Optimizing the EDM Parameters to Improve the Surface Roughness of Titanium Alloy (Ti-6AL-4V)

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Abstract: *The purpose of this paper is to optimize the EDM parameters to get the better surface finish on the Titanium alloys Ti- 6AL- 4V. The continuous advancement of the alloy is fulfilling the demand of the industry but for advance material like Titanium alloys Ti- 6AL- 4V partially adopted by industries cause of the difficulties in machining. Non Conventional machining process like Spark Erosion Electrical Discharge Machining (EDM) is the process of machining these hard alloys. The designs of experiment for machining process control parameter are Pulse Time (T_{on}), Pulse off (T_{off}) and Current (I), while tool used for machining alloy Ti- 6AL- 4V was Copper (Cu) electrode. The experimental results have given optimal combination of input parameters which give the optimum surface finish of the EDM machined surface.*

Keywords*: Surface Roughness, Taguchi, ANOVA, Current, EDM*

I. INTRODUCTION

Titanium and its alloys have good electrical conductivity and thermal conductivity.Ti-6AL-4V is the most widely used titanium alloy. It features good machinability and excellent mechanical properties. The Ti-6AL4-V alloy offers the best all-round performance for a variety of weight reduction applications in aerospace, automotive and marine equipment. Ti-6AL-4V also has numerous applications in the medical industry. Biocompatibility of Ti-6AL-4V is excellent, especially when direct contact with tissue or bone is required. Ti-6AL-4V is used in applications up to 400 degrees Celsius. The use of titanium alloy in various engineering field is due to its high specific strength and high temperature strength within a broad temperature range, and also high corrosion resistance. Comparing to other metal, titanium have lower values of thermal conductivity, electrical resistance and thermal expansion.

According to the used state, it can be divided as type titanium, β type titanium and (α+β) type titanium. α titanium has good machining character, while (α+β) titanium takes the second place and β titanium the third. α titanium and (α+β) titanium are for common use. Ti-6AL-4V titanium alloy belongs to (α+β) type titanium alloy which contains favorable synthesized mechanical property [1].

In aerospace applications, where weight saving is always a crucial requirement, the strength to weight ratio of Ti alloys allows their use in a variety of components. However, they cannot withstand the same elevated temperatures as HRSA alloys, and typically can not be exposed to operating conditions above 595°C.

Manuscript Received on August 2013.

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Consequently their use in gas turbine engines is limited to the cooler, pre-ignition areas around the compressor, in parts such as casings, fan blades, high pressure blades and discs/rotors [2].

EDM is the advance machine widely used to machine difficult-to-machine materials and high strength temperature resistant alloys. Spark Erosion EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive. The EDM process machines materials using electrical current which generates spark erosion between the electrode and work piece. The electrode is positioned at the fixed small distance (spark gap) above the work piece, both submerged in a dielectric fluid. A pulsating dc power supply or EDM generator applies voltage pulses between the electrode and workpiece generating sparks or current condition through the gap. The gap is stabilized by the servo control unit mechanism. When the current starts to flow the work piece, extreme high heat is generated in the cutting zone, sparks or current conduction are generated through the gap. Each spark result in localized heating and particles of metal become to molten having a very small area and at the end of the pulse duration the molten metal particles are flashed away by the dielectric fluid and remaining liquid material resolidifies [3]. EDM are commonly used in tool and die industry to produce mould and die component. In the Dielectric fluid is usually a petroleum product or deionized water usually die sinker machines use hydrocarbon dielectric fluids. Dielectric fluid functions for spark machining is that it prove a known electrical barrier between the electrode and workpiece, cooling for the electrode and workpiece, cooling for the vaporized material that becomes the EDM chip upon solidification and for removal of the EDM spark debris form the sparking gap. Dielectric fluid is an insulator that resists the flow of electricity until voltage is high enough to cause the fluid to change into an Electrical conductor applied which is called the ionization point. As the spark electricity flow between the electrode and the workpiece, heat is generated, and dispersed within the electrode and surround the sparking area. The dielectric fluids Help to remove heat as it surround the sparking area. It also cools and remove chip. As vapor cloud is form in the sparking-gap area which is then cool and solidifies produce a sphere with a hollow center known as the EDM chip [4].

II. MATHEMATICAL MODEL-TAGUCHI METHOD

Dr. Taguchi of Nippon Telephones and the Telegraph Company, Japan had developed method based on "ORTHOGONAL ARRAY" experiments which gives us much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain the BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr.Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum result[5].

III. STEPS IN TAGUCHI METHODOLOGY

Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process,
Step-l: Identify the main function, side effects, and failure mode.
Step-2: Identify the noise factors, testing the conditions, and quality characteristics.
Step-3: Identify the objective function to be optimized.
Step-4: Identify the control factors and their levels.
Step-5: Select the orthogonal array matrix experiment.
Step-6: Conduct the matrix experiment.
Step-7: Analyze the data; predict the optimum levels and the performance.
Step-8: Perform the verification experiment and plan the future action.

IV. EXPERIMENTAL SETUP

The experimental set up adopted for present study is given in Figure 1. The EDM experiments were conducted in Spark Erosion EDM 5030 machine using copper as the tool electrode. The input parameters are: Pulse–on–time T_{on} (µs), Pulse–off–time T_{off} (µs), and current I (Amp). The output measures being the surface roughness of the machined surface of work material (Ra).

Figure 1: Spark Erosion EDM 5030 machine

Values of the controllable factors were chosen based on the literature review and capability of the commercial EDM machine used. Different settings of the three controllable factors were used in the experiments and have been divided into three different levels as shown in Table 4. Moreover, this work adopted L9 orthogonal array based on Taguchi method to conduct a series of experiments to optimize the EDM parameters. Experimental data were evaluated statistically by analysis of variance (ANOVA) and all other machine parameters were kept constant during the time of experiment.

Table 1: Show the Chemical Composition of the test specimen i.e. Ti-6AL-4V

Element	Ti	Al	V	C	Fe	O	N	H
Weight %	89.464	6.08	4.02	0.02	0.22	0.18	0.01	0.0053

Figure 2: Titanium Alloy Ti-6AL-4V before EDM machining

Figure 2 and figure 3 shows the Titanium Alloy Ti-6AL-4V before and after machining on Spark Erosion EDM.

Figure 3:Titanium Alloy Ti-6AL-4V after EDM machining

Table 2: Shows the Mechanical Properties of Ti-6AL-4V specimen

Hardness (HV20)	600
Melting point (°C)	1660
Ultimate tensile strength (MPa)	832
Yield strength (MPa)	745
Impact-toughness (J)	34
Elastic modulus (GPa)	113
Density(Kg/m^3)	4420
Tensile strength (MPa)	1000
Young's Modulus (GPa)	110

Table 3: Shows the experimental setup followed by the experiment

Work piece material	Ti-6AL-4V
Length of work piece	50mm
Diameter of work piece	10mm
EDM used	EMS 5030 (500X300)
Tool Material	Copper
Measuring Instrument	Profilometer (Talysurf), Mitutoyo SJ-201P (for measuring Surface Roughness R_a)
Environment	Wet
Dielectric Fluid	Kerosene oil

Table 4: Levels for Controllable Factors.

Factors	EDM Machining Parameters	Symbol	Levels		
			L1	L2	L3
A	Pulse -on time (µs)	T_{on}	24	32	40
B	Pulse -off time (µs)	T_{off}	7	8	9
C	Current (amp)	I	5	10	15

The Experimental setup was developed based on Taguchi's Orthogonal Array Experimentation Technique. An L9 Orthogonal Array Experimental layout was selected to satisfy the minimum number of Experiment conditions for the Factor and Levels shows in Table 4.

Table 5: Shows Standard L9 Orthogonal Array

Experiment No.	T_{on} (µs)	T_{off} (µs)	I(amp)
1	24	7	5
2	24	8	10
3	24	9	15
4	32	7	10
5	32	8	15
6	32	9	5
7	40	7	15
8	40	8	5
9	40	9	10

Table 6: Shows the L9 Orthogonal array with Performance

Exp No.	T_{on} (µs)	T_{off} (µs)	I (amp)	Ra- 1	Ra- 2	Ra- 3	R_a (Avg) (µm)
1	24	7	5	2.25	3.973	3.752	3.325
2	24	8	10	6.002	5.936	6.911	6.283
3	24	9	15	6.282	5.674	4.811	5.589
4	32	7	10	7.899	6.602	5.509	6.67
5	32	8	15	9.748	9.507	8.213	9.156
6	32	9	5	4.686	4.458	4.692	4.612
7	40	7	15	9.802	9.34	5.833	8.325
8	40	8	5	5.86	5.781	9.809	7.15
9	40	9	10	5.214	4.885	6.611	5.57

Figure 4: Profilometer (Talysurf)

Figure 5 : Profilometer Measuring Surface roughness

Table 7 shows the General Linear model for Surface roughness R_a

Factor	Level	Type	Values
Pulse -on time	3	Fixed	24, 32, 40
Pulse -off time	3	Fixed	7, 8 ,9
Current	3	Fixed	5, 10, 15

Table 1 Shows the chemical composition of the test specimen i.e. Ti -6AL-4V. Table 2 shows the Mechanical properties of the test specimen. Table 3 shows the experimental conditions followed during the present experiment. Table 4 shows the EDM Machining parameters are Pulse on Time (T_{on}), Pulse off Time (T_{off}) and Current (I) with their values at 3 levels. Table 5 shows the Standard L9 Orthogonal Array. Table 6 shows the L9 Orthogonal Array with Experimented values for each parameter. Table 7 shows the General Linear model for Surface Roughness R_a..

Table 8: Analysis of variance (ANOVA) for SN Ratio

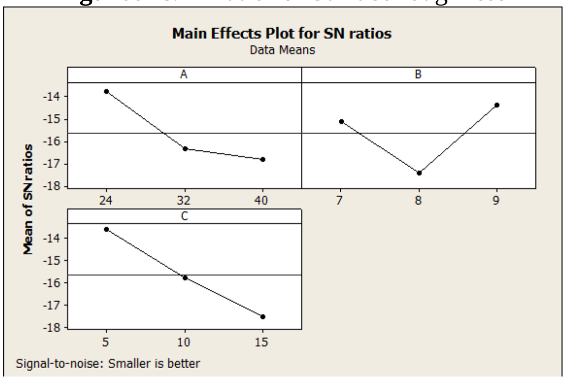
Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contri-Bution
T_{on}	2	6.89	6.89	3.44	19.11	0.050	26.66
T_{off}	2	7.91	7.91	3.95	21.93	0.044	30.60
Current	2	10.69	10.69	5.34	29.64	0.033	41.35
Error	2	0.36	0.36	0.18			1.39
Total	8	25.85					100

Table 9: Response Table for Signal to Noise Ratios Smaller is better

Level	T_{on}	T_{off}	Current
1	-13.78	-15.11	-13.60
2	-16.33	-17.43	-15.79
3	-16.80	-14.38	-17.53
Delta	3.02	3.05	3.93
Rank	3	2	1

By using the Minitab 15 software determined Table no 8 Analysis of variance (ANOVA) and Response Table for signal to Noise Ratios Smaller to better which is shows on Table no 9. Figure 6 shows the S/N ratio for Surface Roughness (Signal to noise: Smaller is better).

Figure6- S/N Ratio for Surface roughness



V. CONCLUSIONS

From the experimental results, S/N ratio and ANOVA analysis and predicted optimum machining parameters, the following conclusions are drawn:-

(i) From ANOVA Table 8 and Response table 9 for Signal to Noise, based on the ranking it shows that Current has a greater influence on the surface Roughness followed by Pulse off time. Pulse on time had the least influence on Roughness.

(ii) The optional setting of process parameters for optimal Roughness is Pulse on Time (24µs), Pulse off time (9µs), and Current (5amp).

(iii) The validation experiment confirmed that the error was less than .37 % between equation and actual value.

VI. REFERENCES

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