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Optimization of Surface Roughness in Wire Electrical Discharge Machining of Nickel Based Super Alloy

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Abstract: This paper presents the experimental results for the optimization of Wire Electrical Discharge Machining process in machining of Nimonic 90 and Monel 400 using Taguchi's method. Using Taguchi's L18 orthogonal array, process parameters namely work material, pulse on time, pulse off time, peak current and servo voltage were investigated for surface roughness. Analysis of variance shows that all the input process parameters are highly significant for surface roughness.

Key words: **wire electrical discharge machining, Nimonic-90, monell-400, Taguchi method**

I. INTRODUCTION

Nickel based super alloys are growing class of exotic materials which is potentially used in the manufacturing of components for aerospace engine in gas turbine compartments and other applications such as sub marine equipment's, nuclear reactors, petrochemical plants, aircraft gas turbines components, medical equipments e.g. dentistry uses, prosthetic devices and orthopaedic application etc (Ezugwu et al. 2005, Choudhury et al. 1998). Nearly two third of nickel based superalloy production is consumed by aerospace industries for manufacturing of aircraft engine parts. Since it possess excellent mechanical and chemical properties at elevated temperature and high corrosion resistance (Ezugwu et al. 2005).

Nickel based alloys may contain the constituents of chromium, aluminium, titanium, cobalt, molybdenum and other elements in varying quantity to give their outstanding high temperature strength and extreme toughness which create difficulties during machining and resulting in development of very high cutting forces (Ezugwu et al. 1999, Kwong et al. 2009). Machining of nickel alloys with conventional processes creates built up layer on cutting tool face resulting large crater wear and poor surface integrity involving several surface defects such as surface drag, material pull-out/cracking, tearing surface etc (Ulutan et al. 2011, Kortabarria et al. 2011 , Herbert et al. 2012, Krainet al. 2007, Sharman et al. 2004). These surface defects significantly lower the fatigue life of nickel based aero-components.

Wire electrical discharge machining (WEDM) process is best non-conventional machining process to machine complex geometries in high strength, high hardness materials with high precision. Several investigations have also been carried out on EDM and WEDM. In Electrical Discharge Machining of Nickel based heat resistance alloy Hastelloy–X, machining characteristics Pulse on time was the main factors that affect the surface integrity of the work material (Kang et al., 2003). The most influential factor on MRR was discharge current and duty factor. High value of discharge current was suggested for obtaining high MRR during the electrical Discharge machining of Inconel 718 with hollow tools (Rajesha et al., 2010). The Taguchi method is used to analysis the significance effect of each parameter i.e. peak current, gap voltage,pulse on time and duty cycle during machining of Inconel 718 using WEDM with a copper electrode on machining characteristics such Material Removal Rate, Electrode wear rate and Radial over cut and half taper angle .Peak current significantly affect the Material Removal Rate and pulse on time significantly affect the Electrode wear rate (Ghewade and Nipanikar 2011, Hewidy et al. 2005). WEDM process parameters of Incoloy 800 super alloy with multiple machining performance characteristics such as material removal rate, surface roughness and kerf were optimised by using Gray – Taguchi method (Kumar et al. 2010, Antar et al. 2011).

In present study two Nickel based alloy Nimonic 90 (Nickel –Chromium – Cobalt alloy) and Monel 400 (Nickel - Copper alloy) are taken as work materials. Using Taguchi's design of Experiment, effect of machining parameters namely pulse on time, pulse off time, peak current and servo voltage has been evaluated on surface roughness in Wire EDM machining of two Nickel based super alloys. An optimal setting of machining parameters has been obtained for minimising the surface roughness in WEDM of Nickel alloys.

II. EXPERIMENTAL PROCEDURE

2.1 Experimental set up

The machining experiments were performed on 5 axis sprint cut (ELPUSE-40) wire EDM manufactured by Electronic M/C Tool LTD India. In present machine tool ,parameters can be varied under following range; discharge current (Ip), 10-230 amp; pulse on time (Ton) ,101-131 µs; pulse off time (Toff) ,10-63 µs ; servo voltage (SV), 0-90 V; dielectric flow rate (DFR) , 0-12 liter per minute ; wire feed rate(WF) ,1-15 m/min; wire tension (WT) ,1-15 N. Copper coated brass wire of diameter 0.25mm was used as an electrode because of its good capability to sustain high discharge energy. Distilled water was used as a dielectric fluid with conductivity 20 S. The chemical composition and mechanical properties of Nimonic 90 and Monel 400 work-piece materials used in the experiments in the form of a rectangular sheet of 12.5 mm thickness are shown in Tables 1

a. Experimentation

In present work, five process parameters have been chosen for investigation such as work materials (M), peak current (Ip),pulse off time (Toff), and servo voltage (SV). As the thickness of work pieces material is low (12.5 mm), therefore, feed rate of wire was kept constant at a value of 5m/min. Wire off set was taken at zero value. Table 2 show the selected parameters and their levels. L18, orthogonal array was selected in present work to conduct the experimentation. Experiment plan is listed in table 3.

Table 1Chemical composition and mechanical properties of Nickel based alloys

Work Material	Density	Melting point	Co-efficient of Expansion	Modulus of Rigidity	Modulus of Elasticity
Nimonic 90(wt %) (Ni 60, Cr 19.3,Co 15, Ti 3.1, Al 1.4)	8.18 g/cm^3	1370^{0}C	12.7µm/m ^{0}C	82.5KN/mm²	213KN/mm²
Monel 400(wt %) (Ni 63.47, Cu 33, Fe 2.13, Mn 1)	8.8 g/cm^3	1350^{0}C	13.9µm/m ^{0}C	65.3 KN/mm²	115 KN/mm²

Table 2 Machining parameters and their levels

Symbol	Machining Parameter	Units	Level 1	Level 2	Level3
A	Material (M)	Monel	Nimonic-	90	
B	Peak Current	Amp	90	120	150
C	Pulse on Time	µs	106	112	118
D	Pulse off Time	µs	35	40	45
E	Servo voltage	V	30	40	50

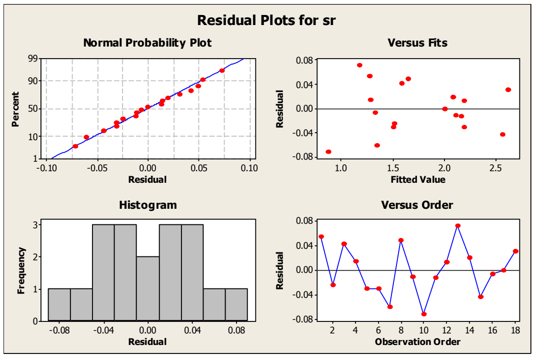
Table 3 Experimental layout using an L18 orthogonal array

	Machining parameters				
Exp No.	A Material type	B Peak current	C Pulse on time	D Pulse off time	E Servo voltage
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	3	3
11	2	1	2	1	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

2.3 Experimental Results

Based on the experimental layout shown in table no.3, the experiments were performed. In this experiment the surface roughness (Rmax. µm) of machined surface is measured by using the digital surface tester Mitutoyo 201P. Observed surface roughness characteristics are shown in Table 3. Residual plot for mean surface roughness are shown in figure no 1.

Residual plots are used to evaluate the data for the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. It can be seen from Figures 1 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.



Residual plot for mean surface roughness are shown in figure no 1.

III. OPTIMIZATION OF SURFACE ROUGHNESS

In Taguchi method, the S/N ratio can be used to measured deviation of the performance characteristics from the desired value, so that the experimental results are transformed into a signal to noise ratio. The objective of using the S/N ratio is a measure of performance to develop products and processes insensitive to noise factors. There are three types of S/N ratio- the lower the better, the higher the better and nominal the better. In present work, we have selected lower the better for Surface Roughness.

S/N for lower the better

$$\text{S/N ratio } \eta = 10 * \text{Log } (1/\sum_{i=1}^{n} \frac{1}{y_{ij}^2}) \quad (1)$$

Where n= repeated number of experiments

y_{ij} =observed machining experiment response value

Where i = 1,2,3,......, n j = 1, 2, 3,......., k

Table 4 shows the S/N ratio and measured mean values of Surface Roughness.

Table 4: Mean value and S/N ratio of Surface Roughness

Experiment No.	SR (µm)	(S/N ratio) SR
1	1.33	-2.47703
2	1.49	-3.46373
3	1.63	-4.24375
4	1.3	-2.27887
5	1.47	-3.34635
6	2.16	-6.68908
7	1.28	-2.1442
8	1.7	-4.60898
9	2.1	-6.44439
10	0.8	1.9382
11	2.15	-6.64877
12	2.2	-6.84845
13	1.25	-1.9382
14	2.1	-6.44439
15	2.52	-8.02801
16	1.32	-2.41148
17	2	-6.0206
18	2.65	-8.46492
Average	1.747222	

The response table using Taguchi method is employed to calculate the effect of each level of process parameter on surface roughness. Table 5 shows response table for mean surface roughness.

Table 5 Response Table for Mean Surface Roughness

Level	A	B	C	D	E
1	1.607	1.600	1.213	1.900	1.945
2	1.888	1.800	1.818	1.723	1.755
3		1.842	2.210	1.618	1.542

Figure no. 2 shows the S/N ratio plot for surface roughness (SR). The optimum parameters combination for Surface Roughness is A1B1C1D3E3 corresponding to largest values of S/N ratio for all process parameters.

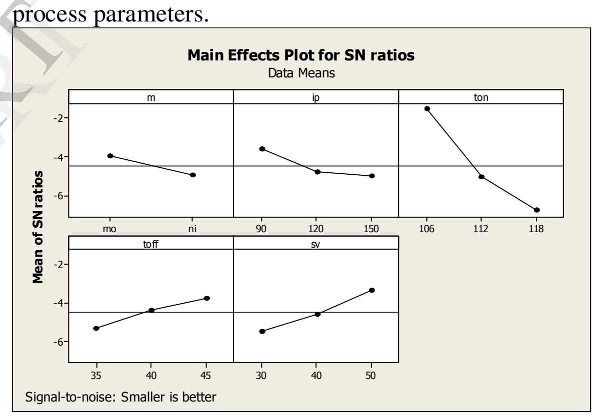


Figure no. 1 Main effect plots for S/N ratio of Mean Surface Roughness.

3.1 Analysis Of Variance (ANOVA)

Using Mini Tab 16, a stastical tool the Analysis of variance (ANOVA) was performed to find out the significantprocess parameters on surface roughness. Table 6 shows the effect of individual machining parameters (with percentage of contribution). P value lower than 0.05 implies that parameter is highly significant under 95% confidence level.

3.2 Predicted optimal results

In order to predict the optimal values of the machining characteristics, only significant parameters are included which were found utilizing analysis of variance (ANOVA). The optimal values are calculated by using the formula

$$\eta_{opti} = M + \sum_{i=1}^{m} (M_{i,j})_{max} - M) \quad (2)$$

η_{opti} = Predicate optimal value
M = Total mean of S/N ratio
m = number of significant process parameters affecting the machining performance
$(M_{i,j})_{max}$= S/N ratio of optimum level i of parameter j

Table 6 ANOVA for mean surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
WM	1	0.33561	0.35561	0.35561	102.29	0.000
Ip	2	0.20028	0.20028	0.10014	28.81	0.000
Ton	2	3.02554	3.02554	1.51277	435.16	0.000
Toff	2	0.24314	0.24314	0.12157	34.97	0.000
SV	2	0.48858	0.48858	0.24429	70.27	0.000
Error	8	0.02781	0.02781	0.00348		
Total	17	4.34096				

S = 0.05896 R-Sq = 99.36% R-Sq(adj) = 98.64%

Table 6 shows ANOVA for mean surface roughness. It is clear from the table 6 all these parameters has significantly (since *p-value* ≤ 0.05) affecting the Surface Roughness under 95% confidence level. Using Eq. (2), the optimum value is calculated as follows,

$\eta_{opti} = M + \sum_{i=1}^{m} (M_{i,j})_{max} - M) = 1.747 + (1.607 - 1.747) + (1.600 - 1.747) + (1.213 - 1.747) + (1.618 - 1.747) + (1.542 - 1.747) = 0.70$

Confirmatory experiments were conducted for surface roughness corresponding to their optimal setting of process parameters to validate the used approach. Table 7 displays the predicted and experimental values of surface roughness

Table 7 Optimal values of individual machining characteristics

Machining Characteristic	Optimal parameterscombination	Significant parameters	Predicted optimalvalue	Experimental value
Surface Roughness	A1B1C1D3E3	A B C D E	0.7 µm	0.8 µm

IV. CONCLUSIONS

In this study, machinability of Nimonic 90 and Monel 400 with wire EDM has been investigated in term of surface roughness. Taguchi's design of experiment technique was used to optimize the four process parameters namely peak current, pulse on time, pulse off time and servo voltage to achieve minimum surface roughness.The optimal predicated value for surface roughness is 0.7 µm .ANOVA was used to predict the significant factors affecting the surface roughness. Using ANOVA on experimental results, all of these process parameters namely work material, pulse on time, pulse off time, peak current and servo voltage were found the most significant affecting the surface roughness under 95% confidence level.

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