Optimization of Material Removal Rate, Surface Roughness in Wire-EDM by using Desirability Function Analysis

A.V.S Ram Prasad, Koona Ramji, Arth Verma, J Pavan Kumar, S Kesava Rao

***Abstract:** In this paper, the behavior of a lead induced Ti-6Al-4V alloy has been studied using wire electrical discharge machine (WEDM). The machining process parameters such as peak current (A), pulse-on-time (B), spark gap voltage (C) and pulse-off-time (D) are to be optimized. Taguchi's L_{27} Orthogonal Array (OA) has been chosen for design and conduction of experiments. Material removal rate (MRR) and surface roughness (SR) are the multiple performance measures which are to be measured. Zinc-coated brass wire is used as electrode wire material. Analysis of variance (ANOVA) technique has been utilized to understand the effects, contribution, and significance of machining process parameters. The experimental results observes that the performance measure were highly influenced by peak current with a contribution of 81.34 % to material removal rate and 58.79 % to surface roughness. The optimal parametric combination for MRR were $A_3B_3C_1D_1$ and $A_1B_1C_1D_1$ for SR. Optimum machining parameters will be identified by composite desirability grade which will be obtained from desirability function analysis (DFA).*

***Keywords:** Lead induced Ti-6Al-4V alloy, WEDM, MRR, SR, Taguchi technique, Desirability function analysis.*

I. INTRODUCTION

In the present studygrade 5 Titanium alloy (Ti-6Al-4V) has been considered for experimentation. Generally, Titanium alloys were widely used in various medical applications, automotive and aerospace industry [1]. They have outstanding properties like heat resistivity, corrosion resistivity, low weight and high strength [2].

The addition of refractory elements such as lead compounds to Titanium alloys increases ductility and enhances the mach inability characteristics of the alloy [3]. Such lead added Titanium alloy machined parts find applications in compressor assemblies which can improves engine performance by reducing the engine knocks. However, refractive elements induced titanium alloys and the products made by them which are to be machined by a conventional machining process is a continues problem. [4]J Barryet al have investigated that severe plastic deformation and thicker distributed layer on machined surfaces for rough machining of Ti-6Al-4V alloy.

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It was also observed that the hardness of the distributed layer of the machined surface increased significantly, when continues machining was carried out with higher flank wear. Not only did the tool life affect but also the original characteristics of these alloys get changed because of the heat generated during conventional machining processes[5]. Hence, unconventional machining processes such as Water Jet Machining (WJM), Ion Beam Machining (IBM) and electrochemical polishing can be used successfully to machine difficult to cut material to overcome the above said problems.

Wire electrical discharge machining (WEDM) is a type of unconventional machining process which was used to generate difficult profile on difficult to machine material like Titanium and its alloy [6].

Fig. 1, illustrate the working principle of wire electrical discharge machining process. It works on the principle of electro-thermal mechanism to machine any work piece material which is good conductor of electricity.

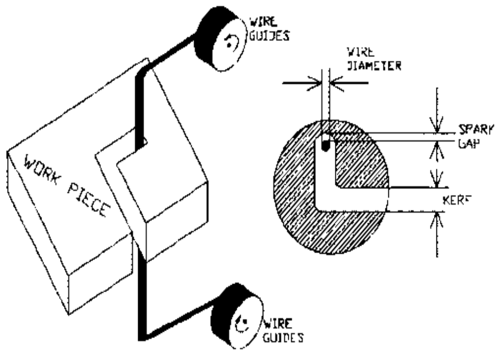

Fig. A.1 WEDM basic working principle

Wire electrical discharge machining is an unconventional machining process which works with electrical and non electrical parameters. It has more number of process parameters, selection of good process parameter combination is always a difficult task[7]. Many researchers have conducted number of experiment to analyze the effect of machining parameters on performance measures in WEDM process[8].JB Saedon [9] conducted experiment on Titanium alloy while machining with wire electrical discharge machining process. In his experimentation he has adopted Taguchi orthogonal array for conduction of experiment followed by grey relational analysis(GRA). Muhammad Azam [10] performed experiment on HSLA steel material and studied about recast layer formed on the

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surface of the machined surface. Process parameters namely pulse on time, pulse ratio, discharge current, spark gap and wire speed rate were varied during the machining process. G Ugrasen[11] used molybdenum wire for machining process. The process parameters namely pulse on time , pulse off time, current and bed speed were considered. In order to find the response of each factor on the objective function, analysis of variance (ANOVA) was used. G Rajyalakshmi [12] has developed utility concept in conjunction with PCA for her experimental work. Material removal rate, surface roughness and spark gap were investigated by considering many of machining parameters on WEDM. KP Rajurkar [13] in his paper presented about adaptive control system which optimizes on line sparking frequency. Sanjeev K Garg [14] has characterized the wire electric discharge machine of Al/10 ZrO2 metal matrix composite. The input process parameter such as pulse width, time between pulses, servo control and mean reference voltage, short pulse time, wire feed and wire mechanical tension were considered. Mechanical properties says successful machining of material can be used on aerospace industries. S S Mahapatra [15] [16] has been employed on rough cutting operation in wire electric discharge machining is a challenging task with some combination factor in process parameter such as discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow optimized performance can be observed.

II. EXPERIMENTAL STUDY

In this paper experiments were performed on Grade 5 Titanium plate which is of 11mm thickness. A CNC operated Ultracut–S1 4-axiswire-EDM(Electronica Machine Tools Ltd, India) was used for conducting the experiments. The electrode material utilized used was zinc coated brass wire of 0.25 mm diameter, whose wire tension is 1300 g. The nominal chemical composition of lead induced grade 5Ti-6Al-4V is represented in Table A.1.

Table. A.1 Nominal chemical composition of Grade 5 Ti-6Al-4V

Element	Al	V	Pb	Fe	Other Elements	Ti(remainder)
Wt %	6.61	4.20	1.09	0.11	0.06	Balance

Four parameters such as, peak current, pulse on time, spark gap voltage and pulse off time were considered as the machining parameters. Three level of process parameters are listed in Table A.2. An orthogonal array L_{27} has been adopted to accommodate all the above machining factors at their respective levels.

Table. A.2 WEDM process parameters

S No.	Machining parameters	Levels 1	Levels 2	Levels 3
A	Peak current (Amp)	10	11	12
B	Pulse-on-time (μs)	105	110	115
C	Spark gap voltage(SV)	40	50	60
D	Pulse-off-time (μs)	50	55	60

Grade 5 Titanium alloy plate of 11mm thickness were machined as per the combination of process parameters as shown in Table A.3. The material removal rate (MRR) is calculated using the under mentioned formula:

M R R = Cutting speed X Width of cut(w) X Height of the work piece(h) (mm^3/min)…(1)

Taylor Hobson made surface roughness testerat 0.8 mm cut-off value was utilized to check the average surface roughness of each machined sample. The surface roughness value on the machined sample was taken at twelve different locations and their average was taken as surface roughness Ra value.

III. RESULTS AND DISCUSSION

In order to analyze values of experimentally observed data and to assess the significance of each parameter, analysis of variance (ANOVA) was used on the material removal rate and surface roughness. Taguchi suggested signal-to-noise (S/N) ratio as the objective function for matrix experiments and classified the objective functions are larger the better, smaller the better and nominal the best type. Table 3 shows the Taguchi orthogonal array and results obtained from the experimental plan of material removal rate and surface roughness.

Table. A.3 Taguchi L_{27} Orthogonal array and their experimental value

S.No	I_P	T_{on}	SV	T_{off}	MRR	R_a
1	10	105	40	50	2.4973	1.150
2	10	105	50	55	1.2455	1.390
3	10	105	60	60	1.1606	1.730
4	10	110	40	55	3.2765	1.350
5	10	110	50	60	1.9195	1.580
6	10	110	60	50	1.7326	1.800
7	10	115	40	60	4.9065	1.430
8	10	115	50	50	2.8901	1.660
9	10	115	60	55	2.4938	2.190
10	11	105	40	55	5.4831	1.450
11	11	105	50	60	4.8656	1.750
12	11	105	60	50	4.8882	1.970
13	11	110	40	60	6.8776	1.840
14	11	110	50	50	5.2094	1.980
15	11	110	60	55	4.9129	2.210
16	11	115	40	50	9.3717	1.970
17	11	115	50	55	7.7490	2.150
18	11	115	60	60	6.7499	2.462
19	12	105	40	60	10.9570	1.923
20	12	105	50	50	8.1500	2.120
21	12	105	60	55	7.5230	2.360
22	12	110	40	50	13.5320	2.210
23	12	110	50	55	10.2675	2.430
24	12	110	60	60	8.5980	2.540
25	12	115	40	55	12.5970	2.450
26	12	115	50	60	10.6570	2.760
27	12	115	60	50	9.8513	2.690

A. Effect on material removal rate

The S/N ratio values of the experimental responses namely material removal rate and surface roughness are represented in Table A.4. In order to identify the effect of each and every individual process parameters and interaction between them, we go for the use of ANOVA. The average value of the material removal rate and their respective levels in Fig A.2.

Table. A.4 Experimental and S/N ratio values for MRR and RA

S.No	MRR (mm^3/min)	S/N ratio of MRR	RA (µm)	S/N ratio of RA
1	2.4973	7.9494	1.150	-1.21396
2	1.2455	1.9069	1.390	-2.86030
3	1.1606	1.2937	1.730	-4.76092
4	3.2765	10.3082	1.350	-2.60668
5	1.9195	5.6638	1.580	-3.97314
6	1.7326	4.7740	1.800	-5.10545
7	4.9065	13.8154	1.430	-3.10672
8	2.8901	9.2183	1.660	-4.40216
9	2.4938	7.9372	2.190	-6.80888
10	5.4831	14.7805	1.450	-3.22736
11	4.8656	13.7427	1.750	-4.86076
12	4.8882	13.7830	1.970	-5.88932
13	6.8776	16.7487	1.840	-5.29636
14	5.2094	14.3358	1.980	-5.93330
15	4.9129	13.8268	2.210	-6.88785
16	9.3717	19.4364	1.970	-5.88932
17	7.7490	17.7849	2.150	-6.64877
18	6.7499	16.5859	2.462	-7.82576
19	10.9570	20.7938	1.923	-5.67959
20	8.1500	18.2232	2.120	-6.52672
21	7.5230	17.5278	2.360	-7.45824
22	13.5320	22.6272	2.210	-6.88785
23	10.2675	20.2293	2.430	-7.71213
24	8.5980	18.6879	2.540	-8.09667
25	12.5970	22.0053	2.450	-7.78332
26	10.6570	20.5527	2.760	-8.81818
27	9.8513	19.8699	2.690	-8.59505

Fig A.2. shows the effect of machining process parameters on the performance characteristic namely material removal rate. It is observed from the figure that material removal rate is increased linearly with increase in process parameters namely peak current. When pulse on time increases from 105 to 115µs, material removal rate increases. This is because of more discharge energy which is caused because of increase in pulse on time. Similarly, as spark gap voltage increases from 40 to 60, material removal rate start decreasing. As Pulse off time exceed from 50 to 60µs material removal rate initially decreases because of number of discharges within a certain period of time become smaller. Finally the S/N ratio response graph which is shown in Fig. 2 states that optimal combination of WEDM process parameters which maximizes MRR of WEDM on Grade 5 Titanium alloy were as follows: higher value of peak current (A_3), higher value of pulse-on-time (A_3), lower value of spark gap voltage (C_1) and lower value of pulse-off-time (D_1).

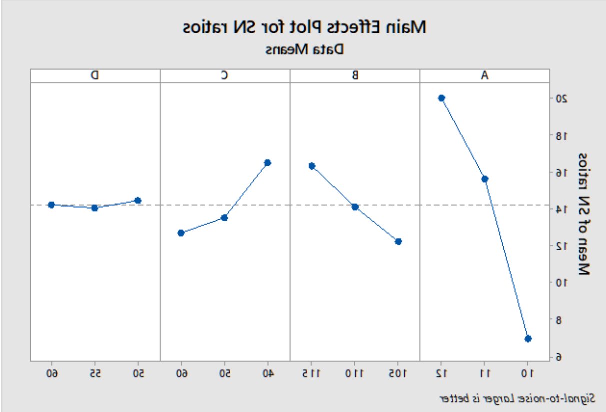

Fig. A.2 S/N response graph for MRR

B. Analysis of Surface Roughness

Fig. A.3 shows the effect of process parameters on surface roughness. Increase in surface roughness was shown Fig 3(A). With increase in peak current and with increase in discharge energy results high melting of molten metal, resolidified and more debris is formed.

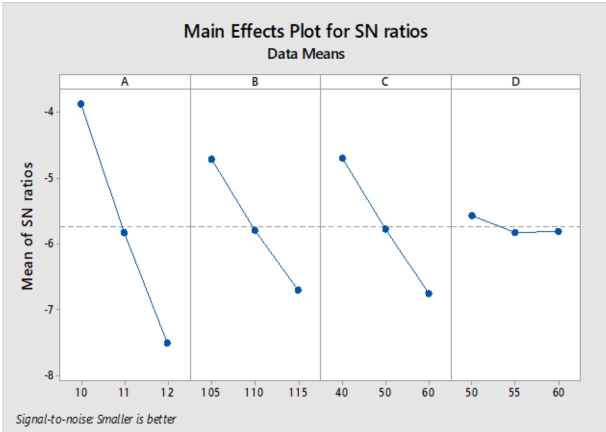

Fig.A.3 S/N response graph for SR

From Fig 3(B) it was observed that surface roughness increases with increase in pulse on time. When pulse on time increases larger discharge energy was produced between wire electrode and workpiece material. It was observed from Fig 3(C) that at lower value of servo voltage surface roughness value tends to be poor. Fig. A.3 demonstrates that the optimal combination levels of machining parameters that minimized SR were as follows: lower value of peak current (A_1), lower value of pulse-on-time (B_1), lower value of spark gap voltage (C_1) and lower value of pulse-off-time (D_1).

IV. MULTI OBJECTIVE OPTIMIZATION: DESIRABILITY FUNCTION ANALYSIS

A. Desirability function approach

It is a nice approach for optimization of responses which are more in number and is used for simultaneous optimization approach. It was one of the important optimization technique introduced by Derringer and Suich.

B. Desirability Function Analysis Optimization Step

Step 1: To calculate the individual desirability index(di) for each responses using the formula

a) When output character is "Larger-is-better"

$X \le x_{min}$

$Di = \frac{X-Xmin}{Xmax-Xmin}$, $x_{min} \le x \le x_{max}$, $r \ge 0$….(1)

$X \ge x_{min}$

here, d_i=Single desirability index;

X_{min} and X_{max} are the lowest and highest values of x;

R= Weight.

b) When output character is "smaller-is-better"

$X \le x_{min}$

$Di = \frac{X-Xmax}{Xmin-Xmax}$, $x_{min} \le x \le x_{max}$, $r \ge 0$….(2)

$X \ge x_{max}$

Step 2: By using the following equation the overall desirability grade (Dg) of each process parameters has been combined to give performance characteristic of grade 5 Titanium alloy.

$D_g=(d^{w1}*d^{w2}*d^{w3}*\ldots\ldots*d^{wi})^{1/w}$….(3)

where,

d_i= Single desirability index ;

w_i= weight assigned to individual response respectively; w = sum of all individual weights.

Highest D_g value is reflected as ideal setting of respective process parameters.

Step 3: To identify the optimal performance parameters of the matrix and their level. Most of the desirability value better the performance. Therefore on the basis of desirability grade we can get the performance characteristics.

Step 4: Taguchi based ANOVA has been performed for process parameter values and it produces a relative performances.

Step 5: Optimum design process parameter characteristics has been calculated and then the performance characteristic has been determined.

Table. 5.A Evaluated individual desirability, desirability grade and rank

S.No	Individual desirability of MRR	Individual desirability of SR	DG	Rank
1	0.1096	1	0.3599	16
2	0.0068	0.8509	0.0913	25
3	0	0.6397	0	26
4	0.1710	0.8757	0.4116	11
5	0.0622	0.7329	0.2344	22
6	0.3027	0.5962	0.4358	10
7	0.3027	0.8260	0.5194	5
8	0.1397	0.6832	0.3280	18
9	0.1077	0.3540	0.2042	23
10	0.3493	0.8136	0.5504	4
11	0.2994	0.6273	0.4456	8
12	0.3013	0.4906	0.3916	14
13	0.4621	0.5714	0.5179	6
14	0.3272	0.4844	0.4040	12
15	0.3033	0.3416	0.3233	19
16	0.6637	0.4906	0.5641	2
17	0.5325	0.3788	0.4433	9
18	0.4517	0.1850	0.2794	20
19	0.7918	0.5198	0.6314	1
20	0.5649	0.3975	0.4676	7
21	0.5142	0.2484	0.3476	17
22	1	0.3416	0.5611	3
23	0.7360	0.2049	0.3699	15
24	0.6011	0.1366	0.2709	21
25	0.9244	0.1925	0.3975	13
26	0.7676	0	0	26
27	0.7024	0.0434	0.1571	24

V. CONCLUSION

The effects of process parameters on MRR and SR of machined components by WEDM of grade 5 Ti-6Al-4V have been investigated experimentally. Based on experimental results obtained and analysis done on the results, following conclusions were drawn. It is observed that main responsible parameter is peak current and the significant factors are pulse-on-time and spark gap voltage. When the WEDM process was used to machine lead induced grade 5 Ti-6Al-4V alloy, the MRR increased with increased peakcurrent. The optimum condition for MRR is higher value of peak current (12A), higher value of pulse-on-time (115 µs), lower value of spark gap voltage (40 V) and lower value of pulse-off-time (50 µs).

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