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Optimization of process parameters of machining pure titanium by wire-cut EDM using response surface methodology

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ABSTRACT

It is a specialized spark erosion machining process capable of precisely machining components of hard materials with complex shapes. The objective of the study is the effects of machining parameters on wire cut Electrical Discharge Machining of machining Pure Titanium, which is now widely used in many engineering applications such as Aerospace **-** jet engines, air frames, Marine, chemical processing**,** Medical, Computer industry**,** Automobile industry-engine valves, exhaust pipes and mufflers**,** Emerging markets. The conventional technique for machining these materials damages the workpiece and tool because of chipping, cracking and the presence of burrs due to their higher hardness of work material. The present work investigates the significance of machining parameters on pure Titanium with brass wire as tool electrode using wire electrical discharge machining process and to an optimal combination of control parameters has been found to maximize metal removal rate and to minimize surface finish using Response Surface Methodology (RSM).

KEYWORDS: Minitab, Pure Titanium, Response Surface Methodology, Electric Discharge Machining.

1.INTRODUCTION

Wire Electrical discharge machining process is one of the vital non-traditional machining techniques. It is a controlled machining process that is used to remove material by electric spark erosion produced between the tool and workpiece. In this WEDM process, a pulsating (ON/OFF) electrical charge of high-frequency current is applied between the electrode and work piece to produce electric spark to remove the metal. Wire-cut EDM machining process will come under electro- thermal machining process in which a thin metal wire in combination with de-ionized water permit the wire to remove the metal by utilizing the heat from electric sparks. Due to this inherent property of the process, wire-cut EDM can easily use to machine complex shape machine parts and high-quality precise components from hard conductive materials.

Wire EDM has remarkable potential in its applicability in the present metal cutting industry for achieving a significant dimensional accuracy, surface finish and contour generation features of products or parts. Wire EDM machines are used to tremendously machine complicated shapes automatically, precisely and economically even hard materials like carbide.

The effect of three different machine rates with constant current on wire EDM for machining Titanium Ti-6Al-4V was investigated. It was found that Kerf width decreases with the increase of machine feed rate. The MRR increases with increase in machine feed rate. An investigation of the influence of machining parameters on metal removal rate and cutting speed for machining of Nimonic 80 A with brass wire as tool electrode was done. The study indicates that cutting speed and MRR, both increases with increase in pulse-on-time and peak current, whereas decreases with increase in pulse-off-time and spark set voltage. Therefore, in this present study, investigates the influence of process parameters such as Wire Tension (WT), Pulse on Time (T_{on}) and Pulse off Time (T_{off}) on Material removal rate and Surface roughness for machining pure titanium on wire electrical discharge machine using Response Surface Methodology.

2. MATERIALS AND METHODS

Set-Up of WEDM: In wire electrical discharge machining (WEDM), a thin single-strand metal wire, customarily brass, is alimented through the work piece, placed underwater in a tank of dielectric fluid, usually deionized water. The upper and lower diamond guides are usually accurate to 0.004mm.

Work piece Material: Titanium metal has a property of high tensile strength, shock resistance, good ductility and resistance to wear. **Titanium** is prominent for its wear resistance properties and also was high strength properties are required. Table 1 illustrates the chemical composition of Titanium. The specimen pure Titanium size of 200×100×10 mm^3, rectangular profiles was cut.

Tool Electrode Material: The electrode material is generally made of brass, copper or tungsten and is typically about 0.25mm in diameter, making narrow cuts possible. Zinc or brass coated wires are also used. The wire is generally used only once as it wears away during the cutting process. Therefore, in this present work the brass wire electrode 0.25 diameter has been selected to get better material removal rate and surface roughness.

Dielectric Fluid: The most commonly used dielectric medium in WEDM is distilled water. The water flushes the cut debris away from the cutting zone. Flushing is a paramount factor in deciding the highest possible feed rate for a given workpiece thickness. The primary requirements of dielectric fluid are should remain electrically non-conductive until the required breakdown voltage is reached. They must have high dielectric strength, Quench the spark rapidly, Good fluidity and economical and ease of availability. In this present work, de-ionized water has been chosen as its dielectric fluid, controlling its resistivity and other electrical properties by means of filters and de-ionizer units.

Selection of Process Parameters: The process parameters are well-known as factors which influence the nature of response variables. The various factors affecting the surface integrity of workpiece machined by wire EDM have been identified as Dielectric pressure, Pulse on time, Pulse off time, Wire tension, Wire feed rate, Gap voltage, Average gap current. In this present work, the most influence parameters such as Pulse on time, Pulse off time, Wire tension has been chosen. The pulse on time has been selected as 6 to 10µs. Pulse off time is denoted by T_{OFF}. Higher the T_{OFF} setting larger is the pulse off period. This results in a better surface finish. The pulse off time has been chosen as 1-4 µs. Wire tension is a gram-equivalent load with which the perpetually alimented wire is kept under tension with the intention that it remains straight between the wire guides. The Wire tension has been selected as 1000, 1150, 1300 grams.

Performance Measures: Wire EDM performance, without any concern of the type of the electrode material and dielectric fluid, is quantified usually by the following criteria:

Material Removal Rate: Maximum of MRR is a significant index of the efficiency and cost effectiveness of the Wire EDM process, however increasing MRR is not always appropriate for all applications because this may affect the surface integrity of the workpiece. The material removal rate (MRR) for Wire EDM process can be calculated from the given expression

$$MRR = V_c * H * B \qquad (1)$$

Where,

$V_c \rightarrow$ Machining speed in mm/min,

$H \rightarrow$ Work piece thickness or height in mm,

$B \rightarrow$ Kerf given by: $B = D + 2W_g$ (2)

Where

$D \rightarrow$ Wire diameter in mm,

$W_g \rightarrow$ Gap between work piece & tool in mm.

Surface Roughness: The machined surface produced by a Wire EDM process consists of a large number of craters that are created by the discharge energy. The quality of surface primarily depends on the energy per spark. The surface finish has been found by using surftronic 3 surface tester.

Response surface modeling: Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques that are utilizable for modelling and analysis of problems in which output or response influenced by several variables and the objective is to find the connection between the response and the variables. The Pulse on time (T_{on}), Pulse off Time (T_{off}) and Wire Tension (WT) are the machining variable, selected for our investigation.

The total number of experiments conducted with the combination of the process parameter is shown in Table 2. The central composite design used since it gives a comparatively precise prediction of all response variable averages related to quantities quantified during experimentation. Experiments have been carried out on the Wire EDM set-up as showed, and the information was collected with respect to the influence of the predominant process parameters on MRR and surface roughness. The relationship between the process variable and response is shown in the developed mathematical model. The reduced model results denote that the model is significant (R2 and adjusted R2 are 94.1% and 88.8%, respectively). After removing the insignificant terms, the final response equation for MRR is given below,

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j \qquad (3)$$

$$MRR = 13.3755+1.2005T_{on}-0.4141T_{off}-1.0934WT-1.0960T_{on}*T_{on} + 0.4332\, T_{on}*T_{off}-0.5280\, T_{on}*WT \qquad (4)$$

For the appropriate fitting of Ra the non-significant terms (p-value is greater than 0.05) are eliminated by backward the elimination process. After eliminating the non-significant terms, the final response equation for Ra is given as follows.

$$Ra = 3.03552+0.21155\, T_{on}-0.04469\, T_{off}-0.19859\, WT-0.14864\, T_{on}*T_{on} + 0.05688T_{on}*T_{off}-0.13500\, T_{on}*WT \qquad (5)$$

The final model tested for variance analysis (F-test) denotes that the adequacy of the test is established. From the computed values of response parameters, a model graph has been engendered for the further analysis. For analyzing the data, checking of a goodness of fit of the model is very much required. The model adequacy checking includes the test for significance of the regression model, test for significance on model coefficients, and test for lack of fit. This fit summary suggested that the quadratic model is more significant for analysis of material removal rate and surface roughness.

3. RESULTS AND DISCUSSIONS

The obtained response variables are given as input into the Minitab software for further analysis following the steps summarized. The second-order model has been proposed in find the correlation between the response and the process variables are taken into account.

Effects of Process Parameters on MRR: The check of the normality assumptions of the data is then conducted; it can be seen in Figures 1 and 2 that all the points on the normal plot come proximate to forming a straight line. This denotes that the data are fairly normal and there is no deviation from the normalness. This shows the efficacy of the developed model. From the figure it was noted that all the residuals are drop on a straight line, which indicates that the errors are normally distributed.

Table.1.Chemical Composition of Titanium

Elements	C	N	H	O	Pd	Fe	Ti
Weight %	0.08	0.03	0.015	0.18	0.08-0.14	0.20	99.67

Table.2.Response (MRR and Ra) Data

Pulse On Time (μs)	Pulse Off Time (μs)	Wire Tension (g)	MRR (mm^3/min)	Ra (μm)
8	3	1300	12.5755	2.86
10	1	1300	12.4193	2.81
10	4	1000	15.5386	3.52
6	1	1000	12.9298	2.92
6	4	1300	10.0126	2.56
6	1	1300	10.9298	2.66
6	3	1150	11.2995	2.69
8	3	1150	12.9488	3.05
10	3	1150	13.3454	3.10
8	2	1150	13.3454	3.08
8	1	1150	13.6174	3.13
10	1	1000	15.0486	3.41
9	2	1150	13.1012	3.06
6	4	1000	10.1236	2.60
7	3	1150	12.5436	2.84
9	3	1150	13.4528	3.11
8	4	1150	12.8661	3.03
8	3	1000	15.0040	3.16
10	4	1300	11.8328	2.74
7	2	1150	12.8000	2.90

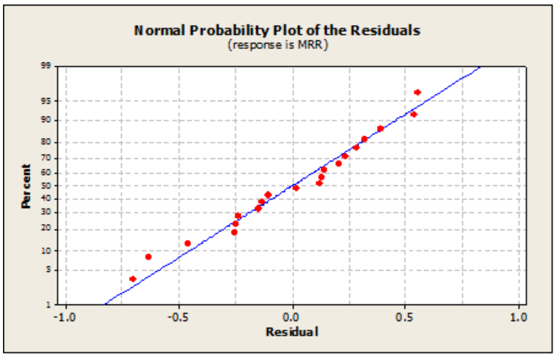

Figure.1.Normal Probability Plot for MRR

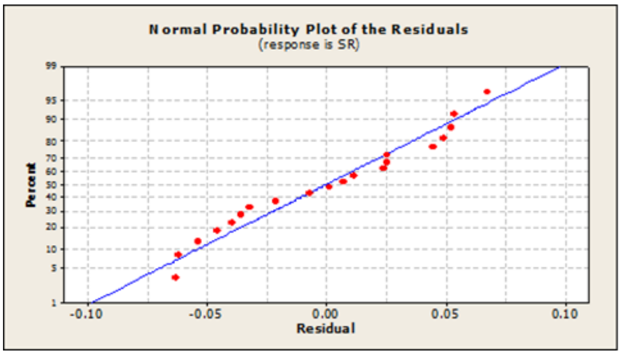

Figure.2.Normal Probability Plot for Ra

The results obtained from the experiment are compared with the prognosticated value evaluated from the model in Figures 1 and 2. It indicates that the regression model is reasonably well fitted with the observed values. The residues which are evaluated as the difference between the predicted and observed value lies in the range of -0.09 to 0.10 and -0.3 to 0.25.

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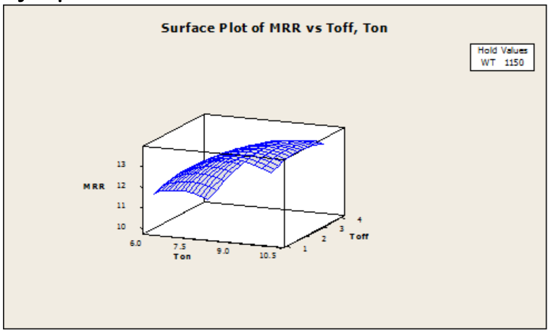

Figure.3.Surface Plot of MRR vs Toff, Ton

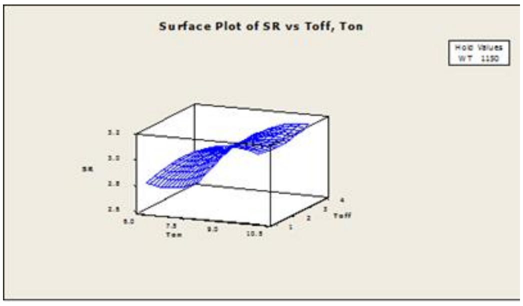

Figure.4.Surface Plot of Ra vs. Ton, Toff

Figure 3 depict the expected response surface for MRR in relation to the process parameters of Toff and Ton. It can be visually perceived from the Figure, the material removal rate tends to increase, significantly with increase in pulse on time for any value of pulse off time. Hence, maximum MRR is obtained at high pulse on time and high pulse off time. This is due to their major control over the input energy i.e., with the increase in pulse on time generates a strong spark which produces the higher temperature cause the most material to melt and erode from the work piece.

Effects of Process Parameters on Surface Roughness: An experiment was carried out on the optimal parameter settings for surface roughness so that the targeted result of response parameter can be obtained.

Figures 4 depict the influence of pulse-on time and pulse-off time on surface roughness. According to this plot, the value of surface roughness increases when the pulse-on time increases, whereas pulse-off time has the adverse effect of surface roughness. As the value of pulse-off time increases the surface roughness decreases.

Confirmation Experiment: An experimental study was conducted in the optimal parameter settings for material removal rate and surface roughness so that all the targeted values of response parameters can be obtained simultaneously. Table 3 depict the predicted value of MRR and surface roughness obtained from the response optimization graph for each response are shown in Figure 5 and experimental result with the parametric optimal setting as obtained from RSM model.

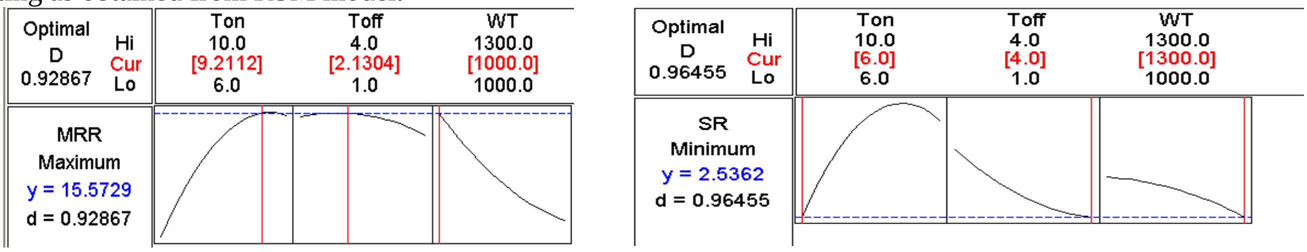

Figure.5.Response Optimization Graph

Table.3.Optimal Condition for Each Response

Response	Optimize value of input parameters			Modified value of input parameters			Predicted value	Experimental value	% error
	T_{on} (μs)	T_{off} (μs)	WT (g)	T_{on} (μs)	T_{off} (μs)	WT (g)			
MRR (mm³/min)	9.2112	2.1304	1000	9	2	1000	15.5729	15.7813	1.34
SR, Ra (μm)	6	4	1300	6	4	1300	2.5362	2.59	2.12

Table.4.The best working conditions for multi-response optimization

Response	Optimize value of input parameters			Modified value of input parameters			Predicted value	Experimental value	% error
	T_{on} (μs)	T_{off} (μs)	WT (g)	T_{on} (μs)	T_{off} (μs)	WT (g)			
MRR (mm³/min)	7.9402	4	1000	8	4	1000	14.0208	14.2450	1.60
SR, Ra (μm)							2.5990	2.65	1.96

Figure 6 shows the multi-response optimization of Wire EDM process to achieve higher Material Removal Rate with the good surface finish for machining pure titanium utilizing response surface method. The optimization goals for multi-response optimization are, minimum for surface roughness and maximum for MRR. The substantiation test for the optimal parametric setting with its preferred levels was conducted to estimate the quality characteristics for Wire EDM of pure Titanium and the results are shown in table 4.

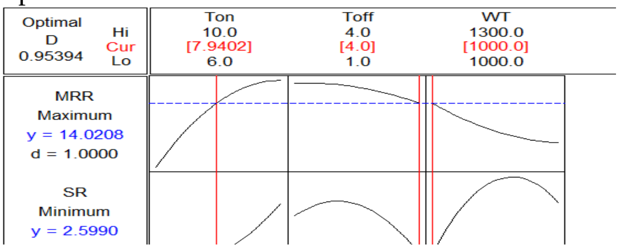

Figure.6.Multi-response Optimization Graph

The results obtained from the experiments were compared with the presaged value calculated from the model. It has been seen that the regression model is plausibly well fitted with the observed values. The residues, which are, calculated as the difference between the predicted and observed value lies in the range of -0.09 to 0.10.

4. CONCLUSION

In this study, an application of combined Response surface method is to improve the multi-response characteristics of Material Removal Rate and Surface roughness in the Wire-Cut EDM of Pure Titanium has been reported. As a result, the optimization of complicated multiple functioning characteristics is highly simplified by this method and since it does not have complicated mathematical computations, this can be easily adapted by the stakeholders of the Manufacturing world. The present study develops MRR models for three different parameters namely wire tension, pulse on time and pulse off time for Wire EDM process for machining pure titanium using response surface method. It was found that all the three process parameters and some of their interactions have a significant effect on MRR and Ra.

i. The MRR tends to increase, significantly with increase in pulse on time for decreases of pulse off time.

ii. The MRR decreases when the WT increases, however with the increase in T_{on}, MRR increases.

iii. The surface roughness value increases with increase in pulse-on time, whereas pulse-off time increases surface roughness decreases.

iv. The surface roughness value increases with increase in T_{on}, whereas it decreases with the increase of wire tension.

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