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Research Article

Experimental Investigations of EDM to Optimize Surface Roughness of Titanium Alloy (Ti-6AL-4V) through Taguchi's Technique of Design of Experiments

Shailendra Kumar Singh[A], Narinder Kumar[A], and Ashwani Kuma[A]

[A]Rayat and Bahra Institute of Engineering and Bio-Technology, Kharar, Punjab. India

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Abstract

In this paper, various parameters of EDM are studied. By using Design of Experiment techniques these parameters are obtained to get the better surface finish on the Titanium alloy (Ti-6AL-4V). The adequate selection of manufacturing conditions is one of the most important aspects to take into consideration in the die-sinking electrical discharge machining (EDM) of conductive materials. In this work, the input parameters selected for the experimental study were Current, Pulse On Time and Pulse off Time. The response parameter that was studied in this test was surface roughness. On the basis of Input and response parameter an orthogonal array 'L9' was used for the statistical analysis. The Minitab version 15 software was used to get optimal values for the test and then a confirmation experiment was done in order to validate the result.

Keywords*: Surface Roughness, EDM, Orthogonal Array, Anova, T_{on}, $T_{off,}$*

1. Introduction

EDM is the thermal erosion process in which metal is removed by a series of recurring electrical discharges between a cutting tool acting as an electrode and a conductive workpiece, in the presence of a dielectric fluid. This discharge occurs in a voltage gap between the electrode and workpiece. Heat from the discharge vaporizes the minute particles of workpiece material, which are then washed from the gap by the continuously flushing dielectric fluid. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. Work material to be machined by EDM has to be electrically conductive. The selection of optimum machining parameters in EDM is an important step. Improperly selected parameters may result in serious problems like short-circuiting of wire, wire breakage and work surface damage which is imposing certain limits on the production schedule and also reducing productivity. As material removal rate (MRR) and Surface Roughness (Ra) are most important responses in EDM; various investigations have been carried out by several researchers for improving the MRR, surface finish and kerf width. However, the problem of selection of machining parameters is not fully depending on machine controls rather material dependent.

This study investigated the response optimization of EDM process parameters for machining of Titanium alloy using DOE method to achieve better surface roughness (R_a). The analysis of variance (ANOVA) and necessary confirmation tests were conducted to validate the experimental results the quality of an EDM product is evaluated in terms of its surface integrity, which is characterized by the surface roughness, the presence of white layer, surface crack formations, the metallurgical alterations on the surface and under surface regions, hardness distribution, etc. Additionally, considering the total product production process entirely, it must to take into account the selection of the optimum machining parameters and electrode selection for the maximum material removing and minimum wear rate.

2. Literature Review

K. Ponappa et.al: The EDM is well established machining choice for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage for manufacturing of mold, die, and automotive, aerospace and surgical components. Proper selection of the machining parameters can result in a higher material removal rate, better surface finish, and lower electrode wear ratio. The EDM of titanium alloy (Ti–6Al–4V) with different electrode materials has been accomplished to explore the influence of EDM parameters on various aspects of the surface integrity of Ti6Al4V.

P. Fonda et.al: The EDM technology is widely used in applications such as die and mild machining, micromachining, and prototyping. Among all EDM processes, die sinker EDM is widely used.

H.T. Lee et.al: Die sinking EDM is a machining process where positive feature shapes on the work piece are

*Corresponding author: **Shailendra Kumar Singh**

mapped from the negative features in the electrode. It is relatively low machining process and it require electrode made especially for machining of a given product. The advantage of EDM machine is its ability to produce small, even micro features. The EDM process is used mostly for making dies and moulds.

Basil Kuriachen: have shown that the most efficient parameters are pulse current and pulse duration on the surface integrity of the material among the other EDM parameters. Hence, these two principle EDM parameters were selected for this study also and the experiments were established upon full factorial design of these parameters observed that increase in pulse duration, voltage and wire speed increase the surface roughness whereas increase in flushing pressure of dielectric fluid decrease the surface roughness.

M.M. Rahman: Titanium alloy is to be considered as a rather new material used in the market for manufacturing purpose. It has been become one of the essential metal materials for modern machine building. The use of titanium alloy in various engineering field is due to its high specific strength and high temperature strength within a broad temperature range, and also high corrosion resistance. Comparing to other metal, titanium have lower values of thermal conductivity, electrical resistance and thermal expansion.

Mohd Zahiruddin B Md Zain: Advanced materials such as Titanium Alloy exhibit very excellent technical properties especially in term of strength, hardness and toughness. These materials are suitable in either macro components such as in aerospace and automotive industries or micro components such as in electronic industries. These industries depend increasingly on higher geometric accuracies and micro or nano structured surfaces to meet the growing need for improve performance and reliability. However, it is partially acceptable in industrial application due to difficulties in machining especially when utilizing conventional machining. Therefore, for many industries the above requirements is leading to capabilities of conventional machining methods and machine tools being eclipsed by new processes and machine systems which currently at the research stag.

3. Experimental Setup

Figure 1: Spark Erosion EDM 5030 machine

The experiments were carried out on Electronica EDM machine 5030 (Figure no 1).The electrode material used was copper. The di-electric fluid (de-ionized water) is continuously flashed through the gap between electrode and workpiece, to the sparking area to remove the debris produced during the erosion. The electrode once used cannot be reused again, due to the variation in dimensional accuracy. The work piece i.e. Titanium alloy (Ti-6al-4v) before and after machining is shown respectively in figure 2 & figure 3.

Figure 2: Titanium Alloy Ti-6AL-4V before EDM machining

Figure 3: Titanium Alloy Ti-6AL-4V after EDM machining

Table 1: Shows the experimental setup followed by the experiment

Work piece material	Ti-6AL-4V
Length of work piece	50mm
Diameter of work piece	10mm
EDM used	EMS 5030 (500X300)
Tool Material	Copper
Measuring Instrument	Profilometer (Talysurf), Mitutoyo SJ-201P (for measuring Surface Roughness R_a)
Environment	Wet
Dielectric Fluid	Kerosene oil

Table 2: Levels for Controllable Factors

Factors	**EDM Machining Parameters**	**Symbol**	**Levels**		
			L1	**L2**	**L3**
A	Pulse -on time (µs)	T_{on}	24	32	40
B	Pulse -off time (µs)	T_{off}	7	8	9
C	Current (amp)	I	5	10	15

Table 1 shows the experimental setup detail and experiments were carried out on the basis of DOE techniques. In this work, it is planned to study the behavior of three control factors viz., Pulse on time, pulse off time and current. Table 2 shows the levels of input parameters whereas the Table 3 shows the response value obtained after experimentation.

Table 3: Shows the L9 Orthogonal array with Performance

Exp No.	T_{on} (µs)	T_{off} (µs)	I (amp)	Ra-1	Ra-2	Ra- 3	R_a (Avg) (µm)
1	L1	L1	L1	2.25	3.973	3.752	3.325
2	L1	L2	L2	6.002	5.936	6.911	6.283
3	L1	L3	L3	6.282	5.674	4.811	5.589
4	L2	L1	L2	7.899	6.602	5.509	6.67
5	L2	L2	L3	9.748	9.507	8.213	9.156
6	L2	L3	L1	4.686	4.458	4.692	4.612
7	L3	L1	L3	9.802	9.34	5.833	8.325
8	L3	L2	L1	5.86	5.781	9.809	7.15
9	L3	L3	L2	5.214	4.885	6.611	5.57

Table 4: Analysis of variance (ANOVA) for SN Ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contri-bution
T_{on}	2	6.89	6.89	3.44	19.11	0.050	26.66
T_{off}	2	7.91	7.91	3.95	21.93	0.044	30.60
Curre	2	10.69	10.69	5.34	29.64	0.033	41.35
Error	2	0.36	0.36	0.18			1.39
Total	8	25.85					100

By using the Minitab version 15 software ANOVA was carried and results were shown in Table 4. The results shows that the maximum percentage contribution is 41.35 i.e. by factor Current, while the other factors Pulse on time and pulse off time contributes 26.66 & 30.60 respectively. Figure 4 shows the S/N ratio for Surface Roughness (Signal to noise: Smaller is better).

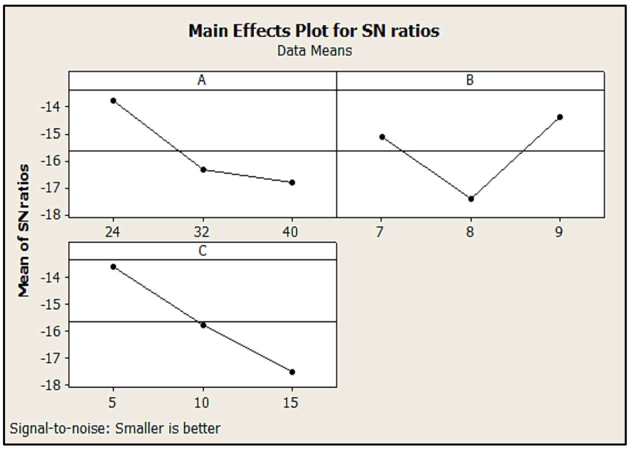

Figure 4- S/N Ratio for Surface roughness

4. Validation

The optimum values for maximum percentage improvement in R_a are $A_1B_3C_1$ for both raw and S/N data. The mean at the optimal percentage improvement in R_a (optimal Value of the response characteristic) is estimated as:

$\Delta R_a = \bar{A}_1 + \bar{B}_3 + \bar{C}_1 - 2 \text{ x } \bar{T}$

Where,

$\bar{T}$ = overall mean of the response = 6.29775 (Table 3)

$\bar{A}$ = Average value of R_a at the first level= 5.0650 (Table 3)

$\bar{B}$ = Average value of in R_a at the third level = 5.257

C = Average value of R_a at the first level of factors = 5.029

Substituting these values of various terms in above equation,

$\Delta R_a = 5.0650+5.257+ 5.029 - 2\times6.29775 = 2.7561$

The Confidence Interval of Confirmation Experiments (CI_{CE}) and of Population (CI_{POP}) is calculated by using the following equations:

$$CI_{CE} = \sqrt{F_{\alpha}(1, F_e) V_e \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

And

$$CI_{POP} = \sqrt{\frac{F_{\alpha}(1, F_e) V_e}{n_{eff}}}$$

Where,

$F\alpha$ (1, f_e) = The F-ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e = 18.51 (Tabulated F value)

f_e = error DOF = 2 (Table 4)

N = Total number of result = 27 (Treatment =9, Repetition = 3)

R = Sample size for confirmation experiments = 3

V_e = Error variance = 0.18 (Table 4)

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean responce}]}$$

So, $CI_{CE} = \pm 1.2181$ and $CI_{POP} = \pm 0.6091$

The 95% confirmation interval of predicted optimal range (for confirmation run of three experiments) is:

Mean $\Delta R_a - CI_{CE}$ < Improve $\mathbf{R_a}$ > Mean $\Delta R_a + CI_{CE}$

1.538 < Improve R_a > 3.9742

The 95% confirmation interval of the predicted mean is:

Mean $\Delta R_a - CI_{POP}$ < Improved $\mathbf{R_a}$ > Mean $\Delta R_a + CI_{POP}$

2.147 < Improve R_a > 3.3652

The optimal value of process parameter for predicted range of optimal R_a.

Pulse on Time (T_{on}) - A, Level 1^{st} (24)

Pulse off Time (T_{off}) - B, Level 3^{rd} (9)

Current (I) - C, Level 1^{st} (5)

5. Confirmation Experiment

In order to validate the result obtained, three confirmation experiment were conducted at the optimum setting of the process parameter. The machining of Titanium alloy was set at the first level of T_{on} (24), third level set at T_{off} (9), and current kept at the first Level of (5). The experimental value of surface roughness was found 2.7683, which was with in the confidence interval of predicted optimal.

Conclusions

The following conclusion can be drawn from this study:-

1. From ANOVA Table 4 and Response Figure 4 for Signal to Noise, based on the ranking it shows that current has a greater influence on the surface roughness followed by Pulse on time. Pulse off time had the least influence on Surface roughness.
2. The optional setting of process parameters for optimal Roughness is Pulse on Time (24µs), Pulse off time (9µs), and Current (5amp).

3. The optimum value of Surface roughness at the optimum parameters Pulse on Time (24µs), Pulse off time (9µs), and Current (5amp) is 2.7683µm.
4. The 95% confidence interval of the predicted mean for R_a is CI_{CE} : 1.538 < R_a > 3.9742.
5. The predicted optimal range of Ra is CI_{POP} : 2.147 < R_a > 3.3652.

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Er. Shailendra Kumar Singh is recently completed his M.Tech in Mechanical Engineering from Rayat and Bahra Institute of Engineering and Bio-technology, Punjab, India. He did his B.Tech in Mechanical Engineering from Chitkara Institute of Engineering and Technology, Punjab, India. His areas of interest are Advance Manufacturing Techniques and Material Science.

Er. Narinder Kumar is presently associated with Rayat and Bahra Institute of Engineering and Bio-Technology, Kharar, Punjab. He is Pursuing Doctor of Philosophy degree from Punjab Engineering College, Chandigarh. He did his M.E from Punjab Engineering College, Chandigarh, India. He has more than seven year's academic experience. His areas of interest are Advance Machining Processes and Operations Management.

Er. Ashwani Kumar is presently working as Associate Professor Rayat and Bahra Institute of Engineering and Bio-Technology, Kharar, Punjab. He is pursuing his Ph.d (ME) from PEC University of Technology, Chandigarh. He has more than nine years of teaching Experience. Hs areas of interest are Advance machining process and Vibration.