Influence of Roughness Value on Ti-alloy grade 5 in CNC-WEDM using RSM

K.Vickram[1,a],N. Mohanraj[2,b], K.P.Boopathiraja[3,c], R.Harikrishnan[4,d]

[1,2,3,4] Department of Mechanical Engineering, Sri Krishna College of Technology, Kovaipudur, Coimbatore, India.

ABSTRACT

Wire Electrical Discharge Machining (Wire-EDM) is an electro thermal production process in which a thin single strand metal wire along with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. The accuracy and the surface finishes obtained from WEDM makes it perfect for applications of manufacturing stamping dies, extrusion dies and extrusion tools. Without the WEDM it requires a lot of time for grinding and finishing the parts. Present study has been made to analyze the impact of surface roughness during machining of Titanium alloy grade-5 by wire electrical discharge machining (WEDM) using response surface methodology (RSM) under Central Composite Face (CCF) design. Three input process parameters of WEDM namely pulse-on time (T_{on}), pulse-off time (T_{off}) and wire tension (WT) were chosen as variables to study the process performance of surface roughness (Ra). The analysis of variance (ANOVA) was carried out to know the most significant parameter that influencesurface roughnessand the results of the process were validated using MINITAB software.

Keywords:WEDM, RSM, CCF, T_{on} ,T_{off} , WT and Ra

1. INTRODUCTION

Wire Electric Discharge Machining (WEDM) is one of the most important innovationswhich play a major role in precision tooling and machining industry. It is a thermo-electrical process that material is eroded by a series of discrete sparks between the work piece, and the wire electrode (tool) separated by dielectric fluid [1]. The wire movement is controlled numerically to achieve the desired 3D shape and accuracy of the work piece. WEDM has found ready application in the machining of difficult to cut materials which cannot be machined easily by conventional methods. Thus it plays a major role in the machining of dies, tools, etc., made of tungsten carbide or hard steels. This process deals the improvements in accuracy, quality, productivity and earnings.The most important performance parameter is MRR because optimizing the material removal rate will help to reduce the machining time, so increase the production rate considerably [2]. Titanium is a metal with excellent resistance to corrosion & fatigue, a high strength-to weight ratio that is maintained at elevated temperature. Titanium is a very strong and light metal. This property causes that titanium has the highest strength-to-weight ratio in comparison the other metal that are studied to medical use [3]. Machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Thus, titanium and its alloys are classified as difficult-to-machine materials. Therefore, unconventional machining processes are introduced for machining titanium and its alloys [4]. Analpha-beta type titanium alloy (Ti- 6Al-4V)has been selected as work material for this present study. Ti- 6Al-4V has a resistivity on the order of five times larger than steel which is used in various applications such aircraft gas turbine disks and blades, airframe structural components, prosthetic devices, engine components, offshore, power generation industries etc., [5,6].The selection of cutting parameters plays a vital role for obtaining higher material removal rate and better surface finish. Improperly selected parameters may result in serious consequences like short-circuiting of wire and wire breakage and in turn reduces productivity. Hence, the present paper deals the development of mathematical models for correlating the various input parameters such as pulse on time, pulse off time and wire tension on the most response parameters such as metal removal rate (MRR) and surface roughness (Ra) for obtaining controlled WEDM. Process parameters were optimized through response surface methodology (RSM), utilizing the relevant experimental data as obtained through experimentation.

2. EXPERIMENTAL PLANNING

A Maxicut WEDM machine (Electronica- MODEL) was used to perform the experiments as shown in figure 1. Experiments had beenperformed by covering a wide range of pulse-on time, pulse-off time and wire tension. A 0.25 mm diameterbrass wire was used as electrode. Ti- 6Al-4V alloy Ti-alloy Grade 5**,** also known as Ti-6Al-4V or Ti 6-4, which is the most commonly used titanium alloy, has been chosen as work piece material with 3mm thickness. It is significantly stronger than commercially pure titanium while having the same stiffness and thermal properties among its many advantages, it is heat treatable. Table 1 illustrates the chemical composition of Ti-6Al-4V.

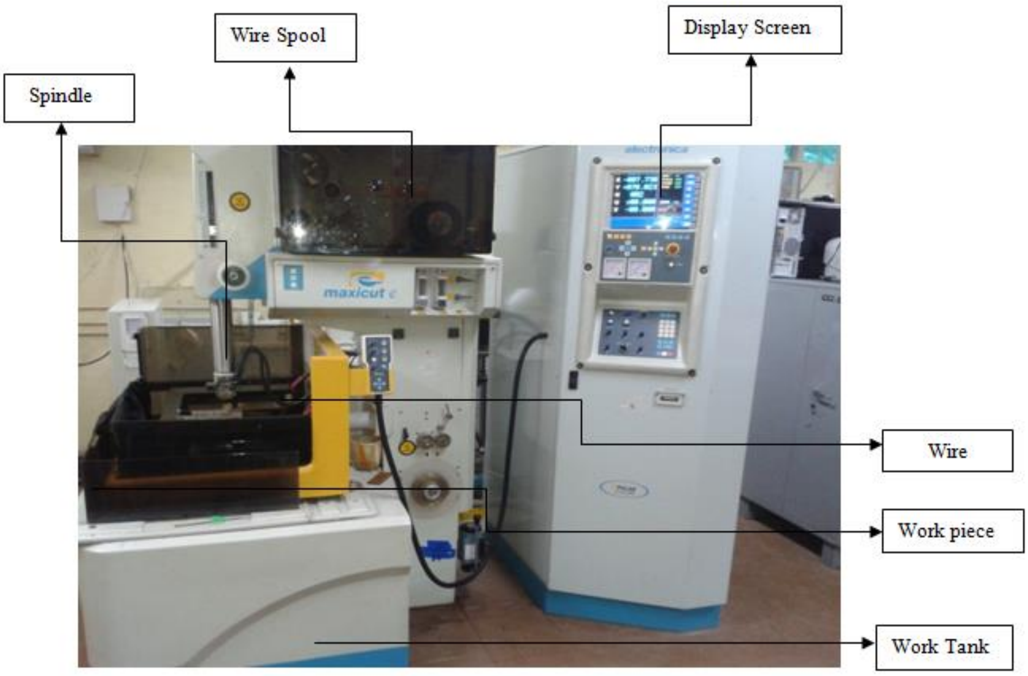


Figure 1: Pictorial View of WEDM

Surface roughness (Ra) was considered as the output response. It was measured by Taylor Hobson surtronic device. An average of two measurements were taken at to-fro motion of stylus on the work surface. The diamond probe of diameter 0.2 microns and cut-off length of 0.8 mm were chosen. Figure 2 shows the Taylor Hobson Surtronic surface roughness tester.

Table 1: Work piecechemical composition.

	C	Fe	N	O_2	Al	V	H	Ti
Ti6Al4V	<0.08%	<0.25%	<0.05%	<0.2 %	5.5 – 6.76 %	3.5 – 4.5%	0-0.15	Balance

Figure 2: Taylor Hobson Surtronic

3.0 DESIGN OF EXPERIMENTS (DOE)

It states that the planning, designing and analyzing an experiment so that valid and objective conclusions could be drawn effectively and efficiently. DOE initiating steps as Problem identification, Brainstorming, Experimental design (choose OA, design experiment), Run experiment, Result analyzes and confirmation results. DOE have so many names such as Taguchi, Factorial or classical and Response surface method (RSM). Taguchi is used for finding a robust answer to the experiment question and it doesn't predict the best combination of factors to achieve your goals. Factorial or classical is 1st technique used with designed experiment, Identify the most important factors and its interactions and it doesn't predict the best combination of factors to achieve your goals. RSM is to make contour plots of predicted behavior and using plots you can actually predict the best combination of factors to meet your goals.

3.1 Response Surface Methodology

It is the collection of mathematical and statistical techniques for developing, improving and optimizing processes. A simple function such as linear or quadratic polynomial, fitted to the data obtained from the experiments is called response surface and the approach is called RSM. By careful design of experiments, the objective is to optimize a response (output variables) which is influenced by several independent variables (input variables).Interactions of control factors cannot be specified using Taguchi experimental design. For this reason, RSM was employed to determine the interactions of the factors. Figure 3 shows RSM procedure.

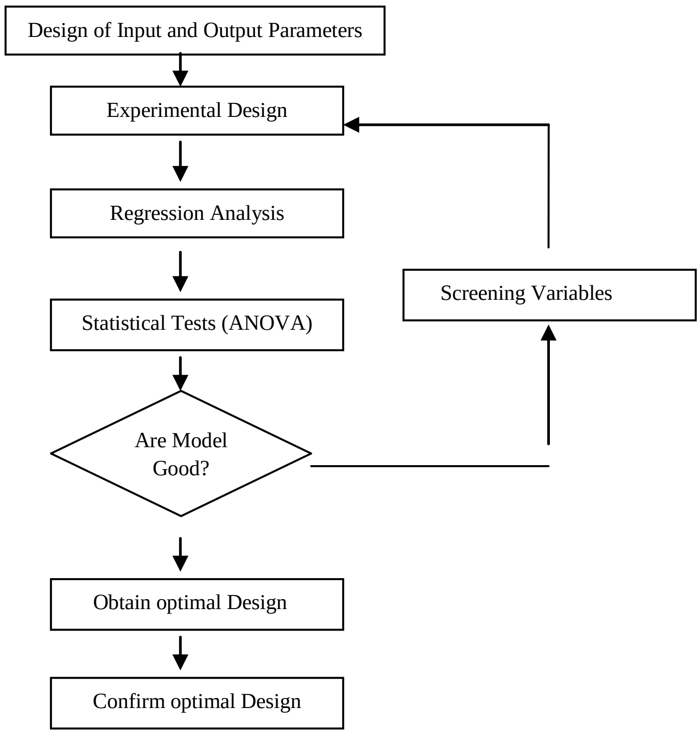


Figure 3: RSM procedure

The general second order polynomial response surface mathematical model can be considered to evaluate the parametric influences on the various criteria as follows:

$$Y_u = b_o + \sum_{i=1}^{n} b_i Xiu + \sum_{i=1}^{n} b_{ii} X^2{}_i u + \sum_{j>1}^{n} b_{ij} X_i u X_j u \qquad \text{------------(1)}$$

Where:

Y*u* = the corresponding response, e.g. MRR and Ra WEDM process,

X*iu*= the coded values of the *i*th machining parameters for *u*th experiment,

n = number of machining parameters, and

b_i ,b_{ii} , b_{ij}= 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 effect. The fourth term of the equation includes the interactive effects of the process parameters. The pertinent process parameter has selected for the present investigations arepulse on time, pulse off time and wire tensionon the metal removal rate (MRR) and surface roughness (Ra) during the WEDM process. Central Composite Face centered design has been implemented for this study with three variables, eight corner points, six axial points and six centre point in axial at zero level, in total 20 runs.The different coding variables are used in the experiment are depicted in Table 2.Total numbers of experiments conducted with the combination of machining parameter are presented in Table 3.

Table 2: Different coding variables used in the experiment

Parameter	**-1**	**0**	**1**
Pulse on time(μs)	7	8	9
Pulse off time(μs)	2	3	4
Wire tension (gms)	1000	1150	1300

Table 3: Total number of experiments

Central Composite Face Centre (CCF)			
Rep	**Pulse On time (T_{on}) in μs**	**Pulse Off time (T_{off}) in μs**	**Wire Tension (WT) in gms**
1	-1	-1	-1
1	+1	-1	-1
1	-1	+1	-1
1	+1	+1	-1
1	-1	-1	+1
1	+1	-1	+1
1	-1	+1	+1
1	+1	+1	+1
1	-1	0	0
1	+1	0	0
1	0	-1	0
1	0	+1	0
1	0	0	-1
1	0	0	+1
6	0	0	0
Total Runs = 20			

4.0 Results and discussions

4.1 Analysis of variance (ANOVA) for the adequacy of the model is then performed in the Subsequent step. The F ratio is calculated for 95% level of confidence. The value which are less than 0.05 are considered significant and the values greater than 0.05 are not significant and the model are adequate to represent the relationship between machining response and the machining parameters. The levels of significant are depicted in the Table 4.The ANOVA Table for the curtailed quadratic model for MRR is shown in Table 5.

4.2 Response Surface Regression: Ra versus T_{on}, T_{off}, WT(The analysis was done using uncoded units)

Table 4:Estimated Regression Coefficients for Ra

Term	Coef	SE Coef	T	P	Factor
Constant	8.04428	0.459675	17.500	0.000	Most Significant
T_{on}	-4.23142	0.102178	-41.412	0.000	Most Significant
T_{off}	-0.05618	0.054136	-1.038	0.324	No Significant
WT	0.01624	0.000658	24.704	0.000	Most Significant
$T_{on}*T_{on}$	0.26263	0.006111	42.933	0.000	No Significant
$T_{off}*T_{off}$	0.01436	0.006111	2.350	0.041	No Significant
WT*WT	-0.00001	0.00001	-25.469	0.000	Most Significant
Ton*Toff	-0.00000	0.003583	-0.000	1.000	No Significant
Ton*WT	-0.00000	0.000024	-0.000	1.000	No Significant
Toff*WT	0.00000	0.000024	0.000	1.000	No Significant

Table 5: ANOVA table for Ra Estimated Regression

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.275805	0.275805	0.030645	298.41	0.000
Linear	3	0.045290	0.200381	0.066794	650.41	0.000
Square	1	0.011290	0.176120	0.176120	1741.99	0.000
Interaction	3	0.000000	0.000000	0.000000	0.00	1.000
Residual Error	10	0.001027	0.001027	0.000103		
Total	19	0.276832				

The value of R^2 is 99.63% and the value of adjusted R^2 is 99.30 which indicate the reduced model results are significant. The lack of fit value is 0.000944 which has non-significant (p-value is less than 0.05). After eliminating the non-significant terms, the final response equation for Ra is given as follows.

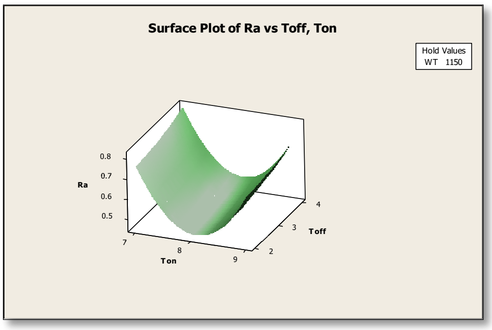
*Ra=8.04428 - 4.23142Ton+0.01624WT+0.26263 (Ton*Ton) -0.00001 (WT*WT)--------* (2)

4.3 Normal Probability Plot

The check of the normality assumptions of the data had been conducted and shown in Figure4(a).It shows that most of the points on the normal plot come closer to form a straight line. This implies that the data are normally distributed and there is no deviation from the normal. This proves the effectiveness of the developed model. The normality plot proves that the residuals are falling on a straight line and the errors are normally distributed.

4.4 Effect of Surface finish on machining parameters

Figure 4(b) indicates the effect of T_{on} and T_{off} over Ra. With reference to these figure the surface roughness increases with increase in T_{on} times of 7 & 9 micro seconds. At particular point of time Ra gets reduced in the value of 8 micro seconds. It clearly depicts the value of Ra first increases and suddenly reduces and again it increases this is due to the phenomena of sparking effect. In those cases there was no effect of T_{off} over Ra.Figure 4(c) depicts the effect of T_{off} and Wire tension on Ra which refers surface roughness had been gradually increased with increasing in Wire tension and had reduced with further increase in Wire tension. Here also T_{off} hadn't produce any impact.



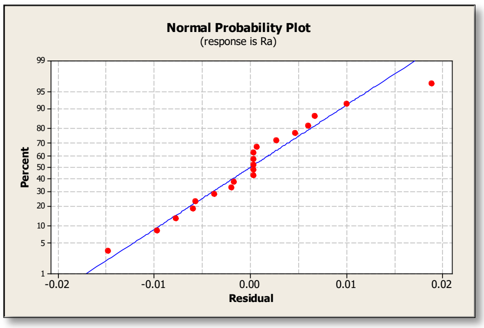
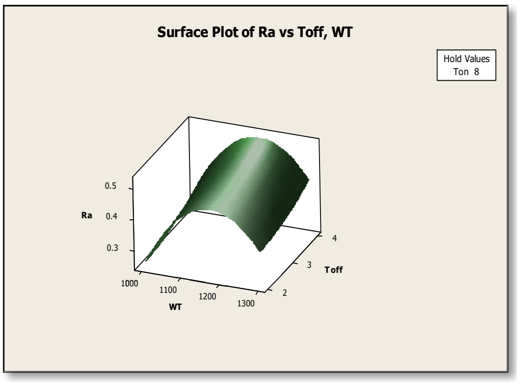


Figure 4(a): Normal Probability Plot Figure 4(b): Surface plot of Ra vs. T_{on},T_{off}



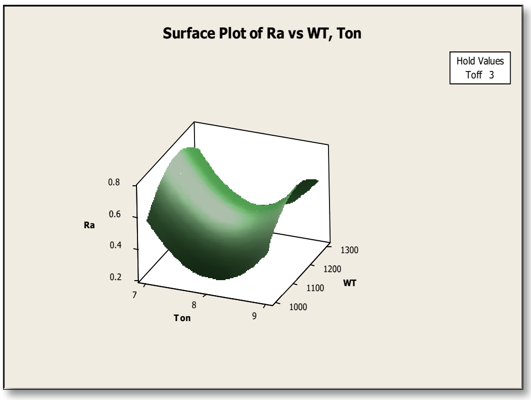


Figure 4(c): Surface plot of Ra vs. WT, Toff Figure 4(d): Surface plot of Ra vs. Ton**,** WT

With reference to Figure 4(d) T_{on} and WT had significant effect over Ra.T_{on} and Wire tension having direct effect on Ra. If you have increased both the parameters, you can expect more damage to the surface.

5.0 CONCLUSIONS

In this present study, an experimental investigation was carried out to analyze the effect of surface roughness over machining parameters in CNC WEDM process ofTitanium alloy grade 5 and the following conclusions were made. The ANOVA results illustrates that there is a significant impact of T_{on} and Wire tension over Surface roughness. The surface plot diagrams using RSM depicts that the optimized parameters for machining over Ra. It can be further concluded that the values of pulse on time and Wire tension had a significant effect over Ra, whereaspulse off timehadn't produce any significant effect. The minimum value of Ra obtained under this study is found to be 0.280µm.

REFERENCES

[1] Kuriakose, S., Shunmugam, M.S., (2004) Characteristics of wire-electro discharge machined Ti6Al4V surface, Materials Letters 58: 2231– 2237.

[2] Kuriakose, S., Shunmugam, M.S., (2005), Multi-objective optimization of wire electro discharge machining process by Non Dominated Sorting Genetic Algorithm, Journal of Materials Processing Technology 170: 133–141.

[3] Kuriakose, S., Shunmugam, M.S., (2004) Characteristics of wire-electro discharge machined Ti6Al4V surface, Materials Letters 58: 2231– 2237.

[4] Gu, L., Li,l.,Zhao, W., Rajurkar, K.P., 2012. Electrical Discharge Machining of Ti6Al4Vwith a Bundled Electrode.International Journal of Machine Tools and Manufacture53(1), p. 100-106

[5] Boyer, H.E., Gall T.L., (1985) Metals Handbook, American Society for Metals, Metals Park, Ohio, pp. 9.1–9.12.

[6] Donachie, Jr., Matthew J. (2000).'' Titanium - A Technical Guide (2nd Edition)'' (ASM International) pp 318-323.