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Experimental Methodology of Surface Roughness Characteristics in Electrical Discharge Machining Using Titanium Alloy

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ABSTRACT: This paper brings out a surface model for correlating the various electrical discharge machining (EDM) parameters and performance characteristics utilizing relevant experimental data as obtained through design of experiments (DOE). The effect of the peak current, pulse on time and pulse off time on surface roughness has been investigated. Experiments are planned on titanium alloy using copper as electrode bearing negative polarity. In order to develop the mathematical model as well as to optimize the EDM parameters Response Surface Methodology is introduced. To check the validity test of fit and adequacy of the proposed models, Analysis of Variance (ANOVA) is established.. It can be noticed that if there is a pulse on time increase then it causes the fine surface till it reaches a value and deteriorates in the area of surface finish. An excellent surface finish is investigated in this study in the case of the pulse on time below 80 µs. This result helps out to select the required process outputs and also economy of industrial machining conditions which optimizes the input factors.

KEYWORDS: Ti-6Al-4V, EDM, DOE, Pulse on time, Pulse off time, surface roughness, surface finish.

I. INTRODUCTION

Titanium alloys have been widely used in aerospace industry because of their low weight, high strength-to-weight ratios.. Titanium and its alloys are difficult to machine materials due to several properties of the material. In spite of its more advantages , the capability to produce parts with high productivity is increasing day by day.

Owing to their poor machinability, it is very difficult to machine titanium alloys economically with traditional machining. Electric discharge machining is a non-traditional type of precision processing using an electrical spark-erosion process between the electrode and the work piece of electrically conductive material immersed in a dielectric fluid.

II. LITERATURE REVIEW

It has been widely applied in modern metal industry for producing complex cavities in moulds and dies, which are difficult to machine by conventional machining[2]. Its main feature in utilising thermal energy to do machining on electrically conductive materials irrespective of hardness has been its salient advantage for manufacturing of dies, automotive, aerospace parts and surgical components. Thus, titanium alloy, which is difficult-to-cut material, can be machined effectively by Electrical Discharge Machining.

Selection of the machining parameters results in a higher material removal rates, better surface finish, and lower electrode wear ratio . An Investigation has been developed to introduce a mathematical model for optimizing the EDM process characteristics on matrix composite Al/SiC material (Habib, 2009)[3]. The authors used RSM concept to determine the optimal settings of the EDM parameters such as the metal removal rate, electrode wear ratio, gap size and the surface finish.

The effect of the thermal and electrical properties of titanium alloy Ti–6Al–4V on EDM productivity has been detected (Fonda et al., 2008). They state that the duty volume ratio(DVR) of pulse duration to total pulse time is a vital EDM condition and is an easy means of changing the energy application to the work piece. These conclusions give the opinion that as the duty factor if it increase, the internal temperature of the workpiece also increases, which causes poor productivity and quality in EDM process.

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Regular and uniform selection of electrical discharge process parameters, for titanium alloys' process performance is a challenging task (Mandal et al., 2009)[5]. Optimum selection of parameters is are essential as this is an expensive process which increases the production rate considerably by reducing the machining time. Hence the present paper focuses mainly on the development of models for explaining the various machining process parameters such as Peak current (IP), Pulse on time (ti) and Pulse off time (to) on the familiar characteristics like surface roughness (SR) (Wang and Tsai, 2001)[10]. Optimization of Machining parameters for the titanium alloy Ti-6Al- 4V has been planned using the design of experiments (DOE) and response surface methodology (RSM). A Single-order model is developed to assess the responses of the EDM machining. The effect of input parameters on the machining characteristics such as material removal rate and surface roughness on Titanium alloy, Ti-6Al-4V has been clearly investigated and studied.

III. EXPERIMENTAL METHODOLOGY

The number of experiments are planned to carry out based on CNC programming based 3-Axis EDM..Titanium alloy (Ti-6Al-4V) was selected as the work piece material and copper electrode were employed to machine the work piece. Pulse on-time (Ti) determines the duration of time (µs) in which the current is allowed to flow per cycle . Pulse off-time (To) determines the duration of time (µs) between the sparks. The machining process is carried out for a fixed period of time and the list of experimental parameters is tabulated in Table 1. The surface roughness was assessed with the help of Talysurf as shown in Figure.

Three different observations were taken on each sample and were estimated on average basis to get the roughness value (Ra). The surface roughness of the work-piece can be expressed in different ways including arithmetic average (Ra), average peak to valley height (Rz), or peak roughness (RP), etc. Generally the Surface Roughness is measured in terms of the Arithmetic Mean according to ISO which defines as the arithmetic average roughness of the deviations of the roughness profile from the central line of the measurement line (Wu 2005). Therefore, arithmetic mean or average surface roughness value is considered in this study for better assessment of roughness.

Table 1. Experimental parameters.

S.No	Working parameters	Description
1	Work piece material	Ti-6Al-4V
2	Size of work piece	22 mm × 22 mm × 20 mm
3	Electrode material	Copper
4	Size of electrode	ϕ 19 mm × 50 mm (length)
5	Electrode polarity	Negative
6	Dielectric fluid	Commercial Kerosene
7	Applied voltage	120 V
8	Servo voltage	70 V
9	Flushing pressure	1.65 MPa
10	Machining time	40 Minutes

IV. EXPERIMENTAL DESIGN

The important objective of the experimental design work is that the study the relationsship between the response as a dependent variable and the different process parameter levels[1].It provides a platform to study about the individual effects of each factor and their interactions. The Design of Experiments(DOE) for highlighting the influence of different and important EDM process parameters, for example, peak current, pulse on time and another pulse off time influence on the machining characteristics of MRR modeled. In the present research paper, experiments were designed and developed based on experimental design techniques using Response Surface Design method. The coded levels for all process parameters used are tabulated in Table 2. A set of designed experiments to obtain an optimal response is presented in Table 3.

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Table 2. Machining parameters and their levels

Designation	**Process parameters**	Levels		
		-1	0	1
x_1	Peak Current (A)	2	16	30
x_2	Pulse on time (µs)	10	205	400
x_3	Pulse of time (µs)	50	175	300

Table 3. Set of designed experiments for different parameters

Expt.No.	**Peak Current(A)**	**Pulse on time (µs)**	**Pulse of time(µs)**
1	0	0	0
2	1	1	0
3	1	0	-1
4	-1	0	1
5	0	-1	1
6	0	0	0
7	-1	1	0
8	-1	0	-1
9	0	1	-1
10	-1	-1	0
11	0	0	0
12	0	1	1
13	1	0	1
14	1	-1	0
15	0	-1	-1

V.REGRESSION MODEL

In this paper, Response Surface Methodology(RSM) is used for finding out the relations between the various EDM process parameters with the different machining[7]&[8] criteria and exploring their effects on the responses of surface finish. In order to perform this effort of activity, a single order response surface in mathematical model can be first studied and developed. In the general case, the response is clearly explained by the linear equation of the form of type (Habib, 2009)[3]:

$$_{i=1}^{n}Y = C_0 + \sum C_i\, x_i \quad (2)$$

where, Y is called the corresponding response, Surface roughness yield by the different EDM process variables and the xi (1,2, . . . , n) are coded levels of n quantitative process variables, the terms C0, and Ci are considered to be single order regression coefficients. The second term in the equation under the summation sign of this polynomial equation is attributable to linear effect. Equation (2) can be rewritten as in (3) according to the three variables (habib, 2009):

$$\mathrm{Y}=C_0 + C_1x_1+C_2x_2+C_3x_3 \quad (3)$$

where: x_1, x_2 and x_3 are peak current (Ip), pulse on time (ti) and pulse off time (to) respectively.

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The values of the different constants of Equation (3) have been evaluated as shown in Table 4 using statistical software. It is observed in Table 4 that the linear term's Ip and ti are significant nevertheless the term to is non-significant. Based on Equation (3), the final mathematical relationship for correlating the SR and the considered process variables was obtained as follows:

$$SR = 4.1514+1.7596I_p + 1.0722t_i + 0.2940t_0 \quad (4)$$

For data analysis, the checking of adequacy of fit of the model is also essential. The adequacy verification of the model includes the test for significance of the regression model, test for significance on model coefficients, and test for lack of fit. Analysis of variance (ANOVA) for the adequacy of the model is then performed in the subsequent step and shown in Table 5. The F ratio is calculated for 95% level of confidence. The P-value which is less than 0.05 is considered significant and the P- value greater than 0.05 is not significant.

Table 4. Estimated regression coefficients

Term	Coefficient	SE Coef	T	P	Remark
Constant	4.1514	0.3386	12.261	0	Most significant
Peak current (A)	1.7596	0.4636	3.795	0.003	Significant
Pulse on time (µs)	1.0722	0.4636	2.313	0.041	Significant
Pulse off time (µs)	0.294	0.4636	0.634	0.539	Non Significant

Table 5. Analysis of variance

Source of variation	Degree of freedom	Sum of squares	Mean squares	F-ratio	P
Regression	3	34.6589	11.553	6.72	0.008
Linear	3	34.6589	11.553	6.72	0.008
Residual error	11	18.9151	1.7196		
Lack-of-Fit	9	18.4756	2.0528	9.34	0.1
Pure Error	2	0.4394	0.2197		
Total	14	53.574			

VI. RESULTS AND DISCUSSION

Fig 1 shows the influence and effect of peak current and pulse on time on surface roughness. It is observed and studied from the plots and figures that increase in peak current produces rough surface. This is mainly caused because when the pulse current increase, more intensely discharges to strike the surfaces and a great quantity of molten and floating metal suspended in the electrical discharge gap during EDM. The higher side in pulse energy cause to increase the material removal rate and that may cause to set off the rough surface (Habib, 2009)[3]. Hence, increase peak current increases the discharge energy and energy intensity started to get deteriorated in the surface finish of the work piece. In the same way, surface roughness goes on increasing as the pulse on time increases. A very long pulse duration may cause the much heat transfer into the sample and the dielectric fluid is not able to clear away the molten material, since the flushing pressure is constant. In other words, while the pulse on time is increased the melting isothermals penetrate further into the interior of the material, and the molten zone extends further into material and this produce a greater white layer thickness. As the pulse duration increase the surface roughness also increase that can be supported by Hascalık and Caydas (2007)[4]. As the pulse duration increase, the surface roughness also increase that can also be supported by Hascalık and Caydas(2007)[4]. Small pulse duration causes more discharges per second. In this way, by applying the same current, short pulse on time, it creates smaller craters leads producing a fine surface finish. Excellent surface finish is detected and observed in this experimentation work while the pulse on time below 80 µs at all the values of peak current.

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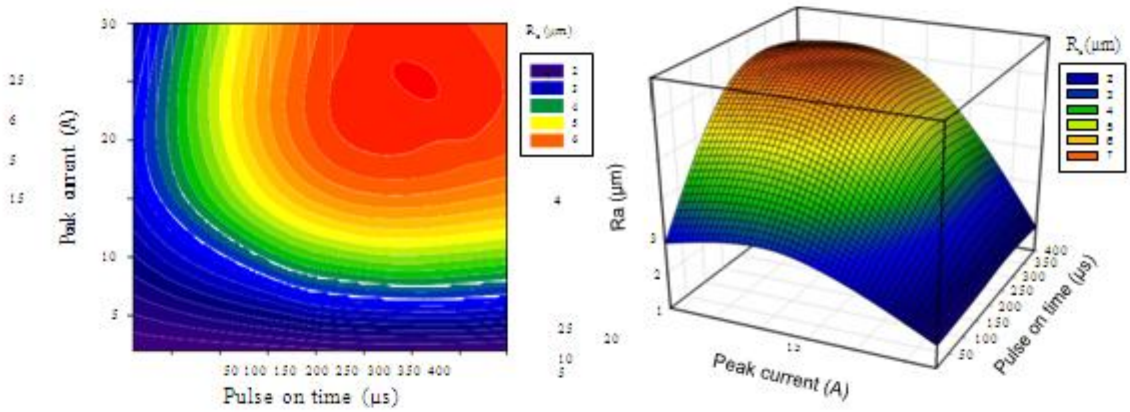

Fig1. Influence & effect of peak current and pulse on time on surface roughness

Fig 2 shows the influence and effect of peak current and pulse on time on surface roughness plot of Effect of peak current and pulse off time on Ra. It is observed and studied from the plots and figures that increase in peak current produces rough surface. This is mainly caused because when the pulse current increase, more intensely discharges to strike the surfaces and a great quantity of molten and floating metal suspended in the electrical discharge gap during EDM[6]. The higher side in pulse energy cause to increase the material removal rate and that may cause to set off the rough surface (Habib, 2009)[3]. Hence, increase peak current increases the discharge energy and energy intensity started to get deteriorated in the surface finish of the work-piece. In the same way, surface roughness goes on increasing as the pulse on time increases[9]. A very long pulse duration may cause the much heat transfer into the sample and the dielectric fluid is not able to clear away the molten material, since the flushing pressure is constant. In other words, while the pulse on time is increased the melting isothermals penetrate further into the interior of the material, and the molten zone extends further into material and this produce a greater white layer thickness. As the pulse duration increase the surface roughness also increase that can be supported by Hascalık and Caydas (2007)[4]. As the pulse duration increase, the surface roughness also increase that can also be supported by Hascalık and Caydas (2007)[4]. Small pulse duration causes more discharges per

second. In this way, by applying the same current, short pulse on time, it creates smaller craters leads producing a fine surface finish. Excellent surface finish is detected and observed in this experimentation work while the pulse on time below 80 µs at all the values of peak current. The Confirmation test for Surface Roughness results is computed in the Table 6 which indicates the error findings at different trial experiments.

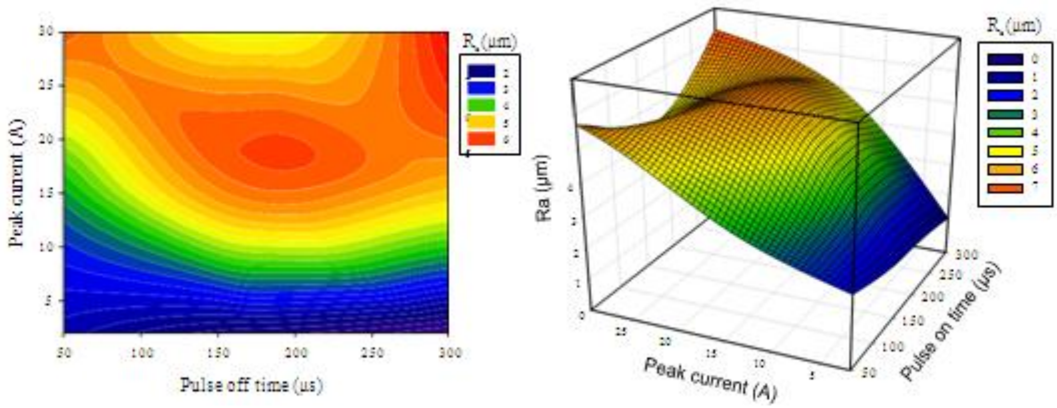

Fig 2. Plot of Effect of peak current and pulse off time on Ra

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Table 6. Confirmation test and their comparison with results

Trial No.	Optimum conditions	Surface Roughness (µm)(%)		Error
		Experimental	Predicted	
1	I_p = 2 A, t_i=10 µs and t_o=300 µs	1.083	1.02555	5.3
2	I_p = 2 A, t_i=10 µsand to=300 µs	0.9836	1.02555	-4.26

VII.CONCLUSIONS

Increase peak current causes the rough surface finish. The product of high ampere and high pulse on time deteriorate in the surface finish more. The finer surface finish is observed at about the pulse on time <50 µs for the all values of ampere. The combination of high ampere (>15 A) and long pulse duration (>180 µs) generate the worst surface in this experiment. Fine surface finish is obtained at the low pulse off time and increasing pulse off time deteriorates in surface finish until the certain value of the pulse interval and subsequently improves the surface finish. The influence of peak current on SR varies as the pulse interval and correspondingly the effect of pulse off time on SR fluctuates as peak ampere. The empirical values of the EDM parameters for optimum machining efficiency are 2A peak current, 10 µs pulse on time and 300µs pulse off time.

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Dr Kalley Harinarayana of CMR Engineering College Affiliated to Jawaharlal Nehru Technological University,Hyderabad,Telangana State holds B.Tech in Mechanical Enggg.,M.Tech (Prod Engg). Ph. D degree in Mechanical Engineering and authored over 20 articles in International Conferences and Journals. His research interests are specifically in the field of Unconventional Machining Processes like EDM,LBM and ECM Processes,,Design and Metallurgical Concepts. Dr.Kalley Harinarayana is a member of many professional bodies like ISTE,Institution of Engineers and IIW.