International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 15 (2017) pp. 4759-4764
© Research India Publications. http://www.ripublication.com

Modeling and Analysis of Wire Electrical Discharge Machining Parameters in Machining of Inconel 718

Hulas Raj Tonday[1] and Anand Mukut Tigga[2]

*[1]Department of Manufacturing Engineering, National Institute of Technology Jamshedpur,
NIT Campus, Jamshedpur, Jharkhand- 831014, India.*

Orcid: 0000-0002-0800-7528

*[2]Department of Manufacturing Engineering, National Institute of Technology Jamshedpur,
NIT Campus, Jamshedpur, Jharkhand- 831014, India.*

Abstract

Persuasive and adept machining and finishing of superalloys, viz. nickel-alloys, titanium-alloys, tungsten-alloys, are very arduous and stiff work, when using conventional machining techniques. Therefore, the authors identified an absolute necessity of non-traditional cutting process like wire electrical discharge machining (WEDM) for cutting and finishing of Inconel 718. In the current study, practical attempt has been made for cutting workpart of Inconel 718 material by utilizing WEDM process. L_{12} Taguchi orthogonal arrays have been adopted for desirable planning of experimental run. Taguchi method and linear model analysis have been exploited in order to optimize machining variables and to correlate the input variables and output variables. Input variables such as spark voltage, pulse on time, wire tension, and dielectric pressure have been taken for analysis. Enumeration of output variables, material removal rate and surface roughness, has been carried out as they are of crucial importance in machining process and measure of productivity. Analysis of variance (ANOVA) is also executed and found that the spark voltage is the most significant parameter which has the highest impact on MRR as well as surface roughness.

Keywords: wire electrical discharge machining; material removal rate; surface roughness; Taguchi method; scanning electron microscopy; Inconel 718.

ABBREVIATIONS

WEDM	Wire Electrical discharge machining
SS	Sum of squares
MS	Mean of squares
DF	Degree of freedom
F	Fisher's statistic
P	p-value
MRR	Material removal rate
S_a	Surface roughness
S/N	Signal to noise
ANOVA	Analysis of variance

INTRODUCTION

WEDM is a significant variant of EDM process, in which the electro-thermal energy is applied. The cutting of workpart takes place due to sequential sparks originated between wire and workpart electrodes. It is a crucial, in terms of accuracy and tolerance, non-conventional thermoelectric machining technique in which the mechanism of material removal is same as the common EDM process. There is no force involved in WEDM process because the wire electrode is not quite touching the workpiece during machining. The difficult job in WEDM process is controlling the spark gap between the wire and workpiece [1-3]. Several research works have been accomplished in the field of WEDM process. Dodun et al. [4] proposed certain devices that could act on the tool electrode in order to improve the machining process efficiency. One of the solutions was the use of electromagnetic subsystems while another solution was the use of a sub-assembly electric motor gear box for periodically changing the wire tool electrode speed. Somashekhar et al. [5] presented the formulation and optimization of various process parameters of a micro-WEDM by using regression models and ANOVA. Durairaj M. Sudharsun et al. [6] summarized the Grey relational theory and Taguchi optimization technique and the objective of their optimization is to attain the minimum kerf width and the best surface quality simultaneously. Ho et al. [7] reviewed the research activities such as optimization of process parameters, monitoring and control of WEDM. Several authors accomplished multi-response variable optimization of WEDM process. There are various optimization techniques such as full factorial design, response surface methodology, Taguchi method, Grey relational analysis, principal component analysis and other non-traditional optimization techniques utilized for optimizing cutting variables [8, 9]. These optimization techniques are also utilized for setting up optimum combination of process variables, i.e., experimental design [10]. Kinoshita et al. [11] have developed a new guide of wire electrode that does not cause locally sharp bending of the wire and enables the smooth running of the wire through the guide. This reduces the defects arising due to the sharp bending of the wire. Sharma et al. [12] used response surface methodology and observed that both the responses metal removal rate and surface roughness increases with increase in pulse on time and peak current. Huang et al. [13] elicited that higher table feed and shorter pulse on time have been requisite for higher MRR value and lower S_a Value. The objective of the current study is to acquire optimum setting of input variables which results in maximum MRR and minimum S_a value in WEDM. When cutting of Inconel 718 material, a little research has been found in the field of WEDM process optimization and experimental investigation simultaneously. Inconel 718 is a widely used material with significant characteristics [14, 15], but many of the research articles have not explored its suitable and economical machining techniques and machining attributes and have not examined the surface morphology in micro units. Keen researches have been essentially desirable in these fields to extend their applications for producing hard materials with complex profiles. In this research work, cutting variables such as spark voltage, pulse on time, wire tension, and dielectric pressure have been taken for analysis measured the MRR and surface roughness for each workpiece.

MATERIALS AND METHODS

A. The workpiece material

A super-alloy Inconel 718 has unique physical properties such as high mechanical and impact strength; higher co-efficient of thermal expansion. Due to its high resistance to chemicals, acids and corrosion, it has wide applications in chemical and acids; oil and gas production [3]. Therefore, in this research, Inconel 718 has been used as a workpiece material, which is a difficult to cut material due to high strength, toughness and stiffness [13]. The chemical composition of the Inconel 718 has been tested by employing optical emission spectroscopy (make Oxford-Instruments) and results are shown in table (I).

Table I: Chemical Composition of the Inconel 718

Element	C	Mn	Ni	Nb	Cr	Fe	Mo	Co	Ti
Content (%)	0.04	0.11	52.7	4.95	17.33	19.63	2.92	0.3	0.9

B. The Machining Set up

The machine tool used in the present research is AGIECUT 100 CNC WEDM machine of traverse 300×200×224 mm, U & V travel ±300 mm, taper ±30º. The electrode wire used in the machine is of brass material with 0.25 mm diameter. The machine is integrated with auto wire threading system which enhances the machining speed and efficiency. The dielectric fluid used is de-ionized water [1, 2]. The test workpieces are prepared in the dimension of 10×15×15 mm. Only four numbers of input parameters spark voltage, pulse on time, wire tension and flushing pressure have been considered for analysis, in which each of the four input factors have two different levels as shown in table (II) and remaining parameters contain the default values machine. Taguchi's L12 orthogonal arrays have been used to design experiments and experimental plan is shown in table (III). On the basis of this experimental design 12 numbers of experiments have been conducted utilizing WEDM with designed cutting conditions.

Table II: WEDM Cutting Parameters and Their Levels

Parameter	***Symbol***	***Unit***	***Level 1***	***Level 2***
Spark Voltage	V_s	V	10	14
Pulse On Time	T_o	µs	7	11
Wire Tension	W	gram-force	1100	1150
Dielectric Pressure	P_d	kg/cm^2	13	15

RESULTS AND DISCUSSION

In present type of experimental investigation, suitable recording and evaluation of experimental data is strongly essential. Hence, after accomplishment of cutting process, measurements of output parameters have been carried out for experiments. To demonstrate the productivity and capability of WEDM process while machining Inconel 718, MRR has been calculated for all the experiments as shown in the table (III). Similarly to evaluate the surface quality of machined workpieces, S_a values of each machined piece has also been measured by utilizing Telysurf instrument and results are shown in the table (III). In this research, it has been found that experiment number (11) consists of maximum MRR value 8.18 mm^3/min. and experiment number (01) consists of lowest surface roughness (S_a) value 2.3 µm, which are desirable according to the objective of the current research. These collected data have been analyzed by using potential statistical software Minitab 15.0. In this software, Taguchi method has been considered for analysis of collected values of response parameters (MRR & S_a). Also, S/N ratio for each output variable has been computed.

Table III. L_{12} Experimental plan and acquired MRR & S_a values

Run	V_s	T_o	*W*	P_d	*MRR*	S_a
1	10	7	1100	13	7.24	2.3
2	10	7	1100	13	6.55	3.1
3	10	7	1150	15	7.12	2.62
4	10	11	1100	15	6.68	3.01
5	10	11	1150	13	7.33	3.5
6	10	11	1150	15	6.62	3.86
7	14	7	1150	15	7.72	2.7
8	14	7	1150	13	7.49	4.07
9	14	7	1100	15	9.56	4.25
10	14	11	1150	13	8.18	3.68
11	14	11	1100	15	10.25	4.42
12	14	11	1100	13	9.77	4.64

C. Statistical Analysis of Output Data

For the purpose of correlating the cutting variables and output parameters (MRR & S_a), it is necessary to execute statistical analysis and optimization of cutting factors. However, by utilizing the Minitab software, linear model analysis, ANOVA, signal to noise ratios, and model coefficients for MRR and surface roughness (S_a) is calculated [5, 14]. ANOVA has been conducted to identify and determine the significant input variables which have the greatest impact on response parameters, so that these input parameters can be controlled suitably to obtain their desired values. 'Larger is better' characteristic has been considered during Taguchi analysis of MRR values and the ANOVA result for S/N ratios of MRR [6, 15] has been shown in the table (IV). The response table for S/N ratios of MRR is shown in the table (V). Both the tables delineate that the factor V_s has the greatest influence on MRR, whereas the factor P_d has the least.

Table IV. ANOVA result for S/N ratios of MRR.

Source	***DF***	***SS***	***MS***	***F***	***P***
V_s	1	11.49	10.76	16.2	0.007
T_o	1	0.86	0.6	0.91	0.41
W	1	2.39	2.25	3.4	0.015
P_d	1	0.071	0.07	0.11	0.76
Residual Error	6	3.98	0.66		
Total	10	18.79			

Table V. Response table for S/N ratios of MRR

Level	V_s	T_o	*W*	P_d
1	16.8	17.73	18.57	17.92
2	18.85	18.08	17.38	17.92
Delta	2.05	0.35	1.19	0.01
Rank	1	3	2	4

Similarly, 'smaller is better' characteristic has been considered during Taguchi analysis of S_a values and the ANOVA result for S/N ratios of S_a is illustrated in the table (VI). The response table for S/N ratios of S_a is shown in the table (VII). Both the tables describe that the factor V_s has the greatest influence on S_a, whereas the factor P_d has the least. F-values obtained from ANOVA results, for both the output factors MRR and S_a, ensures that V_s is the most significant input variable than others. It, therefore, is necessary to control spark voltage (V_s) carefully during machining operations.

Table VI. ANOVA result for S/N ratios of S_a.

Source	***DF***	***SS***	***MS***	***F***	***P***
V_s	1	10.58	10.94	4.86	0.04
T_o	1	8.2	7.07	3.14	0.13
W	1	0.73	0.84	0.37	0.6
P_d	1	0.32	0.3	0.14	0.72
Residual Error	6	13.52	2.25		
Total	10	33.34			

Table VII. Response table for S/N ratios of S_a.

Level	V_s	T_o	W	P_d
1	-9.85	-10.1	-11.42	-11.29
2	-11.824	-11.62	-10.52	-10.63
Delta	1.97	1.53	0.9	0.66
Rank	1	2	3	4

Main effects plot of S/N ratios by considering the input parameters for MRR is shown in figure (1), that for $S_a$is shown in figure (2). From the main effects plot we can see that all the four cutting factors have a considerable main effect on both the output factors, since all the lines of cutting parameters are inclined [2, 6]. Again V_s has the largest main effect on S/N ratios of both the output variables. The experiment numbers with level 2 of V_s have higher S/N ratios than experiment numbers with level 1 of V_s. Normal probability plots for S/N ratios of both the response parameters MRR and S_a have been illustrated in figure (3) and figure (4) respectively, which ensures that the obtained response values are normally distributed.

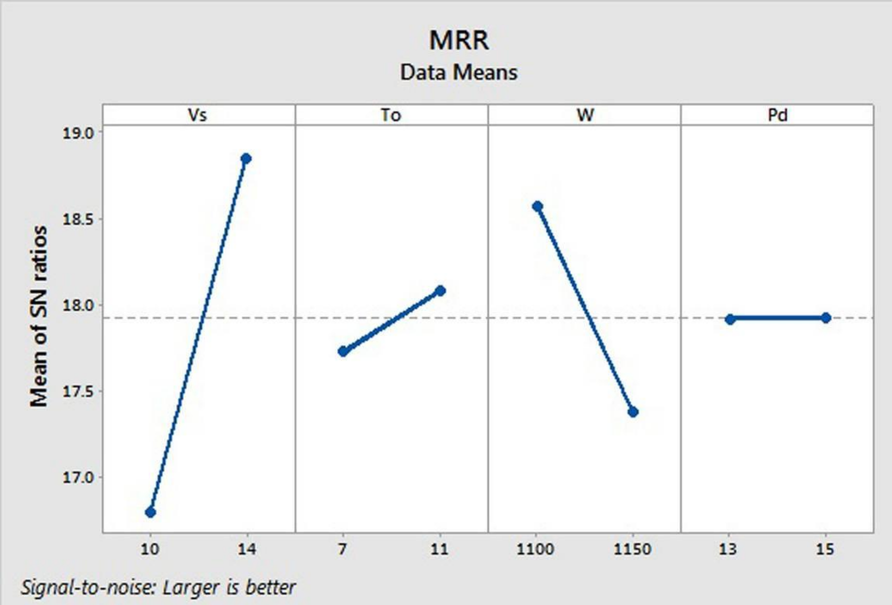

Figure 1. Main effects plot for S/N ratios of MRR.

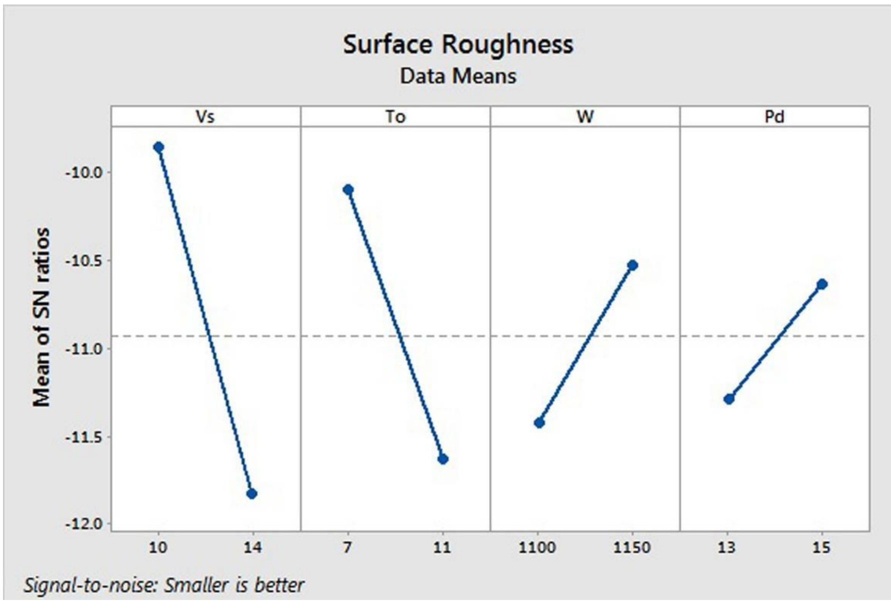

Figure 2. Main effects plot for S/N ratios of S_a.

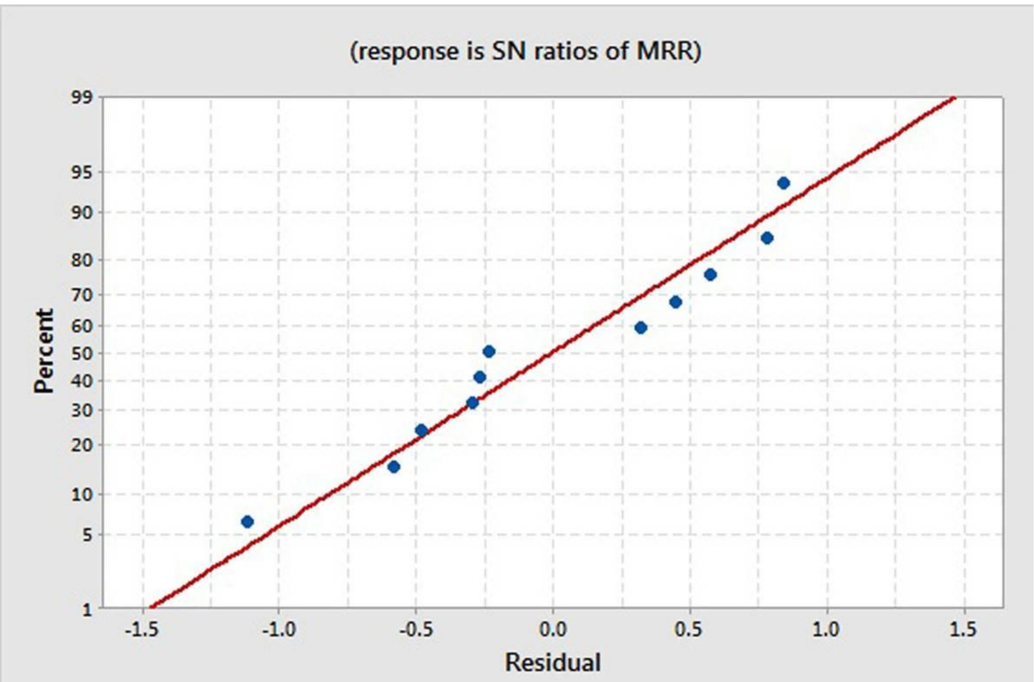

Figure 3. Normal probability plot for S/N ratios of MRR.

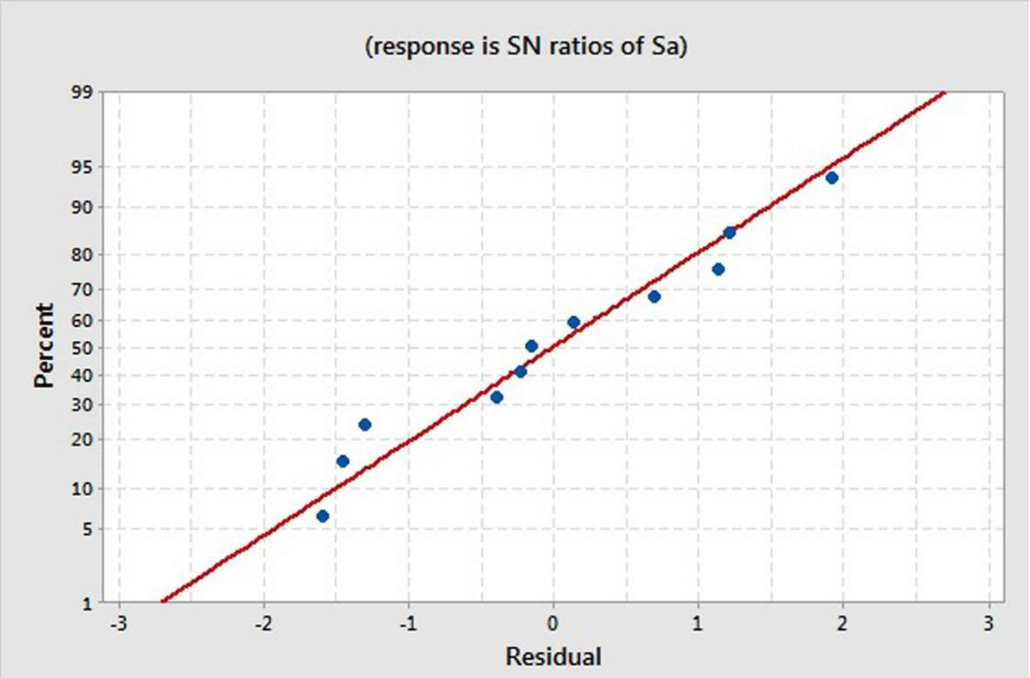

Figure 4. Normal probability plot for S/N ratios of S_a.

CONCLUSION

There is following conclusions made after experimentation and analysis of response data obtained:

1. The cutting parameter spark voltage has the highest impact on both the response variables (MRR and S_a). Hence, it is the most significant parameter.
2. Experiment number 11 has the maximum MRR value as obtained by experiments, which is desirable as per the research objective.

3. Experiment number 01 has the minimum surface roughness (S_a) value as obtained by experiments, which is also considerable.
4. The main effects plot delineates that all the cutting parameters have a main effect on both the output variables.

REFERENCES

[1] L. López de Lacalle and A. Lamikiz, *Machine tools for high performance machining*. London: Springer, 2010.

[2] R. Yang, C. Tzeng, Y. Yang and M. Hsieh, "Optimization of wire electrical discharge machining process parameters for cutting tungsten", *The International Journal of Advanced Manufacturing Technology*, vol. 60, no. 1-4, pp. 135-147, 2012.

[3] V. Aggarwal, S. Khangura and R. Garg, "Parametric modeling and optimization for wire electrical discharge machining of Inconel 718 using response surface methodology", *The International Journal of Advanced Manufacturing Technology*, vol. 79, no. 1-4, pp. 31-47, 2015.

[4] O. Dodun, A. Gonçalves-Coelho, L. Slătineanu and G. Nagîț, "Using wire electrical discharge machining for improved corner cutting accuracy of thin parts", *The International Journal of Advanced Manufacturing Technology*, vol. 41, no. 9-10, pp. 858-864, 2009.

[5] K. Somashekhar, J. Mathew and N. Ramachandran, "A feasibility approach by simulated annealing on optimization of micro-wire electric discharge machining parameters", *The International Journal of Advanced Manufacturing Technology*, vol. 61, no. 9-12, pp. 1209-1213, 2012.

[6] 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 Engineering*, vol. 64, pp. 868-877, 2013.

[7] K. Ho, S. Newman, S. Rahimifard and R. Allen, "State of the art in wire electrical discharge machining (WEDM)", *International Journal of Machine Tools and Manufacture*, vol. 44, no. 12-13, pp. 1247-1259, 2004.

[8] N. Kinoshita, M. Fukui and G. Gamo, "Control of Wire-EDM Preventing Electrode from Breaking", *CIRP Annals - Manufacturing Technology*, vol. 31, no. 1, pp. 111-114, 1982.

[9] N. Sharma, R. Khanna, R. Gupta and R. Sharma, "Modeling and multiresponse optimization on WEDM for HSLA by RSM", *The International Journal of Advanced Manufacturing Technology*, vol. 67, no. 9-12, pp. 2269-2281, 2013.

[10] J. Huang and Y. Liao, "Optimization of machining parameters of Wire-EDM based on Grey relational and statistical analyses", *International Journal of Production Research*, vol. 41, no. 8, pp. 1707-1720, 2003.

[11] Jagadish and A. Ray, "Optimization of process parameters of green electrical discharge machining using principal component analysis (PCA)", *The International Journal of Advanced Manufacturing Technology*, vol. 87, no. 5-8, pp. 1299-1311, 2016.

[12] M. Azam, M. Jahanzaib, J. Abbasi, M. Abbas, A. Wasim and S. Hussain, "Parametric analysis of recast layer formation in wire-cut EDM of HSLA steel", *The International Journal of Advanced Manufacturing Technology*, vol. 87, no. 1-4, pp. 713-722, 2016.

[13] H. Dong, Y. Liu, Y. Shen and X. Wang, "Optimizing Machining Parameters of Compound Machining of Inconel718", *Procedia CIRP*, vol. 42, pp. 51-56, 2016.

[14] E. Ekici, A. Motorcu and A. Kuş, "Evaluation of surface roughness and material removal rate in the wire electrical discharge machining of Al/B4C composites via the Taguchi method", *Journal of Composite Materials*, vol. 50, no. 18, pp. 2575-2586, 2015.

[15] A. Giridharan and G. Samuel, "Analysis on the effect of discharge energy on machining characteristics of wire electrical discharge turning process", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 230, no. 11, pp. 2064-2081, 2016.