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Mrr In Edm Utilizing Copper Electrode And Electrode With Negative Polarity

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Abstract: *The traditional machining techniques are often incapable to machine the titanium alloy economically. Electrical discharge machining (EDM) is a relatively modern machining process having distinct advantages over other machining processes and can machine Ti- alloys effectively. This paper attempts to develop optimization model and investigate the effects of peak current, pulse on time and pulse off time on EDM performance characteristics of titanium alloy Ti-6Al-4V utilizing copper as electrode and negative polarity of the electrode. A mathematical model for correlating influence of process variables and the response of material removal rate is developed in this paper. The optimal machining set-up in favor of material removal rate is estimated and verified. Design of experiments (DOE) method and response surface methodology (RSM) techniques are implemented. Analysis of variance (ANOVA) has been performed for the validity test of the fit and adequacy of the proposed models. The obtained results evidence that the material removal rate increases with ampere and pulse on time and in contrast decreasing tendency is observed while the pulse off time increase. The result leads to desirable process outputs (MRR) and economical industrial machining by optimizing the input parameters.*
Keywords: *EDM, RSM, MRR, Ti-6Al-4V, Peak current, Copper, Negative polarity.*

I. Introduction

The usage of titanium and its alloys is increasing in many industrial and commercial applications because of these materials' excellent properties such as a high strength– weight ratio, high temperature strength and exceptional corrosion resistance (Hascalik and Caydas, 2007). The most common titanium is the α+β type two phase Ti–6Al–4V alloy among several alloying types of titanium. In aerospace industry, titanium alloys have been widely used because of their low weight, high strength or high temperatures stability (Fonda et al., 2008). Titanium and its alloys are difficult to machine materials due to several inherent properties of the material. In spite of its more advantages and increased utility of titanium alloys, the capability to produce parts products with high productivity and good quality becomes challenging. Owing to their poor machinability, it is very difficult to machine titanium alloys economically with traditional mechanical techniques (Rahman et al., 2006).

The EDM is a well-established machining choice for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes (Ho and Newman, 2003). 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, automotive, aerospace and surgical components (Ponappa et al., 2010). Thus, titanium and titanium alloy, which is difficult-to-cut material, can be machined effectively by EDM (Yan et al., 2005). Proper selection of the machining parameters can result in a higher material removal rate, better surface finish, and lower electrode wear ratio (Lin et al., 2002). Several researches have been carried out for improving the process performance and for detection optimum parameters as follows. The electrical discharge machining (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 (Hascalik and Caydas, 2007). The experimental results reveal that the material removal rate, surface roughness, electrode wear and average white layer thickness increase with the increasing of current and pulse duration. The graphite electrode is beneficial on material removal rate, electrode wear and surface crack density but relatively poorer surface finish. A study has been carried out to develop a mathematical model for optimising the EDM characteristics on matrix composite Al/SiC material (Habib, 2009). In order to obtain optimum circumstances low values of peak current, pulse off time and voltage for good surface finish and likewise high values of peak current and voltage to get high MRR and also to attain low electrode wear high pulse off time and low peak current should be used. To investigate the relationships and parametric interactions between the variables on the material removal rate (MRR) using response surface methodology experiments have been conducted on AISI D2 tool steel with Cu electrode (Pradhan and Biswas, 2008). It was acquired that discharge current, pulse duration, and pulse off time affect the MRR significantly. Their observation illustrates that the highest MRR values appeared at the higher ampere and pulse on time and at the lower pulse off time. Research have been attained to assess the effect of three factors-tool material, grit size of the abrasive slurry and power rating of ultrasonic machine on machining characteristics of titanium (ASTM Grade I) using full factorial approach for design and analysis of experiments (Kumar et al., 2008). It has been investigated that the surface finish obtained in USM is better than many of the other non-traditional techniques. It has been reported that the MRR depend on the tool material and the maximum TWR is reached at the points of maximum MRR. Proper selection of machining parameters for the best process performance is still a challenging job (Mandal et al., 2007). Optimal selection of process parameters is very much essential as this is a costly process to increase production rate considerably by reducing the machining time. Thus, the present paper emphasizes the development of models for correlating the various machining parameters such as peak current (I_P), pulse on time (t_i) and pulse off time (t_o) on the most dominant machining criteria i.e. the material removal rate (MRR) and surface roughness (SR). Machining parameters optimization for the titanium alloy material Ti- 6Al-4V has been carried out using the techniques of design of experiments (DOE) method and response surface methodology (RSM). Also the effect of input parameters on the characteristic of machining such as material removal rate and surface roughness on Ti-6Al-4V has been analyzed.

EXPERIMENTAL SET UP

Pulse on-time (t_i) refers the duration of time (μs) in which the current is allowed to flow per cycle (Puertas and Luis, 2003). Pulse off-time (t_o) is the duration of time (μs) between the sparks. The experiments are carried out utilizing a numerical control programming electrical discharge machine known as ‘‘LN power supply AQ55L”. The EDM has the provisions of movement in three axes such as longitudinal (X-axis), lateral (Y-axis) and vertical direction of electrode (Z-axis) and has also a rotary U-axis with maximum rpm ±40. In this effort, titanium alloy (Ti-6Al-4V) was selected as the workpiece material and cylindrical copper electrode were employed to machine the workpiece. The experimental setup is shown in Figure 1. The machining was usually carried out for a fixed time interval. The listing of experimental parameters is also scheduled in Table 1. The weight of the workpiece and electrode before and after machining were measured by a digital balance (AND GR-200) with readability of 0.1mg.

(a) Photograph of EDM during machining (b) EDM tank and sample at operationalcondition.
Figure 1: Experimental setup of electrical discharge machining.

Table 1: Experimental settings

Working parameters	Description
Work piece material	Ti-6Al-4V
Work piece size	22 mm × 22 mm × 20 mm
Electrode material	Copper
Electrode size (diameter × length)	19 mm × 50 mm
Electrode polarity	Negative
Dielectric fluid	Commercial Kerosene
Applied voltage	120 V
Servo voltage	70 V
Flushing pressure	1.75 MPa
Machining time	30 Minute

The amount of metal removed was measured by taking the difference in weights of the workpiece before and after electrical discharge machining. The MRR is expressed as the weight of material removed from workpiece over a period of machining time in minutes (Wu et al., 2005). The MRR was calculated by the formula as expressed in Eq. (1) (Habib, 2009):

$$\text{MRR} = \frac{1000 \times W_w}{\rho_w \times T} mm^3 / \min \qquad (1)$$

where, W_w is the weight loss of the workpiece in gm; ρ_w is the density of the workpiece material (Density of Ti-6Al-4V is 4.37 g/cm^3); T is the machining time in minutes;

Design of Experiment

The experimental design is performed the relations between the response as a dependent variable and the various parameter levels. It provides a prospect to study not only the individual effects of each factor but also their interactions. The design of experiments for exploring the influence of various predominant EDM process parameters e.g. peak current, pulse on time and pulse off time on the machining characteristics such as MRR. In the present work experiments were designed on the basis of experimental design technique using response surface design method. The coded levels for all process parameters used are displayed in Table 2. The set of designed experiments to obtain an optimal response utilizing box-behnken type of design is presented in Table 3.

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

Experiment No.	Peak Current (A)	Pulse on Time (µs)	Pulse off 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

OPTIMIZATION MODELLING

In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a set of designed experiments to obtain an optimal response. In this work, RSM is utilized for determining the relations between the various EDM process parameters with the various machining criteria and exploring their effects on the responses e.g. the MRR and surface finish. To perform this task second order polynomial response surface mathematical models can be developed. In the general case, the response surface is described as Eq. (2):

$$\sum_{i=1}^{n} {}_{i}\;{}_{i} \quad \sum_{i=1}^{n} {}_{ii}\;{}_{i} \quad \sum_{i=1}^{n-1}\sum_{j=2}^{n} {}_{ij}\;{}_{ij}$$

where, Y is the corresponding response, e.g. MRR and SR yield by the various EDM process variables and the x_i (1,2, . . . , n) are coded levels of n quantitative process variables, the terms C_0, C_i, C_{ii} and C_{ij} are the second order regression coefficients. The second term under the summation sign of this polynomial equation is attributable to linear effect, whereas the third term corresponds to the higher-order effects; the fourth term of the equation includes the interactive effects of the process parameters. In this research, Eq. (2) can be rewritten according to the three variables used as Eq. (3):

$$Y = C_o + C_1 x_1 + C_2 x_2 + C_3 x_3 + C_{11} x_1^2 + C_{22} x_2^2 + C_{33} x_3^2 + C_{12}x_1x_2 + C_{13}x_1x_3 + C_{23}x_2x_3 \qquad (3)$$

where: x_1, x_2 and x_3 are peak current (I_p), pulse on time (t_i) and pulse off time (t_o) respectively.

The equations of the fitted model for the MRR is represented in Eq.(4):

$$\text{MRR} = 0.49414 + 0.44098\,I_p + 0.19409\,t_i - 0.26436\,t_o + 0.14671\,I_p^2 - 0.08658\,t_i^2 + 0.07989\,t_o^2 + 0.15465\,I_p t_i - 0.18757\,I_p t_o - 0.07556\,t_i t_o \qquad (4)$$

The analysis of variance of this model is shown in Table 4. The adequacy of the above two proposed models have been tested by the analysis of variance (ANOVA). The variance is the mean of the squared deviations about the mean or the sum of the squared deviations about the mean divided by the degrees of freedom. The fundamental technique is a partitioning of the total sum of squares and mean squares into components such as data regression and its error. The number of degrees of freedom can also be partitioned in a similar way as discussed in Table 3. The usual method for testing the adequacy of a model is carried out by computing the F-ratio of the lack of fit to the pure error and comparing it with the standard value. The values of P (<α-level) in the analysis ascertain that the regression model is significant. Therefore, at least one of the terms in the regression equation makes a significant impact on the mean response. The P-values of the residual error (0.135 for MRR) is not less than α-level (0.05). The results of the analysis justifying the closeness of fit of the mathematical models are enumerated. Therefore it can be concluded that the evolved models given by Eq. (4) has been adequately explained the variation in the machining parameters on the MRR.

Table 4: Analysis of Variance in the case of MRR

Source of variation	Degree of freedom	Sum of squares	Mean squares	F-ratio	P
Regression					
Linear	3	2.41615	0.805384	18.63	0.000
Quadratic	9	2.81177	0.312419	19.56	0.002
Error					
Linear	11	0.47548	0.043225	14.19	0.068
Quadratic	5	0.07986	0.015973	6.59	0.135
Total	14	2.89163			
Linear					
Quadratic	14	2.89163			

II. Resuls And Discussion

Analysis of EDM Parameters on MRR

The influence of peak current and pulse on time against MRR for 2D is presented in Figure 2 and 3D surface plot is shown in Figure 3. The experimental results show that the material removal rate increases with increase of peak current. In EDM process, the material erosion rate is a function of electrical discharge energy. Therefore, the increase of peak current generates high energy intensity and that raises the metal removal rate. Increasing pulse on time increases the MRR at the all values of the peak current. In general, the power of the spark and frequency defined by the number of pulse per second determine the process performance (Drof and Kusiak, 1994). The low frequency and high power combination results in high metal removal. Increasing pulse on time reduces the frequency and the low frequency increases material removal. Thus, it is evident that the combination of high pulse on time and high power conceive more MRR. The same results are achieved by the research of Lee and Li (2001); Pradhan and Biswas (2008).

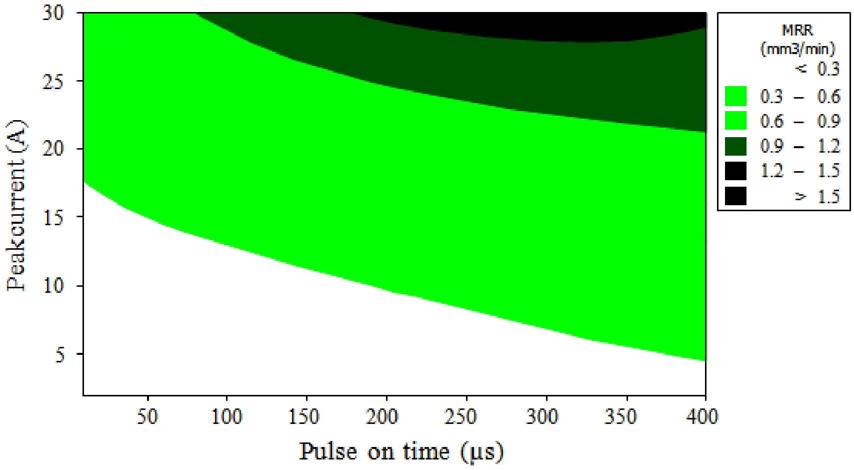

Figure 2: 2-D contour plot of the effect of peak current and pulse on time on MRR.

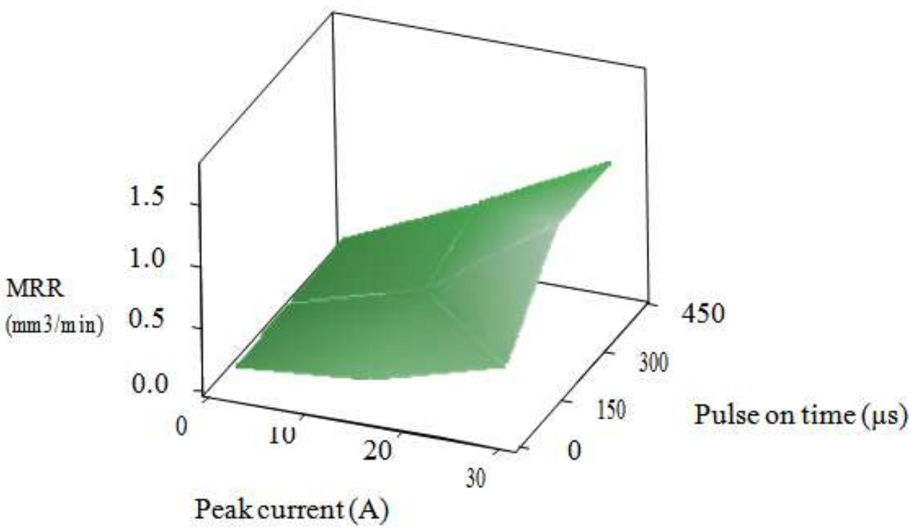

Figure 3: The effect of peak current and pulse on time on MRR (3-D surface plot).

Figure 4 and Figure 5 illustrate the impact of peak current and pulse off time on MRR. The experimental results evidence that the increasing peak current increases the MRR and conversely increasing the pulse off time decreases the MRR. In another words, the short the pulse off time the more the MRR and the long the pulse off time the less the MRR. This is due to the fact that during the pulse off time no energy is applied to the workpiece surface and results low MRR. Then again, since the time available for the application of heat energy on the workpiece surface, the top surface temperature of the workpiece increases as the pulse off time decreases. Thus, the material is eroded at faster rate. The same observation is reported by several authors, such as Kao and Tarng (1997); Kansal et al. (2008) and Pradhan and Biswas (2008). Although short pulse intervals favor removal rate, short circuit is ascertained while the pulse off time is too small particularly in the case of high discharge currents. The machining debris accumulated in the machining gap and with too short pulse interval, there is not enough time to clear the disintegrated particles from the gap between the electrode and the workpiece and ultimately short circuit happened (Lin and Lee, 2008 and Lee and Li, 2001).

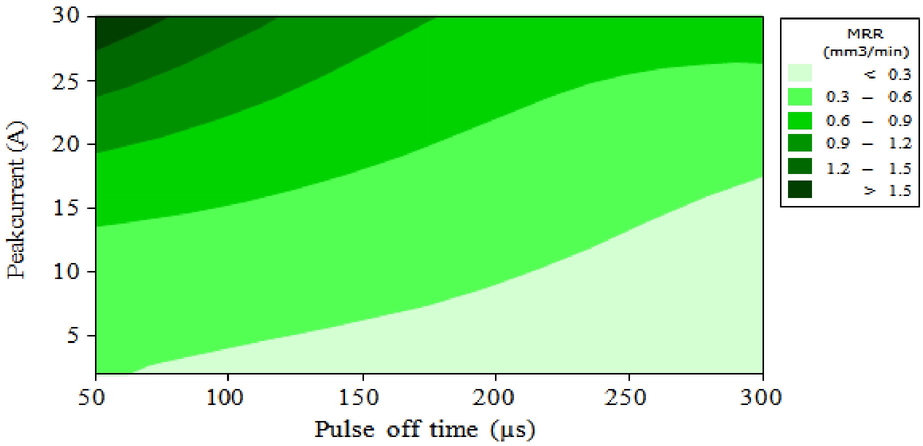

Figure 4: 2-D contour plot of the effect of peak current and pulse off time on MRR.

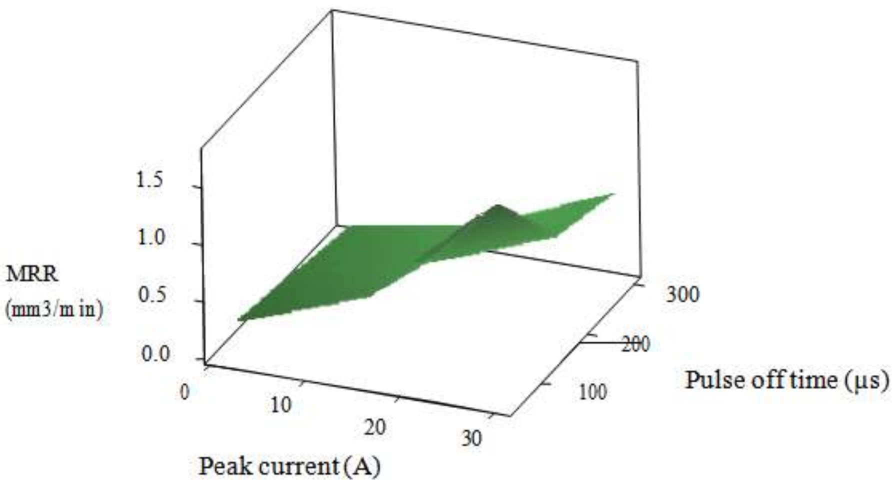

Figure 5: 3-D surface plot of the effect of peak current and pulse off time on MRR.

Optimum Parameter of EDM Process

An attempt is fulfilled to estimate the optimum machining setting to build the best possible MRR within the experimental constraints. The obtained optimum value of the parameters is shown in Table 5. Optimum machining parameter combinations for different EDM characteristics are also testes, which is tabulated in Table 6 through confirmation experiments that verify reasonably good concurrence with prediction of response surface method.

Table 5: Optimal set-up in the case of MRR

Process parameters	Optimum set-up for MRR
Peak current (A)	30
Pulse on time (µs)	400
Pulse off time (µs)	50

Table 6: Confirmation test and their comparison with results for MRR

Trial No.	Optimum conditions	MRR (mm^3/min)		Error (%)
		Expt.	Predicted	
1	I_p = 30 A, t_i=400 µs and t_o=50 µs	1.86723	1.95137	4.51
2	I_p = 30 A, t_i=400 µs and t_o=50 µs	1.85240	1.95137	5.34

III. Conclusions

It was attempted to investigate the influence of the peak current, pulse on time and pulse off time on the EDM performance characteristics and to build mathematical model. The following conclusions can be stipulated from the analysis of the experimental observations.

The MRR is influenced considerably by peak ampere and pulse on time. A significant impact of pulse off time on the material removal rate is also investigated. The material removal rate increases with current. High pulse on time produce MRR more conversely less material removal is obvious at high pulse off time.

i. The empirical values of the EDM parameters for optimum machining efficiency are 30 A peak current, 400 µs pulse on time and 50 µs pulse off time in the case of MRR.

Further study will be continued employing CuW and Graphite electrode to determine their effect on the EDM performance characteristics.

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