Impact Factor 5.8701 (ICI)

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

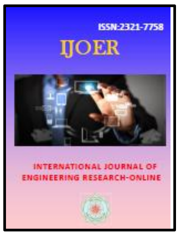
Vol.5., Issue.5, 2017
Sept-Oct

RESEARCH ARTICLE

ISSN: 2321-7758

PERFORMANCE EVALUATION OF ELECTRICAL DISCHARGE MACHINING ON TITANIUM ALLOY TI-6242 USING U-SHAPED COPPER ELECTRODE

FAROOK NEHAD ABED ALBADRY
Department of Mechanical Engineering, Imam Aladham College
farookalbadry1@gmail.com



ABSTRACT

Electrical discharged machining (EDM) which is very prominently among the non conventionally machining methodical is expectedly to be used quite extensively in machining titanium alloys due to the favorable features and advantages that it offers. This thesis presents the EDM of titanium alloy (Ti-6242) using U-shaped copper electrode with diameter of 2.60 mm.

The main idea Interest of study's conclusion in the impact of all parameters involved in the EDM on the machining characteristics, namely, Remove material rate (MRR), electrode wear ratio (EWR), and overcut (OC). The proposed experimental plan was boned on BBD approaching design of experimental software 6.0 and the results were statistic evaluated using analysis of variance (ANOVA).

Results showed that current were the most significant parameter that influenced the machining responses on EDM of Ti-6242. Confirmation tests were also conducted for the selected conditions for each machining characteristics in order to verify and compare the results from the theoretical prediction using Design Expert software6.0.and experimental confirmation tests. Overall, the results from the confirmation tests showed that the percentage of performance was acceptable due to all results obtained were within the allowable values which was less than 15% of marginal error

Keywords: CNC EDM (die sinking EDM), material removal rate (MRR), electrode wear ratio (EWR), and overcut (OC)

1 INTRODUCTION

The high strength, low weight, and outstanding corrosion resistance possessed by titanium and its alloys have led to a wide and diversified range of successful applications in aerospace, automobile, chemical plant, power generation, oil and gas extraction, surgical instruments, and other major industries. However, the susceptibility of titanium alloys to work hardening during machining impair their machinability, hence they are referred to as "difficult-to-machine" materials. Thus, machining of titanium alloys has been a topic of interest for industrial production and scientific research worldwide. These difficult-to-cut materials have physical properties such as tenacity (higher tensile strength) low thermal conductivity, which restricts quick heat dissipation generated during conventional metal cutting operations. Again, the property like strong alloying tendency or chemical reactivity of Ti-6242 with most tool materials, which causes rapid destruction of the cutting tool with galling, welding, and smearing at the interacting surface, leads to excessive chipping and/or premature tool failure and poor surface finish. Therefore, many researchers have been searching for effective methods to machine titanium alloys by conventional and non-conventional machining processes

2 LITERATURE REVIEW

Kunieda et al. [1] proposed that dry EDM is not only a thermal process but also a chemical process. With oxygen gas used as the dielectric medium, three distinct modes of material removal were observed depending on the discharge power density: normal mode, quasi-explosion mode and explosion mode. Thermally activated oxidation of workpiece material becomes uncontrolled at very high discharge powers leading to uncontrolled arcing in the explosion mode. In the quasi-explosion mode there is no discharge delay time and the oxidation reaction is controllable since the reaction stops as soon as the power is switched off. The material removal rate during quasi-explosion mode was found to be as high as in a conventional milling process; however the tool wear was still low. Also, an alternate 'intake method' of gas supply in the gap was proposed for improving the accuracy. Instead of supplying gas through the hollow tool electrode, gas was sucked into the tool electrode in the 'intake method'. Qing Gao et al. [2] Electrical discharge machining (EDM) process, at present is still an experience process, wherein selected parameters are often far from the optimum, and at the same time selecting optimization parameters is costly and time consuming. In this paper, artificial neural network (ANN) and genetic algorithm (GA) are used together to establish the parameter optimization model. An ANN model which adapts Levenberg-Marquardt algorithm has been set up to represent the relationship between material removal rate (MRR) and input parameters, and GA is used to optimize parameters, so that optimization results are obtained. The model is shown to be effective, and MRR is improved using optimized machining parameters. S. Assarzadeh and M. Ghoreishia [3] new integrated neural network-based approach is presented for the prediction and optimal selection of process parameters in die sinking electro-discharge machining (EDM) with a flat electrode (planning mode). A 3–6–4–2-size back-propagation neural network is developed to establish the process model. The current (I), period of pulses (T), and source voltage (V) are selected as network inputs. The material removal rate (MRR) and surface roughness (Ra) are the output parameters of the model. Ko-Ta Chiang [4] Electric discharge machining (EDM) has achieved remarkable success in the manufacture of conductive ceramic materials for the modern metal industry. Mathematical models are proposed for the modeling and analysis of the effects of machining parameters on the performance characteristics in the EDM process of Al2O3+TiC mixed ceramic which are developed using the response surface methodology (RSM) to explain the influences of four machining parameters (the discharge current, pulse on time, duty factor and open discharge voltage) on the performance characteristics of the material removal rate (MRR), electrode wear ratio (EWR), and surface roughness (SR). The experiment plan adopts the centered central composite design (CCD). The separable influence of individual machining parameters and the interaction between these parameters are also investigated by using analysis of variance (ANOVA). This study highlights the development of mathematical models for investigating the influences of machining parameters on performance characteristics and the proposed mathematical models in this study have proven to fit and predict values of performance characteristics close to those readings recorded experimentally with a 95% confidence interval. Results show that the main two significant factors on the value of the material removal rate (MRR) are the discharge current and the duty factor. The discharge current and the pulse on time also have statistical significance on both the value of the electrode wear ratio (EWR) and the surface roughness (SR). Kuang-Yuan Kung et al. [5] In this article, a material removal rate (MRR) and electrode wear ratio (EWR) study on the powder mixed electrical discharge machining (PMEDM) of cobalt-bonded tungsten carbide (WC-Co) has been carried out. This type of cemented tungsten carbide was widely used as moulding material of metal forming, forging, squeeze casting, and high pressure die casting. In the PMEDM process, the aluminum powder particle suspended in the dielectric fluid disperses and makes the discharging energy dispersion uniform; it displays multiple discharging effects within a single input pulse. This study was made only for the finishing stages and has been carried out taking into account the four processing parameters: discharge current, pulse on time, grain size, and concentration of aluminum powder particle for the mach inability evaluation of MRR and EWR. The response surface methodology (RSM) has been used to plan and analyze the experiments. The experimental plan adopts the face-centered central composite design (CCD). This study highlights the development of mathematical models for investigating the influence of processing parameters on performance characteristics. Ali Ozgedik and Can Cogun [6] In this study, the variations of geometrical tool wear characteristics – namely, edge and front wear – and machining performance outputs namely, work piece removal rate, tool wear rate, relative wear and work piece surface roughness were investigated with varying machining parameters. Experiments were conducted using steel work pieces and round copper tools with a kerosene dielectric under different dielectric flushing conditions (injection, suction and static), discharge currents and pulse durations. The experiments have shown that machining parameters and dielectric flushing conditions had a large effect on geometric tool wear characteristics and machining performance outputs. Additionally, published research on tool wear is presented in detail in this study. Yusuf Keskin et al. [7] Electrical discharge machining (EDM) is a nontraditional production method that has been widely used in the production of dies throughout the world in recent years. The most important performance measure in EDM is the surface roughness; among other measures material removal and tool wear rates could be listed. In this study, experiments were performed to determine parameters effecting surface roughness. The data obtained for performance measures have been analyzed using the design of experiments methods. A considerably profound equation is obtained for the surface roughness using power, pulse time, and spark time parameters. The results are discussed. JI Renjiet et al. [8] A new method which employs a group pulse power supply for electric discharge milling of the silicon carbide ceramic with the resistivity of 500 Ω·cm is presented. Due to the good machining stability and high pulse utilization, the material removal rate (MRR) can reach 72.9mm^3/min. The effects of high-frequency pulse duration, high-frequency pulse interval, peak voltage, peak current, polarity, rotate speed and group frequency on the process performance have been investigated. Also the EDM surface microstructure is examined with a scanning electron microscope (SEM), an X-ray diffraction (XRD), an energy dispersive spectrometer (EDS) and a micro hardness tester. The results show that the conditions of smaller high-frequency pulse duration and pulse interval, higher peak voltage and peak current, and positive tool polarity are suitable for machining the SiC ceramic. The optimal rotate speed is 1090 r/min and the preferable group frequency is 730 Hz. In addition, there is a small quantity of iron on machined surface when machining with steel electrode. The average grain size of the EDMed surface is smaller than that of the unprocessed, and the micro hardness of machined surface is superior to that of the unprocessed. Paulo Peças and Elsa Henriques [9] The addition of powder particles to the electrical discharge machining (EDM) dielectric fluid modifies some process variables and creates the conditions to achieve a higher surface quality in large machined areas. This paper presents a new research work that aims to study the improvement in the polishing performance of conventional EDM when used with a powder-mixed-dielectric (PMDEDM). The analysis was carried out varying the silicon powder concentration and the flushing flow rate over a set of different processing areas and the effects in the final surface were evaluated. The evaluation was done by surface morphologic analysis and measured through some quality surface indicators. The results show the positive influence of the silicon powder in the reduction of crater dimensions, whitelayer thickness and surface roughness. Moreover, it was demonstrated that an accurate control of the powder concentration and flushing flow is a requirement for achieving an improvement in the process polishing capability. Young-Cheol Ahn and Young-Seup Chung [10] The electrical discharge manufacturing process of a ceramic composite material consisting of alumina and titanium carbide has been modelled as an unsteady state mathematical model and solved by using Galerkin's implicit finite element method. For several selected currents and powers the spark melted and sublimated the work piece to form a crater which gradually expanded outwards. The size and shape of the crater anticipated by the computation were in good agreement with the scanning electron micrograph of the crater formed in an experiment. An increased electric current and duty factor would increase the material removal rate in expense of roughened surface and deteriorated mechanical properties. Qing Gao et al. [11] In this paper, artificial neural network (ANN) and genetic algorithm (GA) are used together to establish the parameter optimization model. An ANN model which adapts Levenberg-Marquardt algorithm has been set up to represent the relationship between material removal rate (MRR) and input parameters, and GA is used to optimize parameters, so that optimization results are obtained. The model is shown to be effective, and MRR is improved using optimized machining parameters. S. Assarzadeh et al. [12] a new integrated neural network-based approach is presented for the prediction and optimal selection of process parameters in die sinking electro-discharge machining (EDM) with a flat electrode (planing mode). A 3–6–4–2-size back-propagation neural network is developed to establish the process model. The current (I), period of pulses (T), and source voltage (V) are selected as network inputs. The material removal rate (MRR) and surface roughness (Ra) are the output parameters of the model. Experimental data were used for training and testing the network. The results indicate that the neural model can predict process performance with reasonable accuracy, under varying machining conditions. The effects of variations of the input machining parameters on process performance are then investigated and analyzed through the network model. Having established the process model, a second network, which parallelizes the augmented Lagrange multiplier (ALM) algorithm, determines the corresponding optimum machining conditions by maximizing the MRR subject to appropriate operating and prescribed Ra constraints. [13] in this paper a new contribution to the simulation and modelling of the EDM process is presented. Temperature fields within the workpiece generated by the superposition of multiple discharges, as it happens during an actual EDM operation, are numerically calculated using a finite difference schema. The characteristics of the discharge for a given operation, namely energy transferred onto the workpiece, diameter of the discharge channel and material removal efficiency can be estimated using inverse identification from the results of the numerical model. The model has been validated through industrial EDM tests, showing that it can efficiently predict material removal rate and surface roughness with errors below 6%. M.K. Pradhan [14] Response surface methodology was used to investigate the relationships and parametric interactions between the three controllable variables on the material removal rate (MRR). Experiments are conducted on AISI D2 tool steel with copper electrode and three process variables (factors) as discharge current, pulse duration, and pulse off time. To study the proposed second-order polynomial mode for MRR, they used the central composite experimental design to estimation the model coefficients of the three factors, which are believed to influence the MRR in EDM process. The response was modeled using a response surface model based on experimental results. The significant coefficients were obtained by performing analysis of variance (ANOVA) at 5% level of significance. It was found that discharge current, pulse duration, and pulse off time significant effect on the MRR. This methodology is very effectual, needs only 20 experiments to assess the conditions, and model sufficiency was very satisfactory as the coefficient of determination was 0.962.

3 EXPERIMENTAL SET-UP AN PROCEDURE

3.1 EDM Machine and Equipment

All the experiments have been conducted on a CNC die-sinking EDM Machine, (Model: XPERT-1). The EDM Machine is of Elektra, Electronica Machine Tools India make. The servo control feedback is based on the gap voltage between the tool and the work piece electrodes. As machining takes place, the tool is fed into the work piece to maintain a constant gap voltage, and this determines the gap distance. The gap distance cannot be independently controlled on this machine. The machining time is displayed online during machining and is updated after every minute. Through an CNC code, machining can be programmed to occur up to a fixed depth of cut.

Figure 3.1 CNC die sinking EDM(Model: xpert-1, Make: Electronica Machine Tool, India)

3.2 Tool Design and Material

The tool design for Electric discharge machining for using Cu, brass, Al-alloys, silver, tungsten alloys etc. In this experiment using the copper tool electrode and the design of cupper tool is a U- shaped with internal flashing. Shapes of the tool same cavity produced in the workpiece. Using the U-shaped tool so U-shaped cavity produced on the workpiece. The design of the tool as shown in Figure 3.2.

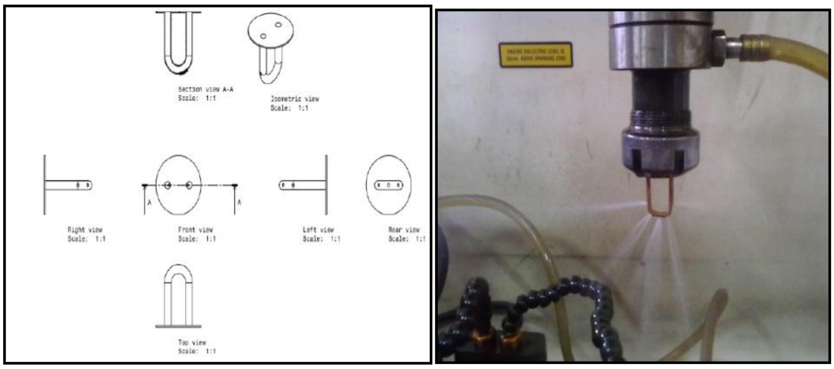


Figure 3.2 U-tube copper electrode

3.3 Work Material

The workpiece chosen for this study was Ti-6Al-2Sn-4Zr-2Mo (Ti-6242). This material belongs to the group of alpha-beta alloys which is used widely for commercial purpose. . The properties of Ti-6242 are listed in the Tables 3.1and 4.2.

Table 3.1 Chemical Composition of Ti 6242 (ASM, 2008)

Element	Al	Sn	Zr	Mo	Si	Fe	O_2	C	N_2	H_2	Ti
Max. Weight (%)	6	2	4	2	0.13	0.25	0.15	0.08	0.05	0.0125	85.3

Table 3.2 Mechanical Properties at Room Temperature (ASM, 2008)

Ultimate Tensile Strength (M Pa)	Yield Strength (M Pa)	Elonga-tion	Hardness (Rockwell)	Hardness (Vickers)	Modulus of Elasticity (G Pa)	Shear Strength (M Pa)	Shear Modulus (G Pa)
1010	1080	3	34	318	120	45.5	300

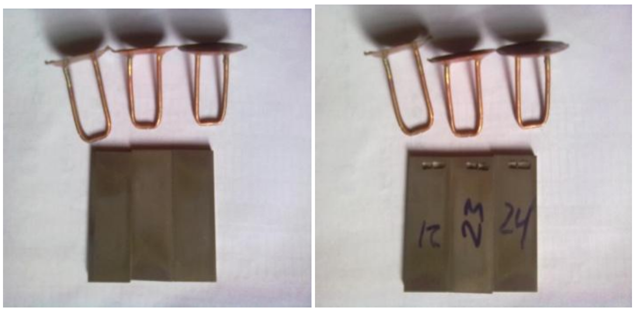


Figure 3.3 Work material before and after machining before After

3.4 Response Parameters

The response parameters include: Material removal rate (MRR). Electrode wear rate (EWR). Overcut (OC)

The experiments were performed on a four-axis CNC type EDM (Electronica XPERT-1) shown in Figure 4.1. The four parameters i.e. pulse on time, pulse off time, peak current, spark gap voltage were varied to investigate their effect on output responses i.e. the MRR, EWR and Overcut. The parameters kept constant during machining are work piece (Ti 6-2-4-2), electrode (U-tube copper with 4.0 mm diameter), thickness of material 5mm and dielectric fluid kerosene oil. The Table 4.3 presents the factors and their levels. The pulse on time and pulse off time was measured in µs.

Table 3.3 Fixed Parameters during EDM Process

Parameters	Description
Work piece	ium Alloy(6-2-4-2)
Electrode material	Copper
Work piece size	22x55x5mm
Dielectric fluid	Kerosene oil

3.4.1 Material Removal Rate (MRR)

The MRR of the workpiece was measured by dividing the weight of workpiece before and after machining (found by weighing method using balance) against the machining time that was achieved. After completion of each machining process, the workpiece was blown by compressed air using air gun to ensure no debris and dielectric was present. A precise balance (Precisa 92SM – 202A DR) was used to measure the weight of the workpiece required. The following equation is used to determine the MRR:

$$\text{MRR} = \frac{1000\ (w_b - w_a)}{\rho\ x\ t_m}\ (\text{mm}^3/\text{min}) \qquad (3.1)$$

Where: W_b = Weight of workpiece material before machining (grams), W_a = Weight of workpiece material after machining (grams), t_m = Machining times (min), ρ = Density of material

3.4.2 Electrode Wear Rate (EWR)

The concept of EWR can be defined in many ways, the present study define the EWR according to ratio in weight of the electrode and the workpiece and is expressed in percentage. The following equation was used for determine the EWR value:

$$\text{EWR} = \frac{A\ x\ L}{t_m} \qquad (\text{mm}^3/\text{min}) \qquad (3.2)$$

Where: A = Area of the electrode,L = Loss in length of the electrode, t_m = Machining time in minutes

4.4.3 Overcut (OC)

It is the discharge by which the machined hole in the work piece exceeds the electrode size and is determined by both the initiating voltage and the discharge energy. During the process of machining EDM cavity produced are always larger than the electrode this deference (size of electrode and cavity) is called Overcut (OC). It becomes important when close tolerance components are required to be produced for space application and also in tools, dies and mouldsfor press work (Singh and Maheshwari [33]).

$$\text{OC}=\frac{Djt\ (mm^3 \frac{Dt}{\text{min}})}{2} \qquad (3.3)$$

Whereas: D_{jt} = diameter of hole produced in the work piece ,D_t = Diameter of tool

4 RESULTS AND ANALYSIS

In this study, randomizations of the run order and analysis sequences were carried out according to the run order by Design Expert 6.0 software. The experiments were performed using Box- Behnken design. A table 4.1 shows the Factors and their levels for EDM of Ti-6242. Table 4.2 shows the experimental design matrix. DOE will be used to determine the significant process variables of EDMing which affect the responses such a (MRR), (EWR) and overcut.

Table 4.1 Factor and level for EDM of Ti-6242

Factor	Name	Units	Type	Low level (-1)	Low level (+1)
A	Peak current	Ampere	Numeric	1	4
B	Servo Voltage	Volt	Numeric	20	60
C	Pulse on Time	(µs)	Numeric	12	50
D	Pulse off time	(µs)	Numeric	12	50

Table 4.2 Experimental design matrix for EDM of Ti-6246

RUN	Peak current IP (Ampere)	Servo Voltage(SV) (Volt)	Pulse on Time(Ton) (µs)	Pulse off time (Toff) (µs)
1	4	60	31	31
2	2.5	40	12	12
3	2.5	40	31	31
4	2.5	60	31	50
5	2.5	40	50	50
6	2.5	40	50	12
7	4	40	50	31
8	2.5	20	12	31
9	4	20	31	31
10	4	40	31	12
11	2.5	40	12	50
12	2.5	40	31	31
13	4	40	31	50
14	1	40	31	12
15	2.5	20	31	50
16	2.5	60	12	31
17	1	20	31	31
18	1	40	50	31
19	2.5	40	31	31
20	4	40	12	31
21	1	40	12	31
22	1	40	31	50
23	2.5	20	31	12
24	2.5	40	31	31
25	2.5	20	50	31
26	2.5	60	31	12
27	2.5	60	50	31
28	1	60	31	31
29	2.5	40	31	31

DOE is a powerful analysis tool for modeling and analyzing the influence of process variables over some specific variables. The insignificant variables were identified and segregated, and were not considered during the confirmation tests. Basically, this chapter covers four main heading namely experimental results, analysis of results, confirmation tests and comparison of test results between values predicted and those obtained experimentally from the confirmation tests.

4.2.1 Effect of process parameters on material removal rate (MRR)

The results from the Table 5.3 were further analyzed according to the steps outlined for BBD design. The transformation is done on the recommended design only which is recommended by Box-Cox plot. An ANOVA table is commonly used to summarize the experimental results. The table concludes information of analysis of variance and case statistics for further interpretation. Design expert 6.0 software has been used to compute the values as shown in Table 4.3. Based on ANOVA Table 4.4 summarizes the effects of process variables and the interactions for second order quadratic model for MRR. This model was developed for 95% confidence level. The model F value of 160.63 implied that the model is significant, with a negligible influence of noise. By checking F values and P values, it is seen that the factor A (Peak current) and B (Spark gap voltage) has a most significant effect on MRR. The P value of this factor is 99%, which shows its strong influence with a contribution of factor A is 68.42%. The value of "Prob>F" less than 0.05 indicates that the model terms A, B, A^2 are significant. Values greater than 0.1000 indicate the model terms are not significant. The lack of fit F value of 0.9655 implies that it is not significant compared to pure error. The "Pred. Rsquared" of 0.9507 is in reasonable agreement with the "Adj. R-squared" of 0.9448. This model can be used to navigate the design space. The developed statistical model for MRR in coded form is

Final Equation in Terms of Coded Factors:

$$MRR = +0.21 +0.21 * A -0.025* B +0.17 * A^2$$

Final Equation in Terms of Actual Factors:

$$MRR = +0.37645-0.23547 * IP-1.22500E-003* SV+0.074850* IP^2$$

Table 4.4: ANOVA table for MRR

ANOVA for Response Surface Reduced Quadratic Model						
Analysis of variance table [Partial sum of squares]						
	Sum of			**MeanF**		
Source	**Squares**	**DF**	**Square**	**Value**	**Prob > F**	
Model	0.73	3	0.24	160.63	< 0.0001	significant
A	0.52	1	0.52	344.82	< 0.0001	
B	7.20E-03	1	7.20E-03	4.78	0.0384	
A2	0.2	1	0.2	132.3	< 0.0001	
Residual	0.038	25	1.51E-03			
Lack of Fit	0.023	21	1.12E-03	0.31	0.9655	not significant
Pure Error	0.01	4	3.55E-03			
Cor Total	0.76	28				

Std. Dev.	0.039	R-Squared	0.9507
Mean	0.28	Adj R-Squared	0.9448
C.V.	14.06	Pred R-Squared	0.9356
PRESS	0.049	Adeq Precision	32.265

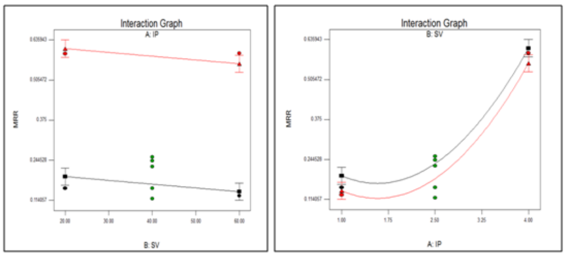


Figure 4.1: Interaction between Peak current (A) and servo voltage (B) Figure 5.2: Interaction between servo voltage (B) and Peak current (A)

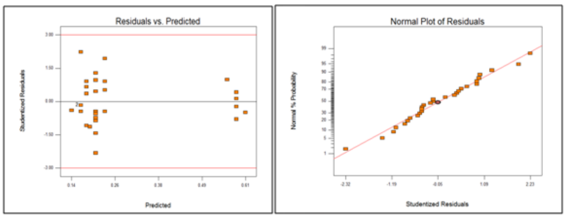


Figure 4.3 Normal probability plots of residuals for MRR in EDM process

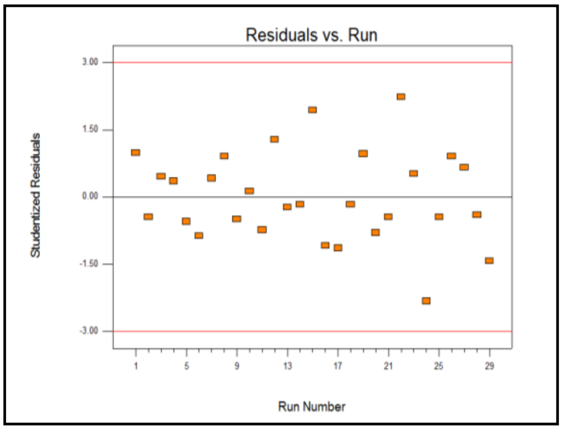


Figure 4.5 Residual vs run number response for MRR in EDM process

From the main effect plots Figure 4.6 it has been observed that whenever peak current is increased from 1.0 amp to 4.0amp, the value of MRR increased significantly. The increment of MRR was approximately 0.166 mm^3/min to 0.583 mm^3/min. when we decreasing spark gap voltage from 60V to 20V the MRR has been increased from 0.18 to 0.23mm^3/min

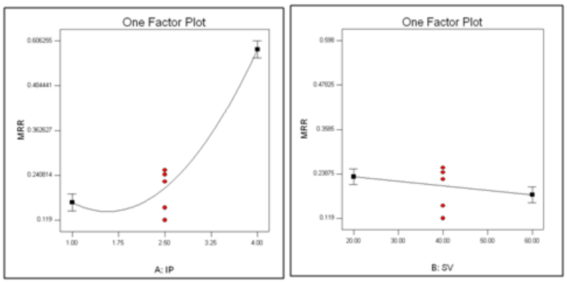


Figure. 4.6- Main factors plot on MRR

4-2-2 Effect of process parameters on electrode wear rate (EWR)

Based on the proposed second-order polynomial model, the effect of the process variable on the EWR has been determined by computing the values using, Design Expert 6.0 software and the relevant data from Table 4.3. The mathematical relationship for correlating the EWR and the considered process variables is obtained as follows:

EWR = +0.070 +0.052 * A -8.333E-004 * B-0.026* C+0.031 * A^2+0.019 *B^2-0.029 * A * C+0.028* B * C

Final Equation in Terms of Actual Factors:EWR= +0.20086-1.99322E-003 * IP-6.12014E-00 * SV-1.80702E-003 * TON+0.013609* IP^2+4.71733E-005 * SV^2-1.00877E-003* IP * TON+7.43421E-005* SV * TON

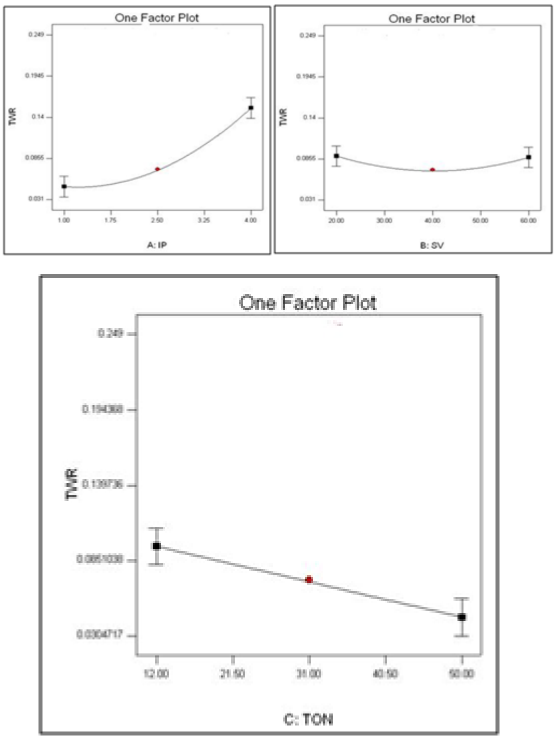


Figure. 4.7- Main factors plot on EWR

From Figure 5.8 the significant interactions IP * TON and SV*TON of the parameters for the EWR. The “Prob>F” value of interactions are 0.0153 and 0.0169 respectively. Therefore, the first interaction to be considered was the interaction between IP and TON. When Ip was set at 1.0A and Ton was varied from 12 to 50 µs, EWR increased at 0.045 to 0.203 mm^3/min. Residuals plots in Figure 5.9 also satisfy the developed model. It was observed that errors are normally distributed that fall on a straight line. The status of electrode tool wear affects the dimensional accuracy of machined components because the die-sinking EDM process is projection manufacture. The electrical erosion resistance of EDM tools is, of course, determined by a combination of thermo-physical and mechanical characteristics of its elements.

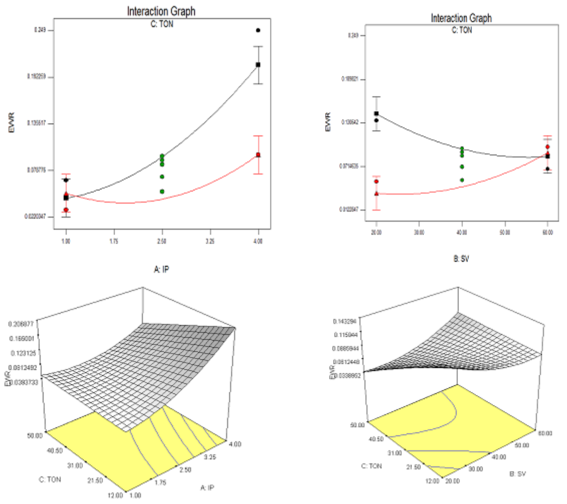


Figure 4.8: Interaction plot between IP * TON and TON * SV

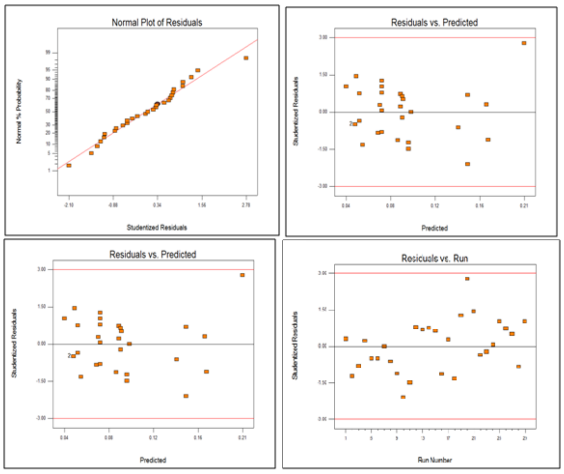


Figure 4.9 Residual plots for EWR

4-2-3 Effect of process parameters on Overcut

The main effect plots based on the Figure 4.10, it has been observed that whenever peak current is increased from 1.0Amp to 4.0Amp, the value of overcut increased significantly. The increment of overcut was approximately 0.037mm to 0.11mm. Meanwhile the effect of spark gap voltage varied from 40V to 60V the overcut was decreased from 0.07mm to 0.051mm.Figure 4.11 shows the interaction effect for Overcut.

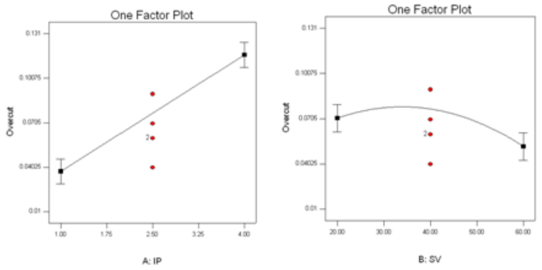


Figure 4.10 Main effect plot for Overcut

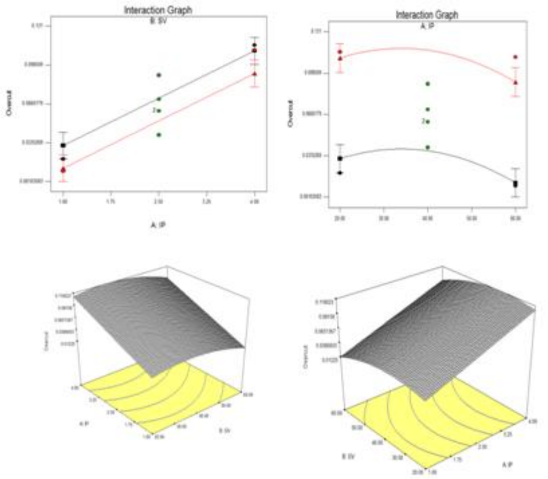


Figure 4.8: Interaction plot between IP * SV and SV * IP

4-3 Multi-Response optimization

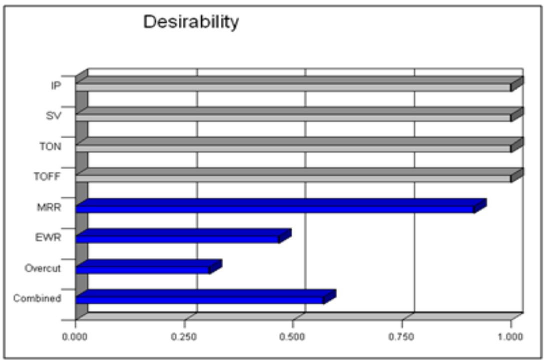


Figure 4.9: Multi response optimization results for maximum MRR and minimum Overcut, EWR

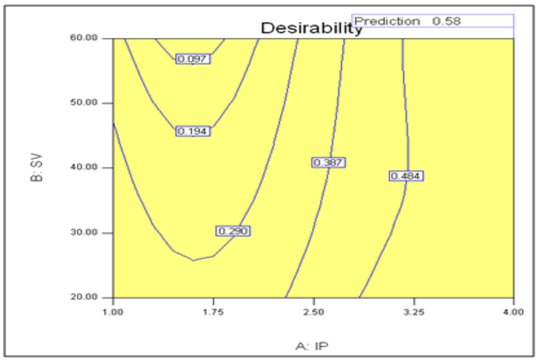


Figure 4.10: Contour plot for results of overall desirability functions

Table. 4.7 Constraints of input parameters and responses

Parameters	Target	Lower limit	Upper limit	Lower weight	Upper weight	Importance
Peak current		1	4	1	1	3
Spark gap voltage		20	60	1	1	3
Pulse on time		12	50	1	1	3
Pulse off time		12	50	1	1	3
MRR(mm^3/min)	maximize	0.119	0.598	1	1	5
EWR(mm^3/min)	minimum	0.031	0.249	1	1	3
Overcut(mm)	minimum	0.01	0.131	1	1	3

Table. 4.8- Process parameters combinations for high value of desirability

	Factors				Predicted Resposes			
Exp. no.	IP (Ampere)	SV (Volt)	Pulse on time (µs)	Pulse off time (µs)	MRR (mm^3/min)	EWR (mm^3/min)	Overcut (mm)	Desirability
1	4.00	60	50	20.45	0.558	0.144	0.091	0.581
2	4.00	60	50	14.92	0.558	0.144	0.091	0.581
3	4.00	60	50	22.31	0.558	0.144	0.091	0.581
4	4.00	60	50	14.37	0.558	0.144	0.091	0.581
5	4.00	60	50	37.32	0.558	0.144	0.091	0.581
6	4.00	60	50	22.95	0.558	0.144	0.091	0.581
7	4.00	59.98	50	29.55	0.558	0.144	0.091	0.581
8	4.00	59.87	50	13.59	0.558	0.143	0.091	0.580
9	3.80	20	50	48.27	0.539	0.078	0.105	0.578
10	3.81	20	50	35.43	0.539	0.078	0.105	0.578
11	3.80	20	50	48.42	0.539	0.078	0.105	0.578
12	3.80	20	50	14.55	0.538	0.078	0.105	0.578
13	3.80	20	50	12	0.537	0.078	0.105	0.578
14	3.81	20	50	33.92	0.542	0.144	0.105	0.578
15	3.80	20	50	29.23	0.539	0.092	0.105	0.578
16	3.91	60	45.89	12	0.526	0.152	0.089	0.570
17	3.97	20.01	48.95	12	0.597	0.079	0.109	0.569
18	4.00	60	43.95	50	0.558	0.158	0.091	0.568
19	3.59	20	47.24	50	0.470	0.162	0.099	0.562
20	3.86	60	32.56	12	0.509	0.0682	0.087	0.542
21	3.83	60	27.01	12	0.497	0.042	0.086	0.531

5 CONCLUDING REMARKS

In this study, the MRR, EWR and Overcut in EDM process of Titanium alloy using U-shaped Cu electrode were modeled and analyzed through RSM. Pulse on time, pulse off time, peak current, spark gap voltage have been employed to carry out the experimental study. Summarizing the main features, the following conclusions could be drawn: EDM is an adequate process to machine high strength temperature resistant (HSTR) pure titanium (6-2-4-2) with good surface finish and dimensional accuracy. Peak current, pulse on time and spark gap voltage was found to be the most important factor effecting the MRR ,EWR and Overcut. The predicted values match the experimental values reasonably well, with R^2 of 0.9507 for MRR, R^2 of 0.8469 for EWR and R^2 0.7847 for Overcut. The error between experimental and predicted values at the optimal combination of parameter settings for MRR, EWR and Overcut lie within 5.10,-9.41 and -5.47%, respectively.

REFERENCES

[1]. C.Sommer (2000). Non-traditional machining handbook. First edition. Advance Publishing. Houston.

[2]. P.C.Pandey, and H.S. Shan, (1980). Modern Machining Processes. New Delhi. Tata Mcgraw-Hill.

[3]. Ho, K.H, Newman, S.T. (2003), "State of the art electrical discharge machining (EDM)", International Journal of Machine Tools & Manufacture 43, pp.1287–1300.

[4]. Kunieda, M, Furuoya, S., Taniguchi, N., "Improvement of EDM efficiency by supplying oxygen gas into gap", CIRP Annals-Manufacturing Technology 40, pp. 215–218.

[5]. Qing gao, Qing, Qin-he zhang, Qin-he, Shu-peng su, Jian-hua zhang (2007) , "Parameter optimization model in electrical discharge machining process" , revision accepted July 5, pp.32.

[6]. S. Assarzadeh & M. Ghoreishi , (2008) , "Neural-network-based modeling and optimization of the electro-discharge machining process", International Journal Advance Manufacture Technology 39:488–500 ,pp .32-33.

[7]. Ko-Ta Chiang, (2008) , "Modeling and analysis of the effects of machining parameters on the performance characteristics in the EDM process of Al2O3+TiC mixed ceramic", International Journal Advance Manufacture Technology, 37:523–533 DOI 10.1007/s00170-007-1002-3, pp-29.

[8]. Kuang-Yuan Kung & Jenn-Tsong Horng & Ko-Ta Chiang, (2007) "Material removal rate and electrode wear ratio study on the powder mixed electrical discharge machining of cobalt bonded tungsten carbide" International Journal Advance Manufacture Technology, , pp-30.

[9]. Ali Ozgedik ,Can Cogun, (2006) "An experimental investigation of tool wear in electric discharge machining", International Journal Advance Manufacture Technology .27: 488–500, pp-30.

[10]. Yusuf Keskin ,H.Selc¸uk Halkacı ,Mevlut Kizil, (2006) "An experimental study for determination of the effects of machining parameters on surface roughness in electrical discharge machining (EDM)", International Journal Advance Manufacture Technology 28: 1118–1121, pp 30-31.

[11]. LIU YongHong ,JI RenJie , Yu LiLi, LI XiaoPeng & DONG Xin, "Study on high efficient electric discharge milling of silicon carbide ceramic with high resistivity", pp-31.

[12]. Paulo Peças & Elsa Henriques, (2008) "Effect of the powder concentration and dielectric flow in the surface morphology in electrical discharge machining with powder-mixed dielectric (PMD-EDM)", International Journal Advance Manufacture Technology 37:1120–1132, , pp-31.

[13]. Young-Cheol Ahn and Young-Seup Chung, (2002), " Numerical Analysis of the Electro-discharge Machining Process for Alumina-Titanium Carbide Composite II". Unsteady State Approach, KoreanZ Chem. Eng., 19(4), 694-702, pp-32.

[14]. Qing gao, Qin-he zhang, Shu-peng su, Jian-hua zhang , (2007)" Parameter optimization model in electrical discharge machining process" , pp-32.

[15]. S. Assarzadeh & M. Ghoreishi , (2008)"Neural-network-based modeling and optimization of the electro-discharge machining process" International Journal Advance Manufacture Technology .39:488–500 , pp 32-33.

[16]. B. Izquierdo, J.A.Sanchez, S.Plaza,I.Pombo, N.Ortega, (2008) "A numerical model of the EDM process considering the effect of multiple discharges ", International Journal of Machine Tools & Manufacture , pp-33.

[17]. M.K.Pradhan, (2008) " Modeling of machining parameters for MRR in EDM using response surface methodology" ,

National Conference on Mechanism Science and Technology,pp-33.

[18]. Dawei Luy and Jiju Antonyy , (2002)"Optimization of multiple responses using a fuzzy-rule based inference system" , international. Journal . prod. res., , vol. 40, no. 7, 1613±1625,pp-33.

[19]. C. L. Lin J. L. Lin and T. C. Ko , (2002) " Optimisation of the EDM Process Based on the Orthogonal Array with Fuzzy Logic and Grey Relational Analysis Method" , International Journal Advance Manufacture Technology ,19:271–277,pp 34.

[20]. A Yahya and C D Manning , (2003)" Modelling, Simulation and Controller Design for Electro Discharge Machine System ", electronic systems and control division research,pp-34.

[21]. Ko-Ta Chiang & De-Chang Tsai , (2008)" Effect of silicon particles on the rapidly resolidified layer of Al-Si alloys in the electro discharge machining process", International Journal Advance Manufacture Technology 36:707–714,pp 34-35.

[22]. S. H. Yeo , (1999) "A Method for Green Process Planning in ElectricDischarge Machining ", International Journal Advance Manufacture Technology 15:287–291 pp-35.

[23]. D.C, Montgomery (2001). Design and analysis of experiments. Fifth edition. John Wiley & Sons, New York.

[24]. G.,Derringer, G., R.Suich (1980) . Simultaneous optimization of several response variables. J. Qual. Technol. 12, 214-219.