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Effect of WEDM Parameters on Machinability of Titanium alloys Ti6AlNb

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Abstract: *In this paper, intricate machining of Titanium alloys Ti6AlNb on using Wire Electric Discharge Machining with a zinc coated brass wire by using Taguchi methodology has been reported. Experimentation has been done by using Taguchi's orthogonal array under different conditions of parameters to analysis the effect of each parameter on the machining characteristics and to predict the optimal choice for each parameter such as wire feed (Wf), peak current (Ip), pulse on time (Ton), pulse off time (Toff) and servo voltage (SV). It is found that peak current (Ip), pulse on time (Ton), pulse off time (Toff) and servo voltage (SV) have a significant influence on the machining characteristics such as cutting speed.*
Keywords *- Analysis of Variance (ANOVA), Cutting Speed, Taguchi, Titanium alloys Ti6AlNb, Wire Electrical Discharge machining (WEDM).*

I. INTRODUCTION

With the continuous development in the field of metallurgy, new advance material are developed which possess light weight, high specific strength, good wear resistance, high toughness and low thermal expansion coefficient. These materials are very difficult to be machined by conventional machining. Wire Electrical Discharge Machining (WEDM) is the most widely recognized and non-traditional machining process used in industry today. The outstanding properties of titanium such as high strength, high strength to weight ratio, high toughness, corrosion resistance and long standing are the main causes of widely use of titanium and its alloys. Machining of titanium in the minimum time and with maximum precision is a considerable issue in all application fields of titanium such as biomedical applications, automobile, aerospace, chemical field, electronic, gas, food and especially biomedical industries. Over the past three decades, application of titanium in medical and biomedical devices has expanded due to development of new processing methods such as computer-aided machining and Wire Electrical Discharge Machining (WEDM). WEDM process is a non-traditional machining method that has provided an effective solution to machine difficult-to-machine materials. The quality of engineering parts and components is measured by surface roughness that is one of the machining factors. The huge heat generated during WEDM leads to the microstructure and material composition change and a layer of oxide produced on the machined material surface. Therefore, machining of titanium with a high quality, smooth surface and high accuracy is a purpose for most of the industries and researchers. Lin et al. [1] investigate an efficient Ti6Al4V electrical discharge machining (EDM) process with a bundled die-sinking electrode. The feasibility of machining Ti6Al4V with a bundled electrode was studied and its effect on EDM performance was compared experimentally using a solid die-sinking electrode. The simulation results explain the high performance of the EDM process with a bundled electrode by through the use of multi-hole inner flushing to efficiently remove molten material from the inter-electrode gap and through the improved ability to apply a higher peak current. A three factor, 3-level experimental design was used to study the relationships between two machining performance parameters (material removal rate: MRR, tool wear ratio: TWR) and three machining parameters (fluid flow rate, peak current and pulse duration). The main effects and influences of the 2-factor interactions of these parameters on the performances of the EDM process with the bundled electrode are discussed. Katsushi et al. [2] proposed surface modification method by electrical discharge machining (EDM) with a green compact electrode to make thick TiC or WC layer. Titanium alloy powder or tungsten powder is supplied from the green compact electrode and adheres on a workpiece by the heat caused by discharge. Aggarwal et al. [3] optimized the multiple characteristics, in CNC turning of AISIP-20, such as tool life, cutting force, surface roughness and power consumption. Four controllable factors of the turning process viz. cutting speed, feed, depth of cut and nose radius were studied. Face centered composite design was used for experimentation. Jangra et al. [4] utilized the grey based Taguchi method to optimize the material removal rate and surface roughness for WEDM of WC-Co composite. Results revealed that taper angle, pulse on time (Ton) and pulse off time (Toff) were found the most significant process parameters. Bobbili et al. [5] carried out a study for optimising the WEDM process parameters like pulse on time, pulse off time, wire feed, flushing pressure, servo voltage and wire feed rate during the machining of high strength Armor steel. By using Taguchi techniques, experiment has been performed and result shows that pulse on time, pulse off time and servo voltage are significant variables to both material removal rate and surface roughness. Bhuyan & Yadava [6] investigated the effect of input process variable on Material removal rate (MRR) and Kerf width during machining of Borosilicate Glass using a hybrid machining process “Travelling wire electrochemical spark machining” (TWECSM). MRR and Kerf width increase with increase in applied voltage, pulse on time and electrolyte concentration. Gupta & Jain [7] investigated the behaviour of the micro geometry parameters of miniature spur gears produced by WEDM process and optimize the process parameters for minimising the total profile and accumulated pitch deviation using response surface methodology. The various experimental and theoretical studies shows that process capability of WEDM can be improved significantly by correct selection of machining parameters and tooling for a given material. Sharma et al. [8] optimized the process parameters of WEDM using response surface methodology. Desirability approach has been adopted for multi response (i.e. cutting speed and dimensional deviation) optimization. Pulse on time is the most significant factor for multi response optimization, while two way interactions also played significant role in the process. In contrast to conventional machining process, wire electrical discharge machining (WEDM), Fig. 1, can be proved more economic and efficient in machining the titanium alloys. A very little literature available on the machining of Titanium alloys Ti6AlNb using Wire Electric Discharge Machining. Experimentation has been done by using Taguchi’s L_{32} orthogonal array under different conditions of parameters to analysis the effect of each parameter on the machining characteristics.

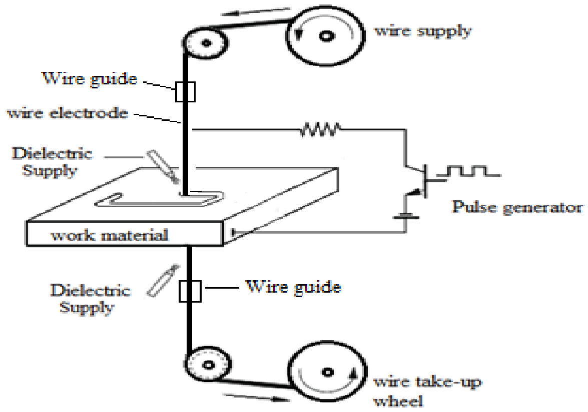

Fig. 1 Wire Electrical Discharge Machining (WEDM) process [12]

a. EXPERIMENTATION

2.1 Experimental setup

In present work, experiments were performed on 5 axis sprint cut (ELPUSE-40) wire EDM manufactured by Electronic M/C Tool LTD India. Titanium alloys Ti6AlNb containing 6.2% Al, 7.1% Nb, 0.25% Fe and remaining Titanium, in rectangular sheet of 12.5 mm thickness; has been selected as work-piece material. It should possess high strength with excellent biocompatibility for surgical implants and also used for replacement hip joints. Using WEDM, work material was machined and samples were obtained in the form of rectangular punch of dimension 8 mm × 6 mm × 12.5 mm. In present investigation, machining parameters namely wire feed (Wf), discharge current (Ip), pulse-on time (Ton), servo voltage (SV) and pulse-off time (Toff) have been selected as variable parameters while parameters under the category of wire electrode and dielectric conditions have been assigned a constant value. Zinc coated brass wire having a fixed diameter of 0.25mm has been selected as wire electrode. Distilled water having conductivity 20 mho has been utilized in present study. High flow rate of dielectric results into complete and quick flushing of the melted debris out of the spark gap which results into high machining rate and good surface finish. Therefore, dielectric flow rate was kept at high value of 12 liters per minute (LM^{-1}). Range and levels of five variable parameters have been listed in Table 1.

2.2 Experimental results

The orthogonal array forms the basis for the experimental analysis in the Taguchi method. The selection of orthogonal array is concerned with the total degree of freedom of process parameters. Total degree of freedom (DOF) associated with five parameters is equal to 9 (1×1+4×2). The degree of freedom for the orthogonal array should be greater than or at least equal to that of the process parameters. 32th experiments were conducted using Taguchi experimental design methodology. These matrix experiments were performed to study the effect of process parameters on the machining characteristics e.g. cutting rate and surface roughness. The experimental results for cutting rate and surface roughness are given in Table 2. Cutting rate was measured in mm/min and directly noted from the machine's control screen. Surface roughness was measured in µm with the help of surface tester named as Mitutoyo Surftest SJ-201P. In order to evaluate the significance or influence of process parameters in present experimentation, analysis of variance (ANOVA) was performed using statistical software, MINITAB 16.

Table 1 shows the names and levels of the process parameters.

Factor	Process Parameters	Level 1	Level 2	Level 3	Level 4
A	Wire feed (Wf)	3	5	—	
B	Peak current (Ip)	90	120	130	150
C	Pulse-on time (Ton)	106	110	114	118
D	Pulse-off time (Toff)	35	40	45	50
E	Servo voltage (Sv)	20	30	40	50

b. OPTIMIZATION OF INDIVIDUAL MACHINING CHARACTERISTICS

In Taguchi method, the S/N ratio can be used to measured deviation of the performance characteristics from the desired value, so that the experimental results are transformed into a signal to noise ratio. The objective of using the S/N ratio is a measure of performance to develop products and processes insensitive to noise factors. There are three types of S/N ratio- the lower the better, the higher the better and nominal the better. In present work, we have selected

The higher the better for cutting speed

S/N ratio $\eta = 10 * \text{Log } (1/\sum_{i=1}^{n} y_{ij}^{2})$ (1)

Where n= repeated number of experiments

y_{ij} =observed machining experiment response value

Where i = 1, 2, 3,_ ,_ ,_,_ ,_ ,_, n

j = 1, 2, 3,_ ,_ ,_,_ ,_ ,_, k

II. RESULTS AND DISCUSSION

In this section, the influence of the various process parameters on the cutting speed and surface roughness for different experimental conditions is discussed. The S/N ratio and average value of the response characteristics for each variable at different levels were calculated from experimental data. The analysis of variance (ANOVA) of raw data and S/N data were performed to determine the significant and insignificant variables and to show their effects on the response characteristic. Then, the response curves (main effect) were plotted for raw data and S/N data in order to examine the parametric effects on the response characteristics. Finally, the optimal values of significant process parameters in terms of mean response characteristics are defined based on analyzing the ANOVA Table and response curves.

4.1 Effect on Cutting rate

In order to see the effect of process parameters on cutting rate, experiments were performed using L_{32} orthogonal array (Table 2). Table 3 shows the S/N Ratio for Cutting Speed and Surface Roughness which were calculated using equation 1 and 2 respectively. The average values of cutting rate for each parameter at levels 1, 2, 3 and 4 for raw data and S/N data are tabulated in Table 4 and 5 respectively. And the same average values for raw data and S/N data are plotted in fig. 2 and 3 respectively. From fig. 2 and 3, it is clear that the cutting rate increases with the increase of pulse on time, peak current and wire feed, and decreases with increase in pulse off time and servo voltage. This is because the discharge energy increases with the pulse on time and peak current which result in faster cutting rate. As the pulse off time decreases, the number of discharges within a given period becomes more which leads to a higher cutting rate. With increase in servo voltage the average discharge gap gets widened resulting into a lower cutting rate. The effect of wire feed on cutting rate is not very significant.

Table 2 Experimental Results for CS and SR

Exp No.	Wf	Ip	Ton	Toff	SV	CS	S/N ratio (CS)
1	3	90	106	30	20	2.13	6.5676
2	3	90	110	35	30	2.77	8.8496
3	3	90	114	40	40	3.12	9.8831
4	3	90	118	45	50	3.78	11.5498
5	3	110	106	30	30	2.34	7.3843
6	3	110	110	35	20	2.88	9.1878
7	3	110	114	40	50	3.18	10.0485
8	3	110	118	45	40	3.95	11.9319
9	3	130	106	35	40	1.93	5.7111
10	3	130	110	30	50	2.75	8.7867
11	3	130	114	45	20	3.90	11.8213
12	3	130	118	40	30	4.35	12.7698
13	3	150	106	35	50	1.79	5.0571
14	3	150	110	30	40	2.89	9.2180
15	3	150	114	45	30	3.42	10.6805
16	3	150	118	40	20	4.58	13.2173
17	5	90	106	45	20	1.50	3.5218
18	5	90	110	40	30	2.43	7.7121
19	5	90	114	35	40	3.89	11.7990
20	5	90	118	30	50	3.78	11.5498
21	5	110	106	45	30	1.50	3.5218
22	5	110	110	40	20	3.35	10.5009
23	5	110	114	35	50	4.35	12.7698
24	5	110	118	30	40	4.55	13.1602
25	5	130	106	40	40	1.58	3.9731
26	5	130	110	45	50	1.67	4.4543
27	5	130	114	30	20	3.80	11.5957
28	5	130	118	35	30	4.50	13.0643
29	5	150	106	40	50	1.80	5.1055
30	5	150	110	45	40	2.17	6.7292
31	5	150	114	30	30	4.40	12.8691
32	5	150	118	35	20	4.60	13.2552

Table 4 Response table for Cutting Rate (Raw Data)

Level	WF	Ip	Ton	Toff	SV
1	3.110	2.925	1.821	3.33	3.343
2	3.117	3.263	2.614	3.339	3.214
3		3.060	3.758	3.049	3.010
4		3.206	4.261	2.736	2.887

For example, the average effect on Cutting Speed (Raw data) for parameters WF and Ip at level 1 can be calculated as follows:

Wf=(2.13+2.77+3.12+3.78+2.34+2.88+3.18+3.95+1.93+2.75+3.90+4.35+1.79+2.89+3.42+4.58)/16=3.104

Ip=(2.13+2.77+3.12+3.78+1.5+2.43+3.89+3.78)/8=2.925

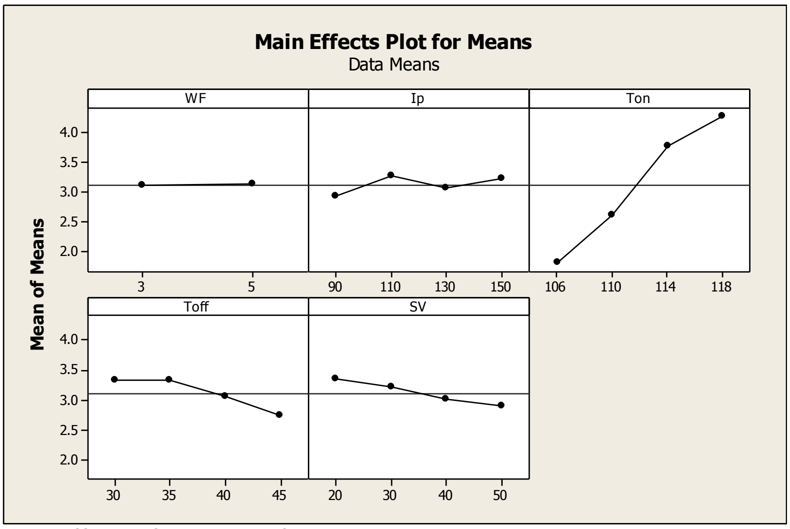

Fig. 2 Effects of response of Process Parameters on Cutting Rate (Raw Data)

2.2 Selection of optimum level

Selection of optimum process parameters have been made from the response table. Here response table is used to calculate the effect of each level of process parameter on performance measure. The response Tables 4 and 5 show the average of each response characteristic (Raw data, S/N data) for each level of each factor. As cutting rate is the "higher the better" type quality characteristic, it can be seen from Fig. 2 that the second level of wire feed (A2), second level of peak current (B2), fourth level of pulse on time (C4), second level of pulse off time (D2) and first level of servo voltage (E1) provide maximum value of cutting rate. The S/N data analysis (Fig. 3) also suggests the same levels of the variables (A2, B2, C4, D2 and E1) as the best levels for maximum CS in WEDM process.

2.3 Prediction Optimal Results

In order to predict the optimal values of the machining characteristics, only significant parameters are considered. Significant parameters are those whose effect is great on the machining characteristics. These significant parameters were found using Analysis of Variance (ANOVA) on S/N data of machining characteristics.

Table 8 Analysis of variance for cutting rate (S/N data).

Source	DF	Seq SS	Adj SS	Adj MS	F	P
WF	1	1.568	1.568	1.568	1.81	0.195
Ip	3	4.187	4.187	1.396	1.61	0.221
Ton	3	272.340	272.340	90.780	105.00	0.000
Toff	3	22.308	22.308	7.436	8.60	0.001
SV	3	7.928	7.928	2.643	3.06	0.055
Error	18	15.562	15.562	0.865		
Total	31	323.894				

Analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of experiments. It calculates parameters known as sum of square (SS), pure SS, variance, degree of freedom (DOF) and F-ratio. Since the procedure of ANOVA is a very complicated and employs a considerable of statistical formulae. ANOVA was performed using Minitab (16 English) software. Results of the ANOVA are given in the Tables 8 and 9 for cutting rate and surface roughness respectively.

2.4 Prediction of optimal value for CS

Form the Tables 8, it is clear that three process parameter namely Servo voltage (SV), pulse on time (C) and pulse off time (D) are the most significant process parameters affecting the cutting rate. Wire feed and peak current shows the least contribution. The optimal value is predicted using the Eq. 3; the optimum value is calculated as follow,

$$\eta = T + \sum_{i=1}^{q} (T_i - T) \qquad (3)$$

Here, significant parameters are three in number. So above equation becomes

$\eta = T + (C4 - T) + (D_2 - T) + (E_1 - T)$

η = 3.113+ (4.261 -3.113) + (3.339 -3.113) + (3.343 -3.113) = 4.72 mm/min.

III. CONCLUSION

In present work, wire electrical discharge machining (WEDM) for Ti6Al7Nb has been studied. Based on the results and discussions, the following conclusions are made:

- Using Taguchi method, CS was optimized individually. The cutting speed is mostly affected by pulse-on time (Ton) , Pulse off time (Toff) and Servo Voltage (SV) .
- Taguchi design of methodology has been utilized to optimize the single performance characteristic. Thus the orthogonal array is selected for above mention five process parameters and L_{32} is chosen as orthogonal array for present experimentation
- The optimal setting of process parameters were obtained as A2 B2 C4 D2 E1 for cutting rate. Optimal predicted values for cutting rate is 4.72 mm/min.
- ANOVA has been applied to find the significant process parameters. Using ANOVA, three process parameters namely pulse on time (C) , pulse off time (D) and Servo Voltage were found the most significant affecting the Cutting rate under 95% confidence level.

REFERENCES

[1]. G. Lin, L. Lei, Z. Wansheng, and K.P. Rajurkar, "Electrical discharge machining of Ti6Al4V with a bundled electrode," International Journal of Machine Tools & Manufacture, vol. 53, pp. 100–106, 2012.

[2]. F. Katsushi, S. Akinori T. Hideki, M. Naotake, and M. Hidetaka**,** "Accretion of titanium carbide by electrical discharge machining with powder suspended in working fluid," Journal of the International Societies for Precision Engineering and Nanotechnology, vol. 25, pp. 138–144, 2001.

[3]. A. Aggarwal, H. Singh, P. kumar, and M. Singh, "Optimization of multiple quality characteristics for CNC turning under cryogenic cutting environment using desirability functions," Journal of Material processing and Technology, vol. 205, pp. 42-50, 2008.

[4]. K. Jangra, S. Grover, and A. Aggarwal, "Simultaneous optimization of material removal rate and surface roughness for WEDM of WC-Co composite using grey relational analysis along with Taguchi method," International Journal of Industrial Engineering Computations, vol. 2(3), pp. 479–490, 2011.

[5]. R. Bobbili, V. Madhu, and A.K. Gogia, "Effect of Wire-EDM Machining Parameters on Surface Roughness and Material Removal Rate of High Strength Armor Steel," Materials and Manufacturing Processes, vol. 28(4), pp. 364–368, 2013.

[6]. B.K. Bhuyan, and V. Yadava, "Experimental Study of Traveling Wire Electrochemical Spark Machining of Borosilicate Glass," Materials and Manufacturing Processes, vol. 29(3), pp. 298-304, 2014.

[7]. K. Gupta, and N.K. Jain, "Analysis and optimization of micro-geometry of miniature spur gears manufactured by wire electric discharge machining," Precision Engineering, vol. 38(4), pp. 728-737, 2014.

[8]. N. Sharma, R. Khanna, R.D. Gupta, and R. Sharma, "Modeling and Multiresponse optimization on WEDM for HSLA by RSM," International Journal of Advance Manufacturing Technology, vol. 67(9-12), pp. 2269-2281, 2013.