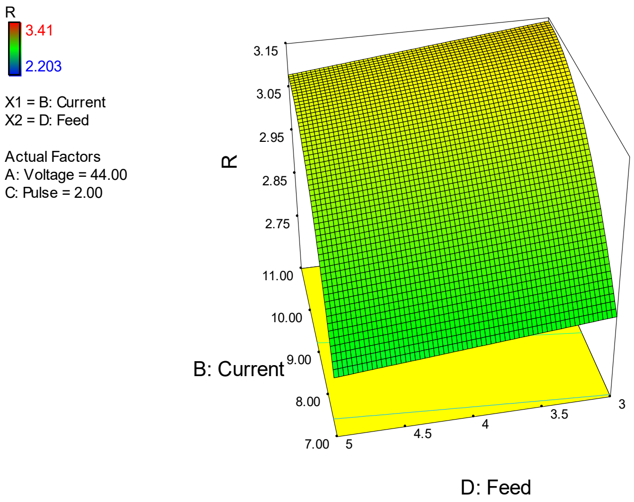

Figure 8. 3d plot of change of surface roughness with feed and current for constant values of voltage = 44 V and pulse on time = 2 µs.

Effect of pulse on time and feed rate for constant values of voltage at 44 V and current at 9 A on surface roughness is depicted in Figure 9. Roughness increases with increase in feed rate. On the other hand roughness is increasing very slightly with decrease in feed rate.

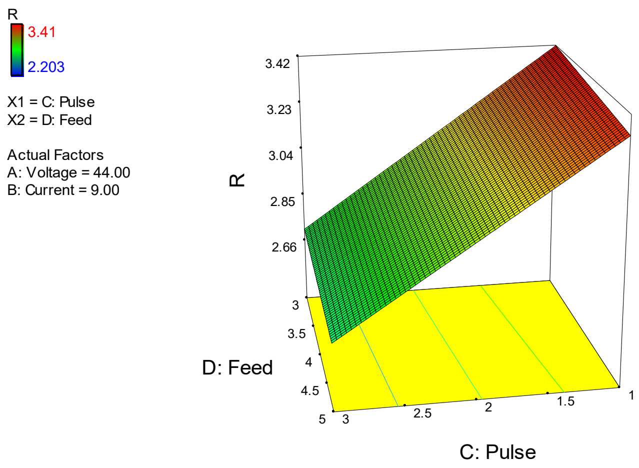

Figure 9. 3d plot of change of surface roughness with feed and pulse on time for constant values of voltage = 44 V and current = 9 A.

Change in surface roughness with respect to pulse on time and current for constant values of voltage of 44 V and feed rate of 4 m/min is shown in Figure 10. Current influences the roughness positively however pulse on time influence it negatively.

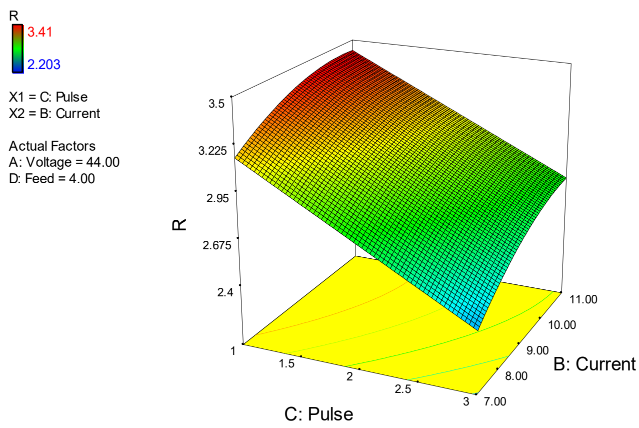

Figure 10. 3d plot of change of surface roughness with pulse on time and current on time for constant values of voltage= 44 V and feed = 4 m/min

4. CONCLUSIONS

A mathematical model to estimate surface roughness of Wire EDM cut spinneret material (AISI 431 martensitic stainless steel) have been developed during this study. Voltage, current, pulse on time and feed rate have been chosen as input variables. Statistical regression analysis have been conducted to get contribution of input variables and their products into the output parameter (surface roughness).

As a result of the study: A mathematical model in a form of cubic polynomial developed to predict surface roughness as a function of voltage, current, pulse on time and feed rate. Developed model predicts the surface roughness with maximum relative error of 19.51%. Voltage (25.8%) and current (19.1%) have been determined as most effective factors on surface roughness. Other effective parameters are listed as interaction of current pulse feed (9.6%), interaction of voltage feed (6.5%) and pulse (4.3%), parameters respectively.

REFERENCES

[1] S. Kalpakjian and S. Schmid, Manufacturing, Engineering & Technology, 5th ed. Lebanon, Indiana, USA: Prentice Hall, 2005.

[2] K. H. Ho, S. T. Newman, S. Rahimifard, and R. D. Allen, “State of the art in wire

electrical discharge machining (Wire EDM),” Int. J. Mach. Tools Manuf., vol. 44, pp. 1247–1259, 2004.

[3] D. SCOTT, S. BOYINA, and K. P. RAJURKAR, “Analysis and optimization of parameter combinations in wire electrical discharge machining,” Int. J. Prod. Res., vol. 29, pp. 2189–2207, Nov. 1991.

[4] Y.-S. Liao, J. T. Huang, and H. C. Su, “A study on the machining-parameters optimization of wire electrical discharge machining,” J. Mater. Process. Technol., vol. 71, pp. 487–493, Nov. 1997.

[5] M. Rozenek, J. Kozak, L. Dąbrowski, and K. Łubkowski, “Electrical discharge machining characteristics of metal matrix composites,” J. Mater. Process. Technol., vol. 109, pp. 367–370, Feb. 2001.

[6] H. J.T and LiaoYunn-Shiuan, “Optimization of machining parameters of Wire EDM based on Grey relational and statistical analyses,” Int. J. Prod. Res., vol. 41, pp. 1707–1720, May 2003.

[7] W. J. Hsue, Y. S. Liao, and S. S. Lu, “Fundamental geometry analysis of Wire electrical discharge machining in corner cutting,” Int. J. Mach. Tools Manuf., vol. 39, no. 1, pp. 651–667, 1999.

[8] J. Abyar Firouzabadi, H., Parvizian and A. Abdullah, “Improving Accuracy of Curved Corners in Wire EDM Successive Cutting,” Int J Adv Manuf Technol, vol. 76, pp. 447–459, 2015.

[9] J. A. Sanchez, J. L. Rodil, A. Herrero, L. N. L. De Lacalle, and A. Lamikiz, “On the influence of cutting speed limitation on the accuracy of Wire -EDM corner-cutting,” Int. J. Adv. Manuf. Technol, vol. 182, pp. 574–579, 2007.

[10] Z. Chen, Y. Huang, Z. Zhang, and H. Li, “An analysis and optimization of the geometrical inaccuracy in Wire EDM rough corner cutting,” Int. J. Adv. Manuf. Technol, vol. 74, pp. 917–929, 2014.

[11] M. Durairaj, D. Sudharsun, and N. Swamynathan, “Analysis of Process Parameters in Wire EDM with Stainless Steel Using Single Objective Taguchi Method and Multi Objective Grey Relational Grade,” Procedia Eng., vol. 64, pp. 868–877, Dec. 2013.

[12] V. Aggarwal, S. Sehijpal, and R. Garg, Parametric modeling and optimization for Wire electrical discharge machining of Inconel 718 using response surface methodology, vol. 79. 2015.

[13] A. Ramamurthya, R. Sivaramakrishnan, and T. Muthuramalingamc, “Taguchi-Grey computation methodology for optimum multiple performance measures on machining titanium alloy in Wire EDM process,” Indian J. Eng. Mater. Sci., vol. 22, pp. 181–186, Apr. 2015.

[14] A. Rutherford, Introducing ANOVA and ANCOVA: a GLM approach. Sage Publications, 2001.

[15] D. Ghodsiyeh, A. Golshan, and J. A. Shirvanehdeh, Review on current research trends in Wire electrical discharge machining (Wire EDM), vol. 6. 2013.

[16] M. Y. A. and A. B. and M. A. Bakar, “Influence of Wire Electrical Discharge Machining (Wire EDM) process parameters on surface roughness,” IOP Conf. Ser. Mater. Sci. Eng., vol. 290, no. 1, p. 12019, 2018.