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Machining Assessment for Alloy 718 through WEDM

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Abstract

When utilising traditional machining processes, convincing and competent processing with ultra precision of superalloys are highly difficult and stiff task. Accordingly, the authors recognised a need for non-conventional machining (NCM) for processing of alloy 718 (other name ‘Inconel 718’ or UNS N07718) using wire electric discharge machining (WEDM). L_{16} Taguchi’s orthogonal array has been utilised for preferred design of experiment. Pulse on duration (Ton), pulse off duration (Toff), wire speed (Uw), and current (I) has been selected as control factors to study the effects of performance. Material removal rate (MRR), Kerf Width (KW) and Surface Roughness (SR) has been assessed as an output performance. Analysis of variance (ANOVA) is also performed and found that I has the greatest influence on MRR while Uw is lowest, with contribution of 47.11 % and 6.05 % respectively. For KW, Toff is greatest influential factor while I is lowest, with contribution of 35.39 % and 4.35 %. For SR, Ton is greatest influential factor while Toff is lowest, with contribution 87.8 % and 3.27 %. Also error between the actual and predicted values is below 5 %. For MRR, the error is 4.20 % while for KW and SR, it is 0.31 % and 2.21 % indicating close alignment with the achieved value.

Keywords: Alloy 718; WEDM; ANOVA; Performance; Error.

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1. Introduction

With ever-increasing industrial demands and necessities for advanced materials, such as high strength heat resistant metals and alloys and tough materials, there is increased dependency on the use of non-conventional machining (NCM) techniques for precise and efficient processing with optimum performances. Wire electric discharge machining (WEDM) is an effective way for processing of intricate, complex or difficult-to-machine materials in which erosion employs with a properly regulated discharge (spark) via a small gap filled with dielectric fluid between an electrode and a testpiece [1-3].Within the gap, the dielectric liquid starts ionising, forming a channel for each discharge and generates around 8000 to 10500 °C heat to erode the material from testpiece [4,5]. Various direct and indirect factors influence this type of NCM technique, including pulse on duration, pulse off duration, discharge current, wire

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speed, discharge voltage, frequency, mechanical and thermal behaviour of the wire, among others. The majority of academic experts have reported their work to examine various WEDM input factors on different machining performances such as materials removal rate (MRR), cutting width, and testpiece surface quality, among others. Important study done by numerous researchers in the last several years with exceptional outcome(s) [6,7] and research effort detailed in next context.

Tosun *et al.* [8] adopted Taguchi's method to quantify the influence of several machining inputs on MRR and kerf length when cutting AISI4140 steel and highlighted the fact that open circuit voltage and pulse length had a meaningful effect on MRR and kerf width. Hewidy *et al.* [9] used the Response Surface Modeling (RSM) technique to machine Inconel 601, highlighting the effect of wire tension, peak current, duty factor, and water pressure on the selected machining performance. Peak current has been observed to enhance MRR and wear ratio while reducing surface finish due to higher discharge energy.The positive influence of several inputs on different responses were investigated using the Genetic Algorithm (GA) for multifunctional WEDM optimization [10]. Furthermore, Kumar and Agarwal used the Non-dominated Sorting Genetic Algorithm (NSGA-II) model to improve the inputs for optimization of surface quality and MRR while with coated wire on high performance cutting steel [11]. Dhanabalan *et al.* [12] emphasised the importance of EDM input variables on the output performance of Inconel (718 and 625) material and produced second-order polynomial graphs for different performance measurements. Caydas and Ay [13] assessed and investigated the machining impact of control variable on WEDM of Inconel 718 for surface roughness, cutting width, and recast layer properties. For model creation, the analysis of variance (ANOVA) approach and regression analysis are employed to explain the influence of variable on WEDM quality. Gołąbczak *et al*. [14] evaluation focused on the impact of WEDM and vibratory abrasive machining on the geometrical structure of hard materials.Optimal electric factors are employed in the processing of materials for final sample, which are polished utilising circular vibratory finishing technology. It was proposed that vibro abrasive technique is appropriate for polishing highly hard materials because to its intricate geometry. Dzionk and Siemiątkowski [15] examined the influence of input factors such as dielectric pressure and pulse duration on WEDM of Inconel 617. The tests for dimensional accuracy, surface properties, and MRR were designed using the Box– Behnken design framework. The pulse duration during machining has a considerable impact on the MRR.Peaks and valleys do not alter as a result of the potential selection of input factor, although there are some variations in waviness structure when compared to the longitudinal and transverse directions of the cutting direction. Mouralova *et al.* [16] employed a set of tests to monitor the various input factors to improves efficiency in processing of Nickel-cobalt-chromium-molybdenum alloy, NIMONIC C 263. Optimal results were obtained for machining precision and surface quality, and the lamella was examined using a transmission electron microscope (TEM). The morphological examination confirms that there are no fractures or charred cavities in the machined samples.

The alloy 718 is a key material in auto manufacturing and aerospace sectors that offer outstanding mechanical characteristics as well and are also widely utilised in the chemical and petrochemical sectors [17-19]. Alloy 718 is known as a incredibly difficult to cut superalloy due to several issues which includes tool degradation, build up edge generation, and high cutting stresses caused by its poor thermal properties, high toughness, and hardness. Therefore, this type of quandary limits the broad applicability of alloy 718 in a variety of sectors. As a result, obtaining high precision, accuracy, and a superior surface quality is extremely difficult, and also traditional machining is inappropriate for acquiring micro forms of the surface [20-23].

As previously reported, numerous researchers have conducted studies on the WEDM method on various materials but not with the above-described material machined with a zinc coated wire electrode. The paper makes an effort to explore the machining attributes of Material Removal Rate (MRR), Kerf Width (KW) and Surface Roughness (SR) in WEDM using zinc coated brass wire of alloy 718 material.This study’s key findings can be put to the collection of the machinability of alloy 718 and will be extremely useful to machinists as the technical stats for WEDM.

2. Experimental Setup and Methodology

The experimental setup, general details and design adapted in this study are depicted (Fig. 1). The experimental trials had been conducted on a Computerised Numerical Control (CNC) WEDM machine. A coated brass wire with negative polarity was utilised as a wire electrode, and deionized water was employed as the dielectric liquid. During the experiments, testpiece and wire were immersed in dielectric liquid without any outside flushing.

Fig. 1. WEDM machining setup.

Table 1 shows the complete specification and description of experimental details. The four input control factors each with four levels were chosen to characterize the effects on output performance using Taguchi L_{16} OA design of experiments as depicted in Table 2. The levels of factors have been used to quantify the experimental design for alloy 718 in WEDM and to optimize the input factor for rectangular slot cutting.

Table 1. Details of experimentation.

S. No.	Instruction	Description
1	Material	Alloy 718
2	Dimension	15 mm*15 mm*5 mm (L*B*H)
3	Wire Material	Zinc coated brass with diameter of 0.25 mm
4	Dielectric fluid	Deionised water
5	WEDM	Model- Electronica Elpulse 40

Table 2. Control factors with their levels.

Input factors	Symbol	Unit	Levels			
			1	**2**	**3**	**4**
Pulse on duration	Ton	Machine unit (mu)	104	107	110	113
Pulse off duration	Toff	Machine unit (mu)	50	52	54	56
Current	I	A	10	11	12	13
Wire speed	Uw	m/min	1	2	3	4

A particular combination of settings was calculated for each experimental run with two repeats to limit any type of errors, and their mean value is considered for all sixteen experiments. The study shows the impact of factors using coated brass wire on alloy 718 testpiece so that industry may choose appropriate machining settings to get the intended outcome.

2.1. *Relevance of output performances*

a) The MRR is an estimation of quantity of material extracted from the testpiece in unit time during the machining and increasing with time results in economic benefits.

b) KW is the indication of width in the testpiece produced during the cutting process. Lower value leads to precision cutting in NCM.

c) SR is an estimation of surface irregularities and it is established in terms of measurement of central line average (Ra).

3. Evaluation and Discussion of Data

The Taguchi method was utilised in the current study for Design of Experiment (DOE), which were then run on Minitab-16 design software.

Table 3. L16 OA used in the experiment with mean and SNR value.

Exp. No.	Ton	Toff	I	Uw	MRR (mm^3/min)	SNR (dB)	KW (mm)	SNR (dB)	SR (μm)	SNR (dB)
1	1	1	1	1	1.092	0.764	0.317	9.979	0.423	7.473
2	1	2	2	2	1.842	5.306	0.322	9.843	0.481	6.357
3	1	3	3	3	2.047	6.222	0.357	8.947	0.471	6.540
4	1	4	4	4	2.745	8.771	0.398	8.002	0.481	6.357
5	2	1	2	3	1.877	5.469	0.350	9.119	0.587	4.627
6	2	2	1	4	1.556	3.840	0.368	8.683	0.537	5.401
7	2	3	4	1	2.290	7.197	0.358	8.922	0.542	5.320
8	2	4	3	2	2.477	7.879	0.375	8.519	0.546	5.256
9	3	1	3	4	2.694	8.608	0.376	8.496	0.721	2.841
10	3	2	4	3	2.616	8.353	0.372	8.589	0.696	3.148
11	3	3	1	2	1.630	4.244	0.349	9.143	0.627	4.055
12	3	4	2	1	2.420	7.676	0.375	8.519	0.584	4.672
13	4	1	4	2	2.925	9.323	0.365	8.754	0.802	1.917
14	4	2	3	1	2.797	8.934	0.357	8.947	0.717	2.890
15	4	3	2	4	3.073	9.751	0.402	7.915	0.692	3.198
16	4	4	1	3	2.532	8.069	0.411	7.723	0.671	3.466

For determining quality attributes in the Taguchi technique, the signal to noise ratio (SNR) is employed. The SNR can be represented using larger the better (LTB), smaller the better (STB), and nominal is best ways, according to the findings. LTB is used to calculate MRR via (Eq. 1) while STB employed for KW and SR using (Eq. 2).

$$(SNR)_{LTB} = -\log_{10}(1/n\Sigma 1/y^2) \quad (1)$$

and

$$(SNR)_{STB} = -\log_{10}(1/n\Sigma y^2) \quad (2)$$

In this, *y* is the outcome of the performance settings, and *n* represents the repetitions. The Taguchi approach changes the values of the target function to SNR as a performance of experiments.ANOVA examines factors such as degree of freedom (DOF), sum of squares (SS), variance, and each factor percentage. SS is the difference between the experimental data and the average value of the data. The F test is used to compute the Fisher's ratio (F value), which reflects the degree of influence of a factor on performance [24]. Table 3 shows the L16 OA used in the experiment with mean and SNR value.

3.1. *Analysis of SNR*

MRR is an essential machining output in establishing the productivity and efficiency of the WEDM technique. It is impacted by different WEDM variables.The greatest value of MRR is reached with factors varied as 113 mu, 54 mu, 11 A, and 4 m/min having value 3.073 mm^3/min and value of SNR from Taguchi analysis is found to be 9.751 dB and Similarly, the lowest KW and SR with corresponding input 104 mu, 50 mu, 10 A, and 1 m/min, each having value 0.317 mm and 0.423 µm with SNR value 9.979 dB and 7.473 dB respectively.There is a substantial impact on MRR when the levels of a factor have varied effectively. As a result, it has been established that the current has the greatest statistical influence on MRR and its SNR, confirming the theoretical aspects of the WEDM method. The MRR increases throughout the range of input values (Fig. 2). This is due to a significant amount of heat energy being created between the wire and the testpiece material, resulting in faster extraction of material in dielectric fluid [25,26]. The quantity of spark energy, i.e. the passage of electrons and the occurrence of sparks, determines the rate of material removal, which extracts the greater amount of material through the melting and vaporisation phase [27]. Table 4 depicts response table for MRR and confirm that I is most and Uw is least influential factor which established that models are adequate.

Table 4. SNR response table for MRR.

Level	Ton	Toff	I	Uw
1	5.266	6.041	4.229	6.143
2	6.096	6.608	7.051	6.688
3	7.220	6.854	7.911	7.028
4	9.019	8.099	8.411	7.743
Delta	3.753	2.058	4.181	1.600
Rank	2	3	1	4

Similarly, Tables 5 and 6 shows response table for KW and SR, Toff and Ton are most while I and Uw are least significant respectively. The main effect plots for SNR are drawn, which also indicates the various effects of input factors by considering the mean of variables at various levels. (Figs. 2-4) provide an impact plot for SNR of MRR, KW and SR. (Fig. 2) depicts that MRR is maximum when Ton is 113 mu, Toff is 56 mu, I is 13 A and Uw is 4 m/min. Similarly, (Figs. 3, 4) depicts that KW is minimum when Ton is 104 mu, Toff is 50 mu, I is 10 A and Uw is 1 m/min while SR is minimum when Ton is 104 mu, Toff is 56 mu, I is 10 A and Uw is 1 m/min.

Table 5. SNR response table for KW.

Level	Ton	Toff	I	Uw
1	9.193	9.087	8.882	9.092
2	8.811	9.015	8.849	9.065
3	8.687	8.732	8.727	8.594
4	8.335	8.191	8.567	8.274
Delta	0.858	0.896	0.315	0.818
Rank	2	1	4	3

Table 6. SNR response table for SR.

Level	Ton	Toff	I	Uw
1	6.682	4.215	5.098	5.089
2	5.151	4.449	4.713	4.396
3	3.679	4.778	4.382	4.445

4	2.867	4.938	4.185	4.449
Delta	3.814	0.723	0.913	0.693
Rank	1	3	2	4

3.2. *Analysis of variance*

The primary focus of ANOVA is to identify the influence of individual and interacting variables. Tables 7-9 displays the analysis for MRR, KW and SR. This study is being conducted at a 95 % confidence level, implying a 0.05 significance level. F-value which reflects the degree of influence of a factor determines the importance at specified confidence level.

Table 7. ANOVA for MRR.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Ton	3	31.6407	31.6407	10.5469	35.69	0.008	35.63
Toff	3	9.0484	9.0484	3.0161	10.21	0.044	10.19
I	3	41.8336	41.8336	13.9445	47.18	0.005	47.11
Uw	3	5.3792	5.3792	1.7931	6.07	0.086	6.05
Residual Errors	3	0.8866	0.8866	0.2955			
Total	15	88.7885					
S = 0.5436 R-Sq = 99.0 % R-Sq(adj) = 95.0 %							

The use of larger F-Statistics revealed that adjusting of control factors had a considerable impact on performance. R-Square signifies the limits of control factors that intercept changes in the output performance.

Table 8. ANOVA for KW.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Ton	3	1.50321	1.50321	0.501069	116.54	0.001	26.78
Toff	3	1.98627	1.98627	0.662088	154.00	0.001	35.39
I	3	0.24451	0.24451	0.081503	18.96	0.019	4.35
Uw	3	1.86557	1.86557	0.621858	144.64	0.001	33.23
Residual Errors	3	0.01290	0.01290	0.004299			
Total	15	5.61245					
S = 0.06557 R-Sq = 99.8 % R-Sq(adj) = 98.9 %							

Table 9. ANOVA for SR.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Ton	3	33.9501	33.9501	11.3167	156.87	0.001	87.8
Toff	3	1.2681	1.2681	0.4227	5.86	0.090	3.27
I	3	1.9234	1.9234	0.6411	8.89	0.053	4.97
Uw	3	1.3079	1.3079	0.4360	6.04	0.087	3.38
Residual Errors	3	0.2164	0.2164	0.0721			
Total	15	38.6660					

S = 0.2686 R-Sq = 99.4 % R-Sq(adj) = 97.2 %

It was revealed that at the 95 % confidence level, when p is less than 0.05, I and Ton with contribution 47.11 % and 35.63 % had a significant influence on MRR as depicted (Fig. 5). Similarly, Toff and Uw had the highest contribution to KW with 35.39 % and 33.23 % while Ton had highest contribution to SR with 87.8 %, with the other factor being inconsequential.

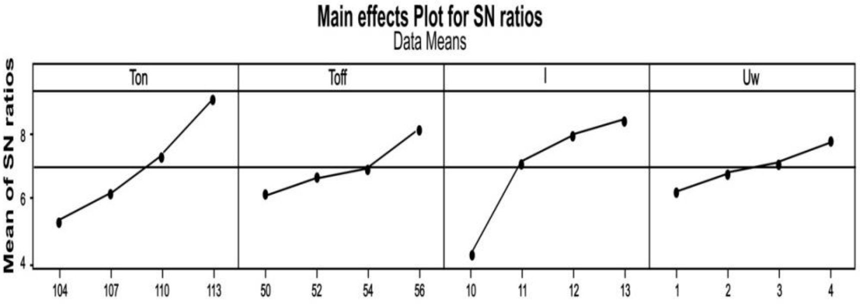

Fig. 2. Effects of inputs for SNR (MRR) at different level.

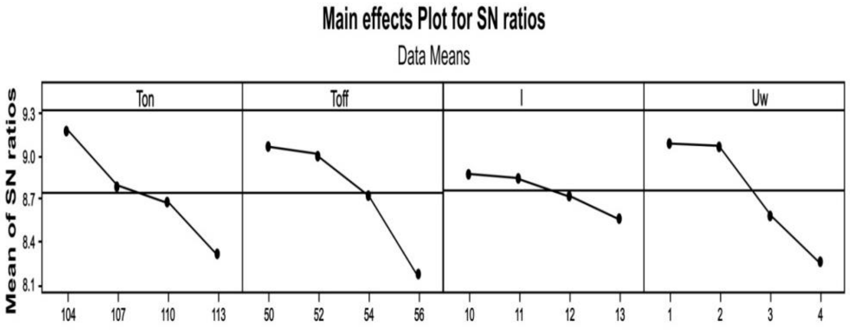

Fig. 3. Effects of inputs for SNR (KW) at different level.

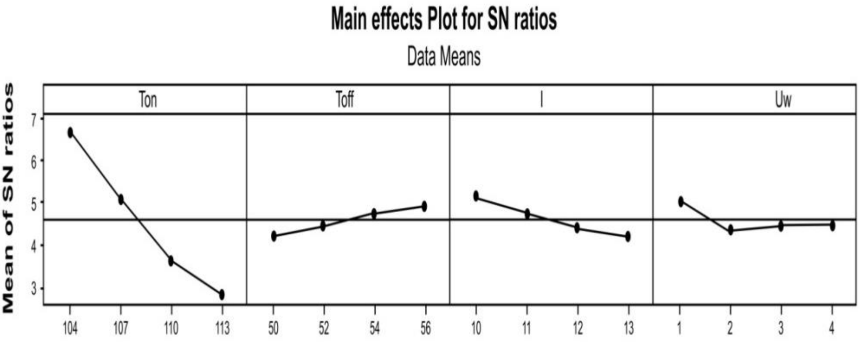

Fig. 4. Effects of inputs for SNR (SR) at different level.

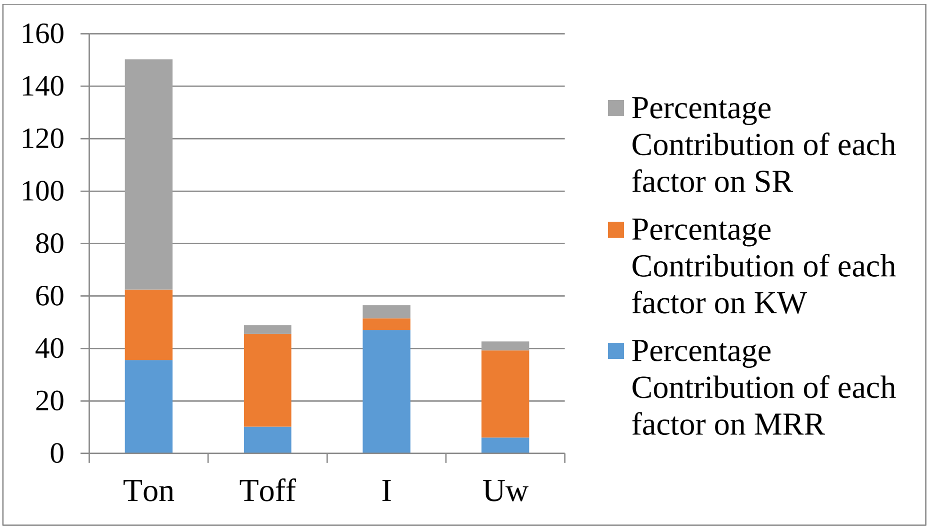

Fig. 5. Percentage Contribution of each factor on MRR, KW and SR.

4. Result Validation

The next step would be to validate the deviations of MRR, KW and SR between the experimental and primary settings. The predicted value at optimum level of input factor and its validation is tabulated in Table 10 which shows some variation from the predicted values. The average of MRR changed by 0.148 mm^3/min for setting of Ton4Toff4I4Uw4 and similarly, the average values of KW and SR varies by 0.001 mm and 0.008 µm for setting of Ton1Toff1I1Uw1 and Ton1Toff4I1Uw1, indicating the best combination of factors to enhance the MRR and to reduce the KW and SR. Also, it confirms that the percentage error between the actual and projected values is below 5 %. It validates the exceptional stability of the outcomes and shows that the optimum levels of factors and output performance are in close alignment with the achieved values.

Table 10. Validation of results.

Output	Levels				Optimum Solution		Difference	% Error
	Ton	Toff	I	Uw	Predicted	Experimental		
Max. MRR	4	4	4	4	3.671	3.523	0.148	4.20
Min. KW	1	1	1	1	0.316	0.317	0.001	0.31
Min. SR	1	4	1	1	0.369	0.361	0.008	2.21

4. Conclusion

The significant effects of WEDM input factors on the performance of alloy 718 material have been discussed. DOEs and ANOVA were used to evaluate the performance characteristics. The major findings are discussed as follows:

During machining of alloy 718, I has the greatest influence on MRR while Uw is lowest, with contribution of 47.11 % and 6.05 % respectively. For KW, Toff is greatest influential factor while I is lowest, with contribution of 35.39 % and 4.35 %. For SR, Ton is greatest influential factor while Toff is lowest, with contribution 87.8 % and 3.27 %. The finding indicates that Ton4Toff4I4Uw4 provide the best combinations of different levels of factors for higher MRR and it has been calculated as 3.523 mm^3/min in the aforesaid combinations.The finding also indicates that Ton1Toff1I1Uw1 and Ton1Toff4I1Uw1 provide the best combinations of different levels of factors for lower KW and SR, and it has been determined to be 0.317 mm and 0.361 μm at the aforesaid combination.From result validation, it confirms that the percentage error between the actual and predicted values is below 5 %. For MRR, the percentage error is 4.20 % while for KW and SR, it is 0.31 % and 2.21 % indicating the close alignment with the achieved value.

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