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A parametric optimization using Taguchi method: effect of WEDM parameters on surface roughness machining on inconel825

G.Rajyalakshmi[1] and P.Venkata Ramaiah[2]

[1]Manufacturing Division, School of Mechanical and Building Sciences, VIT University, Vellore,Tamil Nadu-632014, India.

[2]Department of Mechanical Engineering, Sri Venkateswara University, Tirupati, Andhra Pradesh-517 502, India.

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ABSTRACT

This paper presents an experimental investigation on the influence of cutting parameters of wire cut Electrical Discharge Machining (Wire-EDM) during the machining of Inconel825.Demand for better surface finish has been increasing recently for super alloys. The low rigidity and high material removal rate of Inconel alloys offers a challenging task in obtaining a better surface finish. The analysis of surface characteristics like surface roughness of Inconel-825 is carried out and an excellent machined finish can be obtained by setting the machining parameters at optimum level. Experimentation has been done by using Taguchi's L18 (21x37) orthogonal array under different conditions of parameters. The response of surface roughness is considered for improving the machining efficiency. Optimal combinations of parameters were obtained by this method. The confirmation experiment shows, the significant improvement in surface finish (1.36µm) was obtained. Multiple linear regression model have been developed relating the process parameters and machining performance indicates the suitability of the proposed model in predicting surface roughness. The regression analysis are used to predict the error between actual and regression values of surface roughness in Wire EDM process. Experimental results demonstrate that the machining model is suitable and the Taguchi's method satisfies the practical requirements.

Introduction

The wire-cut electrical discharge machining plays an important role in manufacturing sectors especially industries like aerospace, ordinance, automobile and general engineering etc [1-2]. Conventional machining is more efficient than unconventional machining like wire-cut EDM process but it is difficult to obtain intricate and complex shapes of the components [3] as it is required in the above mentioned applications. Moreover machine tool tables provided by the manufacturer often do not meet the requirements in machining a particular material [4]. So, to obtain various shapes of structural components the wire-cut EDM process is important in many cases, but it requires the improved machining efficiency. Hence, for improving the machining efficiency it requires the models to predict optimum parametric combinations accurately. But wire-cut EDM consists of a number of parameters, which makes it difficult to obtain optimal parametric combinations for machining different materials for various responses like surface roughness, material removal rate, kerf etc. Taguchi's robust design has been used in various applications to obtain optimum parametric combinations [4-9] for desired responses. In many of the manufacturing processes, the surface roughness is one of the response performance measures. Several researchers were attempted previously to improve the surface roughness [10-20] on various materials. Han et al [14] were conducted the experiments on different materials namely aluminum alloy, brass, alloy steel, cemented carbide at the same conditions to obtain surface roughness. They found that the rigidity is a significant factor affecting the surface roughness. The surface roughness decreases accompanying an increase in material rigidity. Therefore high rigidity materials will produce finer surfaces and low rigidity materials like aluminum alloys produces high surface roughness. Inconel is a high strength, temperature resistant nickel-based super alloy. It is extensively used in aerospace applications, such as gas turbines, rocket motors, and spacecraft as well as in nuclear reactors, pumps and tooling. Inconel is difficult to machine, because of its poor thermal properties, high toughness, high hardness, high work hardening rate, presence of highly abrasive carbide particles and strong tendency to weld to the tool to form build up edge [21-23].

In addition, Khan [24] presented his analysis on material removal rate during EDM of aluminum and mild steel using copper and brass electrodes. The highest material removal rate was observed during machining of aluminum due to high thermal conductivity and low melting point when compared to steel at low thermal conductivity and high melting point. As a result highest material removal rates were obtained during machining of aluminum alloy. It is well known fact that a high material removal rate and a very good surface finish can never be achieved simultaneously in WEDM process [25-28]. Hence, wire-cut electrical discharge machining of Inconel825 alloy has been considered in the present set of research work with surface roughness as a response variable. This material is rapidly growing its applications because of its high strength and hardness even at higher temperatures this suits most of the engineering requirements today. So far very limited work has been reported on Inconel alloys in wire electric discharge

Tele:

E-mail addresses: rajyalakshmi@vit.ac.in

machining. The main objective of this paper is to study the effect of different parameters of WEDM using Taguchi's design methodology. To prepare the models for machining of Inconel alloy using standard matrix experiments L18 (21X37) orthogonal array. In several references it is found that very few researches considered parameters like servo gap voltage and servo feed rate setting which also have an impact on surface roughness. The results obtained are analyzed for the selection of an optimal combination of WEDM parameters for proper machining of Inconel825 alloy to achieve better surface finish. Different analyses were made on the data obtained from the experiments. Analysis of variance (ANOVA) is carried out to determine significant factors and signal-to-noise (S/N) ratio is conducted to find the optimal settings and factor levels. To establish a relationship between factors and response variable multiple regression models was used. Finally, experimental confirmations were carried out to identify the effectiveness of this proposed method.

Materials and methods:

Work Material: Inconel825

Inconel825alloy was used for the present investigation.Inconel825 is a high performance alloys, mainly Nickel Alloy and also Cobalt and Titanium. Inconel825 might be used in any environment that requires resistance to heat and corrosion. They have good resistance to oxidation and corrosion at high temperatures. Inconel825 typically finds application in Furnace components, chemical processing, Food processing industry and nuclear engineering. In recent past Inconel825 super alloy gained dominance in aerospace applications because of its special features. This alloy does work-harden during machining and has higher strength and "gumminess" not typical of steels.

Experimental Setup:

Wire Electrical Discharge Machine: All the experiments were conducted on Ultra Cut 843/ ULTRA CUT f2 CNC Wire-cut EDM machine. In this machine, all the axes are servo controlled and can be programmed to follow a CNC code which is fed through the control panel. All three axes have an accuracy of 1µm. Through an NC code, machining can be programmed. Wire-cut electrical discharge machining of Inconel825 alloy has been considered in the present set of research work. The size of the work piece considered for experimentation on the wire-cut EDM is 10 mm x 10 mm x 15 mm. According to the Taguchi method based on robust design a L18 (21X37) mixed orthogonal array is employed for the experimentation. Among the eight WEDM parameters two levels for one control factor (Pulse on time) and three levels for remaining seven control factors, are considered for optimality analysis during machining of Inconel825 alloy.

Fig: 1 Ultra Cut 843/ ULTRA CUT f2 CNC Wire-cut EDM machine

Work-piece after WEDM machining

Figure 2: Work piece after wire cut electrical discharge machining

Machining Parameter selection and performance evaluation

To perform the experimental design, the levels of machining parameters are selected as in Table3.

Data collection

Surface roughness measurement has been done using surfcorderSE3500 in µm a stylus-type profilometer. Surface roughness measurements are taken on the work pieces in the transverse direction; and this procedure have been repeated five times to obtain the average values of surface roughness. In all the measurements of surface roughness cut-off length is taken as 0.25 mm.

Taguchi Method

Two major tools used in Taguchi's method are one is signal(S) to noise (N) ratio i.e. S/N ratio to measure the quality and the other is orthogonal arrays to accommodate many factors simultaneously to evaluate the machining performances. The ability of orthogonal arrays lies in evaluating the machining performance with a less number of experiments when compared to full factorial experiments which reduces the number of trials [9]. This greatly reduces the time required in conducting the experiments and also in evaluating the significant and insignificant parameters.

Analysis of Variance (ANOVA)

Analysis of variance is performed to control the process variation and later on the parameters which affect the performance can be identified and decision can be made based on the results obtained. Through ANOVA, the parameters can be categorized into significant and insignificant machining parameters [5-8]. Table 4 shows the affect of individual parameters and Fisher test values (with percentage of contribution) for surface roughness during the machining of Inconel825 alloy. Here, D.F is the degrees of freedom, SS is the sums of square, V is the variance, F is the Fisher value and %p is the percentage of contribution. From the ANOVA calculations, it is found that, the parameter WF and TON are most significant. WP and SV are significant. TOFF, CS, WT and SF are less significant on performance measure, i.e., surface roughness.

Signal-to-Noise ratios (S/N ratio)

The S/N ratio value is a transformed value of the repeated data indicating the measure of variation. It is denoted by "η" with a unit of dB. Among the available S/N ratios based on their characteristics; "Lower is better" is selected for the performance measure surface roughness. This value is a logarithmic transformation of the loss function as shown in (1) for surface roughness. Table 5 shows the S/N ratio values for the experiments conducted on the Inconel825 alloy. Table 6 shows the mean S/N ratio values of surface roughness for each parameter.

Analysis of Data

S/N ratios are selected based on their characteristics; irrespective of the characteristic a higher S/N ratio value always represents the better performance. Therefore among the levels of each parameter the higher S/N ratio corresponds to optimal level. The S/N ratio calculations were done for all the experiments in L18 (21X37) orthogonal array and the optimal surface roughness was obtained at 110 µs pulse on time (level 1), 60 µs pulse off time (level 3), 60 volts for corner servo voltage (level 2), 6Kg/cm2 flushing pressure of dielectric fluid (level 1), 2 m/min wire feed rate setting (level 1), 11 Kg-f wire tension setting (level 3), 25Volts spark gap voltage Setting (level 2) and 1150mm/min servo feed Setting (level 3). From the signal to noise ratio, optimal combination of parameters was obtained for SR as A1B3C2D1E1F3G2H3. A separate experiment was conducted at this optimal combination and an improved surface roughness value of 1.36µm was obtained. This is 1.514 times the initial surface roughness value (2.06 µm) obtained at A1B1C1D1E1F1G1H1. This is an indication of improvement in the machining performances i.e. surface roughness. Fig. 3 shows the effect of control factors on surface roughness diagrammatically. Figs. 4-5 show the surface roughness at initial and optimal combination of parameters.

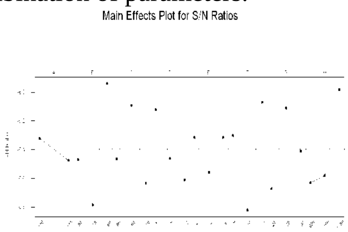
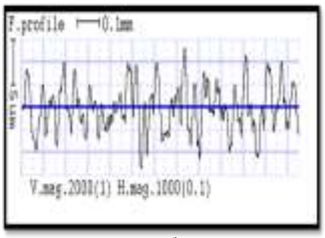
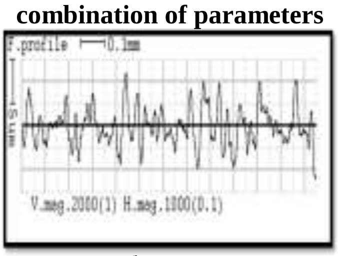


Figure. 3: Effect of control factors on surface roughness



R_a=2.06µm **Cutoff 0.25mm**

Figure. 4: Surface rough ness's obtained during initial combination of parameters



R_a=1.36µm **Cutoff 0.25mm**

Figure. 5: Surface roughness obtained during optimal combination of parameters.

Confirmation Experiment

The final step in Taguchi's design of experiment (DOE) process is the confirmation experiment. The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. The confirmation experiment is performed by conducting a test with specific combination of factors and levels previously evaluated. In this study, after determining the optimum levels, a new experiment is designed and conducted with optimum levels of the machining parameters. The final step is to predict and verify the improvement of the performance characteristics. The predicted S/N ratio using the optimal levels of the machining parameters can be calculated as in (2).

$$\eta_{opt} = \eta_m + \sum_{j=1}^{k} (\eta_j - \eta_m) \qquad (2)$$

Here, η_{opt} is the predicted optimal S/N ratio, η_m is the total mean of the S/N ratios, η_j is the mean S/N ratio at the optimal levels and k is the Number of main design parameters that affect the quality characteristics. The determined optimal combination A1B3C2D1E1F3G2H3.for SR with respect to the actual chosen initial setting (i.e., A1B1C1D1E1F1G1H1) improves the S/N ratio by 7.729 dB .This satisfies the real requirement of wire-cut EDM operations for the proper machining of Inconel825Alloy. The confirmation experiment shows that, the used Taguchi's method enhanced the machining performance and optimized the machining parameters.

Mathematical Models to Relate the Parameters with Surface Roughness

Multiple linear regression (MLR) models can often be an adequate representation of a more complicated structure, within certain ranges of the independent variables [25]. The generalized model of MLR analysis, gives the relationship between response and independent variables and the estimated response is obtained from the generalized simple regression equation. The constants were obtained by using linear regression analysis method with the help of MINITAB 14 software and the obtained coefficients were substituted in (3). Table:7 shows the values obtained in predicting the surface roughness and S/N ratio values using the developed mathematical model and the actual experimental results. Fig. 6 shows the good agreement of predicted values with experimental values for surface roughness. The above mathematical model for SR in WEDM is of great importance for selection of machining parameters during the machining of Inconel825 alloy. So, the suggested mathematical model is as given in (3)

The regression equation is

SR = 3.60 + 0.0080 TON - 0.0118 T OFF + 0.00183 CS + 0.0192 WP + 0.0008 WF - 0.0292 WT - 0.0062 SV - 0.00145 SF ---------------- (3)

S = 0.1857 R-Sq = 36.4%

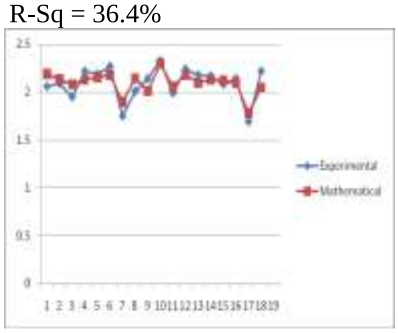


Figure. 6: Comparison between predicted and experimental SR values using Mathematical model

Results and Discussion

The effect of the wire-cut EDM parameters on surface roughness in machining Inconel825 alloy is studied. From the ANOVA and S/N ratio calculations, it is found that, the parameters WF and TON have the most significant effect on surface roughness due to the fact that the energy content of a single spark discharge can be expressed as a product of TON x

WF known as discharge energy. So, increasing the discharge energy generally increases surface irregularities due to much more melting and re-solidification of materials. Because of this, large debris is formed which cannot easily pass through a narrow gap, so it stays between the wire and work piece reducing the surface quality. Hence, it is found that SR tends to decrease significantly with decrease in WF and TON. Here, the minimum SR is obtained at low WF (2m/min) and low TON (110 μsec).

The parameters water pressure and spark gap voltage are observed as significant parameters in obtaining better surface finish. This is due to increase of wire tension reduces its vibration and improves the surface quality of the machined part. The increase of voltage means that the electric field becomes stronger and the spark discharge takes place more easily under the same gap and a coarse surface is always obtained. The minimum SR is obtained at high flushing pressure (12kg-f) and low spark gap voltage (20 V). The proposed mathematical model predicted values at optimum and initial conditions with an error of 2.94% and 5.89% for SR when compared with the experimental values. A good agreement of results was obtained with mathematical model when compared to the experimental work

Conclusions:

The effects of pulse on time, pulse off time, peak current, flushing pressure of dielectric fluid, wire feed rate setting, wire tension setting, spark gap voltage setting and servo feed setting are experimentally investigated in machining of Inconel825 alloy using CNC Wire-cut EDM process. Analysis of variance and S/N ratios determined the importance of parameters and optimum parametric combination respectively for the response of surface roughness. Improved S/N ratio values and confirmation test results showed the possibility of improvement in surface finish using Taguchi's method. From the present analysis it is evident that the optimal parametric combination will be beneficial for the people working on high strength and hardness even at higher temperatures, high thermal conductivity and low melting point materials of nickel alloys. The proposed regression model (with high correlation co-efficient) successfully predicted the parametric values in the machining of Inconel825 alloy.

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Table 1: The Chemical composition of Inconel-825

Elements	C	Si	Cu	Mn	Mo	Cr	Ni	Al	S	Ti	Fe
Content (%)	0.05	0.5	1.5-3.0	1.0	2.5-3.5	19.5-23.5	38-46	0.2	0.03	0-1.2	22

Table 2: Typical Properties of Inconel825

Property	Metric	Imperial
Density	8.14 g/cm^3	0.294 lb/in^3
Melting point	1400°C	2550°F
Co-Efficient of Expansion	14.0 µm/m.°C (20-100 °C)	7.8x10^{-6} in/in.°F (70-212 °F)
Modulus of rigidity	75.9 kN/mm^2	11009 ksi
Modulus of elasticity	196 kN/mm^2	28428 ksi

Table: 3: Experimental factors and their levels for Wire Electrical Discharge Machining process

S.No	Factor	Parameter	Symbol	Level-1	Level-2	Level-3
1	A	Pulse On Time	T ON(µs)	110	115	-
2	B	Pulse Off Time	T OFF(µs)	50	55	60
3	C	Corner servo	CS(volts)	50	60	70
4	D	Flushing pressure Of Dielectric Fluid	WP(Kg/cm^2)	6	9	12
5	E	Wire feed rate	WF(m/min)	2	4	6
6	F	Wire tension N	WT(Kg-f)	9	10	11
7	G	Spark gap voltage	SV(volts)	20	25	30
8	H	Servo Feed	SF(mm/min)	1050	1100	1150

Table 4: ANOVA Table for Surface Roughness (SR):

Source	DF	Sum of Squares	Mean sum of Squares	F ratio	P value
A	1	0.0072	0.0072	0.341	0.631
B	2	0.1140	0.0570	2.704	0.136
C	2	0.0510	0.0255	1.208	0.437
D	2	0.0420	0.0210	0.9952	0.509
E	2	0.0107	0.0054	0.255	0.847
F	2	0.0992	0.0496	2.35	0.182
G	2	0.0444	0.0222	1.05	0.489
H	2	0.0771	0.0385	1.82	0.275
Error	2	0.0422	0.0211		
Total	17	0.4878			

Table 5: Experimental Design Using L18 (21x37) Orthogonal Array

Ex. No	A	B	C	D	E	F	G	H	Surface Roughness (µm)	S/N Ratio Surface Roughness
1	1	1	1	1	1	1	1	1	2.06	-6.2773
2	1	1	2	2	2	2	2	2	2.09	-6.4029
3	1	1	3	3	3	3	3	3	1.95	-5.8006
4	1	2	1	1	2	2	3	3	2.22	-6.9270
5	1	2	2	2	3	3	1	1	2.19	-6.8088
6	1	2	3	3	1	1	2	2	2.27	-7.1205
7	1	3	1	2	1	3	2	3	1.75	-4.8607
8	1	3	2	3	2	1	3	1	2.01	-6.0639
9	1	3	3	1	3	2	1	2	2.14	-6.6082
10	2	1	1	3	3	2	2	1	2.33	-7.3471
11	2	1	2	1	1	3	3	2	1.99	-5.9770
12	2	1	3	2	2	1	1	3	2.24	-7.0049
13	2	2	1	2	1	1	3	2	2.18	-6.7691
14	2	2	2	3	2	2	1	3	2.17	-6.7292
15	2	2	3	1	3	3	2	1	2.08	-6.3612
16	2	3	1	3	3	3	1	2	2.14	-6.6082
17	2	3	2	1	1	1	2	3	1.69	-4.5577
18	2	3	3	2	2	2	3	1	2.22	-6.9276

Table 6: Mean S/N Ratios for SR at each Level for all the Parameters

Level	TON	T OFF	CS	WP	WF	WT	SV	SF
1	-6.31893	-6.46835	-6.46495	-6.11812	-6.31532	-6.29893	-6.67282	-6.3093
2	-6.47576	-6.78601	-6.08995	-6.46229	-6.56140	-6.82361	-6.10839	-6.58103
3	-----	-5.93767	-6.63713	-6.61162	-6.31531	-6.06949	-6.41082	-5.98007
Delta	0.15682	0.84834	0.54718	0.49350	0.24610	0.75412	0.56443	0.65087
Rank	8	1	5	6	7	2	4	3

Table 7: Comparisons of Experimental SR Data with Mathematical Model

S. No		Experimental Model	Mathematical Model
		SR	SR
1	Initial conditions	2.06	2.189
2	Optimum conditions	1.32	1.36
3	Improvement	1.56times	1.574times