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STUDY THE EFFECTS OF PROCESS PARAMETERS DURING ELECTRIC DISCHARGE MACHINING OF TITANIUM ALLOY (Ti-6246)

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Abstract*— *The major concern identified with machining of Titanium based super alloys which are considered very hard for machining purpose is surface integrity and tool wear. The major problem faced by any industry is to obtain the optimal machining process parameters and minimize the surface roughness(Ra) and tool wear(Tw) of a super alloy. In present work effect of cutting parameters (current A, Pulse on time µs, Pulse off time µs) on output parameters (i.e. Ra, Tw) has been studied during machining of Ti6246 while machining it with graphite electrode. Machining parameters are optimized by RSM based BBD Technique, using the desirability analysis for minimizing the surface roughness, and tool wear. The study indicated that the optimal parameters for Multi Response Optimization were found to be at current 4.5 A, Pulse on time 50.07 µs, Pulse off time 100 µs

Keywords—Ti6246, Graphite electrode, RSM Technique, Multi Response Optimization(BBD).

I. INTRODUCTION

Ti6246 which appertain to the family of Titanium based alloys are generally utilized in Marine and aerospace industries[1]. Ti6246 have high corrosion resistance properties therefore it is tremendously used as the application in processing of chemicals, processing of nuclear fuel, acid production and equipment for pickling except from its general aerospace industry[2]. These alloys are also used in the pollution control systems. These properties lead to reduced tool life during machining, due to which its usage is limited despite excellent mechanical properties[3]. Therefore, the tool used for cutting of these alloys should have higher wear, abrasion and adhesion resistance. Luo et al[4] investigated the dependence of interspace transitivity upon the gap debris in precision electric discharge machining, process. Chen et al.[5] studied the behaviour of kerosene and deionized water as the dielectrics on Ti64 alloy. Yan et al.[6] studied the behaviour of Urea solution and water as dielectrics on Titanium alloy. By using urea solution and increasing the peak current MRR increases and TWR decreases and also get smoother surface finish. Kibria et al.[7] comparative study have been done on different dielectrics viz. kerosene, deionized water with and without suspended particles of Boron Carbide (B_4C) and their effect on output parameters with respect to input process parameters such as peak voltage, current, impulse, polarity etc. This study was revealed that MRR and TWR were lesser using kerosene than deionized water with a micro thick white layer.

After going through the literature, it can be observed that very less study has been done on the machining of Ti6246. In this present investigation an exertion has been taken to conduct the electric discharge machining and optimizing the input parameters (i.e. current, pulse on time and pulse off time) on Ti6246. The experiments were performed with variation in parameters using DOE approach. ANOVA analysis was used to obtain mathematical models. Optimization of the results was carried out through desirability approach.

II. EXPERIMENTAL METHODOLOGY

During the experimentation work, different sheets of Ti6246 {Ti –(81.13%), Al – (6%), Sn -(2% max), Zr- (4%), Mo –(6% max)} having 60mm length, 10mm width and 6mm thickness (refer Fig.1) were machined on Non Traditional electrical discharge machining of tool craft. The present work considered 3 levels of Design of Experiment. RSM based BBD Technique was used to develop a Design of Experiment by Design expert 11.1.0 software. Three input variables were selected with current 1.5 A, 3 A and 4 A , pulse on time 50 µs, 75 µs and 100 µs& pulse off time 100 µs, 200 µs and 300 µs. Commercially available graphite used as electrode with dimension of 10mm diameter and 50mm length as shown in figure 2.The depth of cut was taken constant at 1mm. Measurement of Ra was done by Mitutoyo SJ 301 Ra Tester and measurement of Tw by weight(i. e initial weight-final weight/Machining time).

Figure 1: Ti6246 work piece

III. RESULTS AND DISCUSSION

3.1 Experimental Results

Experiments were carried out for graphite electrode.17 experiments were designed by RSM based BBD technique. Three levels of each input parameters (i.e. current, pulse on time, pulse off time) were taken for experimentation & results were calculated as shown in Table I. After conducting the experiments for electrical discharge machining the surface roughness values of work piece and tool wear value of electrode were measured using Mitutoyo surface roughness tester and Sipkon Measurement system. Each run of the experiment contains three trial values for better output of the surface roughness. The average of these three trial values has been taken for the analysis of optimization of input parameters.

TABLE I
EXPERIMENTAL RESULTS

Std	Run	Current (Amp)	Pulse On Time(μs)	Pulse Off Time(μs)	SR (μm)	TWR(gms/min)
12	1	3	100	300	1.02	0.0001854
2	2	4.5	50	200	1.12	0.0002325
6	3	4.5	75	100	1.14	0.0002255
9	4	3	50	100	1.12	0.0003582
3	5	1.5	100	200	0.69	0.0002546
14	6	3	75	200	1.012	0.0002157
8	7	4.5	75	300	1.09	0.0006086
15	8	3	75	200	1.01	0.0006741
16	9	3	75	200	1.01	0.0003714
4	10	4.5	100	200	1.79	0.0006512
7	11	1.5	75	300	0.30	0.0001215
11	12	3	50	300	0.67	0.0004733
17	13	3	75	200	1.31	0.0007942
13	14	3	75	200	1.32	0.0007369
10	15	3	100	100	1.15	0.0003662
1	16	1.5	50	200	0.92	0.0005747
5	17	1.5	75	100	0.84	0.0004309

3.2 Analysis and optimization of Ra and Tw

Analysis and modelling of Ra and Tw was performed by Design Expert 11.1.0 software. Diagnosis plots were made in order to validate regression models. Graphs were drawn in order to find variation of surface roughness with current, pulse on time and pulse off time. Multi Response Optimization for minimization of Ra and Tw was performed by desirability analysis.

3.2.1 Analysis of variance

ANOVA analysis was conducted on output responses for determining the experimental results. Significant model was designed after transformation of Data. ANOVA for reduced cubic model was generated. Table II and III shows ANOVA table values of Ra and Tw respectively.

TABLE II

ANOVA TABLE FOR Ra

Source	**Sum of Squares**	**DOF**	**Mean Square**	**F-value**	**p-value**	**Remarks**
Model	0.0119	9	0.0013	10.44	0.0027	significant
A-Current	0.0057	1	0.0057	44.79	0.0003	
B-Pulse onTime	0.0006	1	0.0006	4.95	0.0615	
C-Pulse off Time	0.0014	1	0.0014	11.19	0.0123	
AB	0.0015	1	0.0015	12.09	0.0103	
AC	0.0005	1	0.0005	4.11	0.0821	
BC	0.0002	1	0.0002	1.66	0.2386	
A^2	0.0002	1	0.0002	1.71	0.2327	
B^2	0.0002	1	0.0002	1.36	0.2818	
C^2	0.0015	1	0.0015	12.10	0.0103	
Residual	0.0009	7	0.0001			
Lack of Fit	0.0000	3	9.475E-06	0.0440	0.9860	not significant
Pure Error	0.0009	4	0.0002			
Cor Total	0.0128	16				

From Table II, it can be concluded that the F value of model is 10.44 which implies that the model is significant. There is only a 2.7% possibility that an F value of this large could occur due to noise. P values less than .050 shows that all terms associated with model are significant. It can be also be analyzed that R-squared is 93.06 % which is close to 100 %. The value of Adjusted R-squared is 0.8415 represents that 84.15 % variation is explained by the independent variables that actually affects the dependent variables. Adjusted R- Squared is close to R-Squared which represents that only few percent variation is not explained by independent variables which doesn't actually affect the dependent variable. Adequate Precision is used to measures the signal to noise ratio. The ratio should be larger than 4. The ratio is 15.278 which indicates that the signal is adequate.

TABLE III

ANOVA TABLE FOR Tw

Source	Sum of Squares	DOF	Mean Square	F-value	p-value	Remarks
Model	0.0288	11	0.0026	65.73	0.0001	significant
A-Current	0.0007	1	0.0007	17.17	0.0090	
B-Pulse on Time	0.0007	1	0.0007	17.33	0.0088	
C-Pulse off Time	1.072E-07	1	1.072E-07	0.0027	0.9606	
AB	0.0046	1	0.0046	116.30	0.0001	
AC	0.0042	1	0.0042	105.12	0.0002	
BC	0.0008	1	0.0008	19.35	0.0070	
A^2	0.0038	1	0.0038	94.84	0.0002	
B^2	0.0037	1	0.0037	93.15	0.0002	
C^2	0.0085	1	0.0085	212.72	< 0.0001	
A^2B	0.0006	1	0.0006	15.55	0.0109	
AB^2	0.0002	1	0.0002	5.77	0.0614	
Residual	0.0002	5	0.0000			
Lack of Fit	0.0001	1	0.0001	2.62	0.1808	not significant
Pure Error	0.0001	4	0.0000			
Cor Total	0.0290	16				

From Table III, it can be concluded that the F value of model is 65.73 which implies that the model is significant. There is only a .11% possibility that an F value of this large could occur due to noise. P values less than .050 shows that all terms associated with model are significant. Value for lack of fit is 0.1808 which is insignificant.

It can be analyzed that R-squared is 99.31% which is close to 100% and navigate that the model explains nearly all the variability of the response data around its mean. The value of Adjusted R-squared is 0.9780 represents that 97.80 % variation is explained by the independent variables that actually affects the dependent variables. Adjusted R- Squared is close to R-Squared which represents that only few percent variation is not explained by independent variables which doesn't actually affect the dependent variable. Adequate Precision is used to measures the signal to noise ratio. The ratio should be larger than 4. The ratio is 22.6984 which indicates that the signal is adequate.

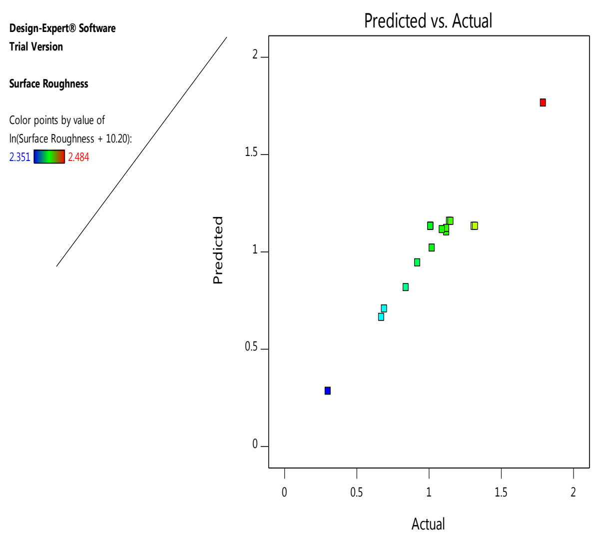
3.2.2 Mathematical Modeling and Regression Analysis

Multiple regression models were developed for Ra and Tw for graphite electrode. The response variable was Tw and Ra and predictors were current, pulse on time and pulse off time. The mathematical equations for Ra and Tw are given below.

Surface Roughness =2.53369 + -0.0175196*Current + -0.0033319 * Pulse on Time + 0.000184722 * Pulse off Time + 0.000522682 * Current* Pulse on Time + 7.62181e-05 *Current * Pulse off Time + 2.90445e-06 * Pulse on Time * Pulse off Time + -0.0031902 * Current ^2 + 1.02511e-05 * Pulse onTime^2 + -1.91132e-06 * Pulse off Time^2
…... (3.1)

Tool Wear rate = 5.47787 + 0.0538392 * Current + 0.00265595 * Pulse on Time + 0.00156251 * Pulse off Time + 0.000745825 * Current * Pulse on Time + 0.00021568 * Current * Pulse off Time + -5.55267e-06 * Pulse on Time * Pulse off Time + -0.0367737 * Current ^2 + -1.31842e-05 * Pulse onTime^2 + -4.48564e-06 * Pulse off Time^2 + 0.000312831 * Current ^2 * Pulse on Time + -1.14359e-05 * Current * Pulse onTime^2 ……….(3.2)

The equation (3.1) & (3.2) in terms of actual factors can be used to make predictions about the response for given levels of each factor.



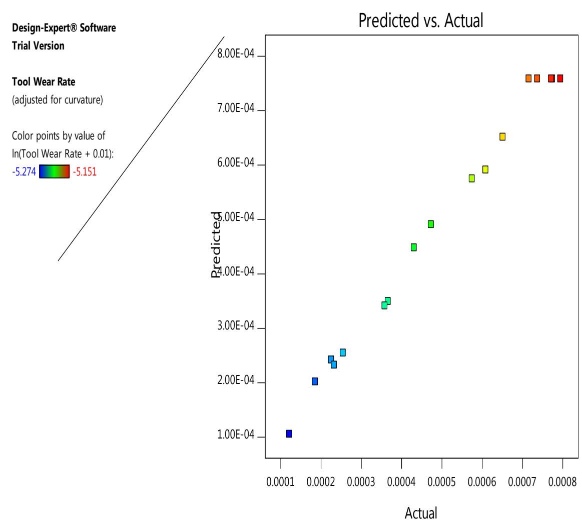
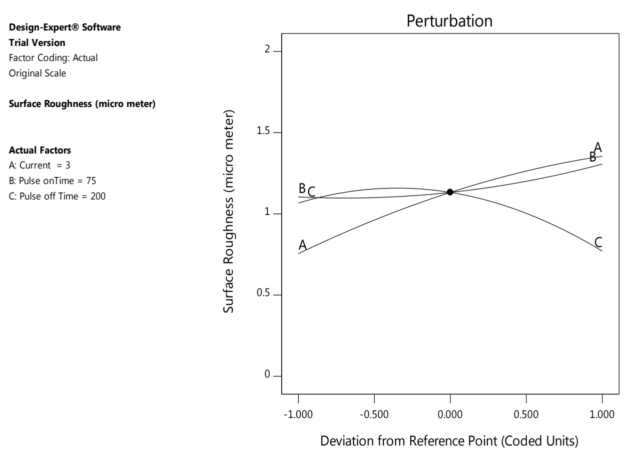
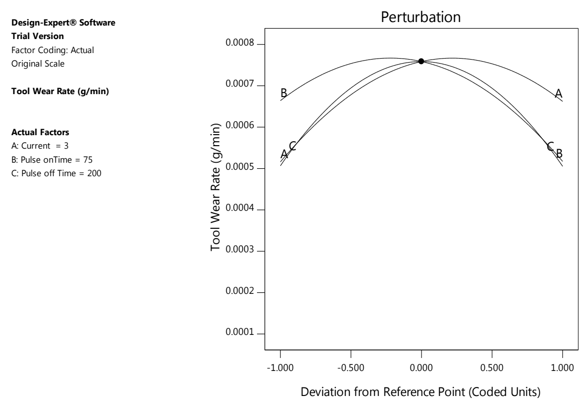


Fig.4 depicts that approximately all points are lying closer to predicted value which means that residual error ar





Perturbation plots

It can be depicted from Fig.4 (a), current and pulse on time are the most influential factors for Ra. Fig. 4 (b) illustrates that pulse on time and pulse off time are most influential factors for Tw.

3.3 Multi Response Optimization

Multi Response optimization was carried out by Design Expert Software 11.1.0. In present investigation there are two response variables and three input parameters. In case of multi response optimization there are consideration of every response simultaneously and optimize the input parameter for optimization of all responses. Numerical Optimization report contains two tables the first summarizing the criteria constraints (refer TABLE IV) used to produce the second table of optimal solutions (refer TABLE V) for the process.

Table IV

CONSTRAINTS FOR OPTIMIZATION

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Current	is in range	1.5	4.5	1	1	3
Pulse on Time	is in range	50	100	1	1	3
Pulse off Time	is in range	100	300	1	1	3
SR	minimize	2.35138	2.48407	1	1	1
TWR	minimize	-5.27431	-5.1509	1	1	3

TABLE V
OPTIMIZED RESULTS

Number	Current	Pulse on time	Pulse off time	Surface Roughness	Tool Wear	Desirability	
1	4.5	50.071	100	0.991	0.0002	0.886	Selected

The optimum value of cutting parameter for graphite electrode for Ra & Tw were found to be at current= 4.5 A, pulse on time = 50.071µs and pulse off time=100.002µs. The combined desirability was 0.886 which means that experimental results for coated inserts were closer to the predicted values.

IV **CONCLUSIONS**

The 3 levels rotatable Box- Behnken Design is employed for developing mathematical models for predicting the Ra parameter and Tw in machining of Ti6246. Multi objective optimization was applied for analysing the results of Ra and Tw. Desirability analysis was done to minimize the surface roughness and tool wear. The conclusion drawn from the research work are discussed as follows:

- Current and pulse on time were the most influential parameters for Ra. Pulse off time had very less impact on Ra.
- The optimum value of cutting parameter for graphite electrode for Ra and Tw were found to be at current= 4.5 A, pulse on time= 50.07 µs and pulse off time=100 µs.
- Surface roughness was found more at large current. The optimized value predicted for surface roughness was 0.991 µm.
- Greater value for Tw was produced at higher pulse on time and current. The optimized value predicted for tool wear was 0.0002 µm.

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