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PARAMETRIC OPTIMIZATION OF ELECTRICAL DISCHARGE MACHINING DURING TITANIUM ALLOY (TI-6AL-4V) USING TOPSIS METHOD

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ABSTRACT
In the present paper an analysis has been made into the Electrical Discharge Machining of Titanium Alloy (Ti-6Al-4V). To satisfy requirements of Maximum MRR and Minimum TWR and SR. Experiments have been conducted using Taguchi L9 orthogonal array design using peak current (I), pulse on time (T_{on}) and pulse off time (T_{off}), as process control parameters these are varied in three different levels. Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface roughness (SR) of EDM surface have been measured for each experimental run. Tool material chosen as Electrolyte copper electrode. To find the optimal parametric combinations multiple performance characteristics such as highest MRR, least TWR and SR can be solved using Technique for order of preference by similarity to ideal solution (TOPSIS). The suggested settings of process parameters is found from TOPSIS are at Peak current: 28A (Level 3), pulse on time; 100 µs (Level 1) and pulse off time: 125 µs (Level 2), for MRR=2.56 mm3/min, TWR=0.86 mm3/min and SR=6.99 µm. Analysis of variance (ANOVA) and F-test were performed to determine the significant parameters at a 95% confidence interval. Confirmation tests are performed with predicted optimal values of each performance characteristics these are in good agreement with the experimental values of MRR, TWR and SR

KEY WORDS: *Material Removal Rate (MRR), Tool Wear Rate (TWR), and Surface roughness (SR), TOPSIS*

1. INTRODUCTION

Electro Discharge Machining (EDM) also called spark erosion machining it is an electro-thermal non-traditional machining Process, in this electrical energy is used to generate electrical spark between tool and work material so material removal mainly occurs due to thermal energy of the spark. EDM is mostly used to materials which are difficult-to-machine by conventional methods, high strength temperature resistant alloys. We can machine difficult geometries in small batches or even on job-shop basis using EDM. Work material to be machined by EDM has to be electrically conductive. EDM has its wide applications in manufacturing of plastic moulds, forging dies, press tools, die castings, automotive, aerospace and surgical components. In this work considered of Titanium Alloy (Ti-6Al-4V) as work material process parameters are as: Peak Current (A), Pulse On-time (B) and Pulse Off-time (C) and Taguchi's L9 Orthogonal Array was used to conduct the experiments. Now, the optimal combinations of the process parameters were obtained by TOPSIS Method considering each performance measures as multi objective. S.Tripathy et.al [1] implemented Taguchi method in combination with Technique for order of preference by similarity to ideal solution (TOPSIS) and Grey Relational Analysis (GRA) to evaluate the effectiveness of optimizing multiple performance characteristics for PMEDM of H11 die steel using copper electrode. Analysis of variance (ANOVA) and Ftest were performed to determine the significant parameters at a 95% confidence interval. M. Dastagir et.al [2] Traditional Taguchi approach is insufficient to solve a multi response optimization problem. In order to overcome this limitation, a multi criteria decision making method, techniques for order preference by similarity to ideal solution (TOPSIS) is applied in the present study. In order to consider experimental uncertainty, the responses are expressed in process variables rather than crisp values. The variations of output responses with process parameters are mathematically modelled. The models were checked for their adequacy. Ravi Kumar Kanwar et.al [3] was optimized the parameters of the EDM machining has been carried out by using the Topsis Method for design of experiments (DOE). In recent years many ways has been found for improving the MRR of the work piece. Taguchi method has been used for design of experiments with 27 input parameters and their three levels using L27 array. In the research nine experiments had been done along with zrb2-sic had been used as a work piece. Avijeet Satpathy et.al. [4] Has been done Multi objective optimization using a hybrid approach by combining principal component analysis (PCA) and technique for order preference by similarity to ideal solution (TOPSIS) to obtain the optimum set of input parameters. Microstructure analysis was carried out on the machined surface obtained from the optimal set using Scanning Electron Microscope (SEM) to investigate the surface modification on the of AlSiC metal matrix composite (MMC) work piece. R. Manivannan et.al [5]analyzed the process parameters of the micro-Electrical discharge machining (micro-EDM) of an AISI 304 steel with multi-performance characteristics using Technique for order preference by similarity to ideal solution (TOPSIS) method and improved the overall performance of the micro-EDM. Gadakh V.S et.al[6] using techniques for order preference by similarity to ideal solution (TOPSIS).it is for solving multiple criteria (objective) optimization problem in wire electrical discharge machining (WEDM) process. So in this problem we are selected Taguchi method in combination with TOPSIS methodology to find the optimal process parameters.

2. OBJECTIVES

In this Paper, a case study have been done on electric discharge machining of Titanium alloy (Ti6Al4V).L9 Orthogonal Array of Taguchi method is considered the experimentation. Optimization of process parameters for getting maximum MRR, minimum TWR and SR simultaneously using taguchi based TOPSIS multiple objective method.

3. METHODOLOGY

Optimal combinations of the process parameters were obtained by TOPSIS Method considering each performance measures as multi objective

4. SAMPLING DESIGN

Experiments were conducted on EDM machine model MOLD MASTER S605 choosing Stainless Steel 304 as work material and electrolytic copper as tool material. The properties of work material and tool material are shown in Table 1 and Table2 respectively. Commercial EDM oil grade SAE240 is chosen as dielectric fluid. The selected process parameters and corresponding levels for this study are shown in Table3. Table4 presents the experimental conditions. For experimentation Taguchi L9 Orthogonal array was used and is presented in Table5.

5. STATISTICAL DESIGN

Material removal rate (MRR), tool wear rate (TWR), and surface roughness (SR) were chosen as performance characteristics. Then the MRR and TWR are calculated as follows.

$$MRR\left({mm^3}/{min}\right) = \frac{\Delta W}{\rho_w \times t} \dots\dots\dots (1)$$

$$TWR\left({mm^3}/{min}\right) = \frac{\Delta T}{\rho_t \times t} \dots\dots\dots (2)$$

Where ΔW is the weight difference of work piece before and after machining (g), ρ_w is density of work material (g/mm³), ΔT is the weight difference of electrode before and after machining (g), ρ_t is density of electrode material (g/mm³) and t is machining time in minutes. Talysurf surface roughness tester was used to measure surface roughness on machined surface with sampling length of 0.8 mm. Average experimental results ratios of MRR, TWR, and SR are shown in Table 6.

6. GEOGRAPHICAL AREA

Multi-objective optimization: Technique for order of preference by similarity to ideal solution (TOPSIS) TOPSIS helps to determine the most suitable alternative from a finite set. The principle of the technique is that the selected criteria should be nearest from positive best solution and farthest from negative best solution, the finest solution being the one having most relative closeness to the ideal solution. The steps involved in carrying out TOPSIS are expressed as:

Step1: that decision matrix is the first step of TOPSIS which consists of 'n' attributes and 'm' alternatives and can be represented as:

$$D_m = \begin{bmatrix} q_{11} & q_{12} & q_{13} & .. & .. & q_{1n} \\ q_{21} & q_{22} & q_{23} & .. & .. & q_{2n} \\ q_{31} & q_{32} & q_{33} & .. & .. & q_{3n} \\ .. & .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. & .. \\ q_{m1} & q_{m2} & q_{m3} & .. & .. & q_{mn} \end{bmatrix} \quad (3)$$

where q_{ij} is the performance of i^{th} alternative in relation to the j^{th} attribute.

Step2: The normalized matrix can be obtained by using the following I expression

$$r_{ij} = \frac{q_{ij}}{\sqrt{\sum_{i=1}^{m} q_{ij}^2}} \qquad j=1,2,.........n \qquad (4)$$

Step 3: The weight of each attribute was assumed to be w_j (j = 1, 2, . . ., n). The weighted normalized decision matrix $U = \lfloor u_{ij} \rfloor$ can be obtained by

$$U = w_j r_{ij} \qquad (5)$$

$$where, \sum_{j=1}^{n} w_j = 1$$

Step 4: The positive-ideal and negative-ideal solutions have been obtained from the following expressions:

$$U^+ = \left\{ \left(\sum_i^{\max} u_{ij} \middle| j \in J \right), \left(\sum_i^{\min} \middle| j \in J \middle| i = 1,2...m \right) \right\} \qquad (6.1)$$

$$= \left\{ u_1^+, u_2^+, u_3^+ ....u_n^+ \right\}$$

$$U^- = \left\{ \left(\sum_i^{\min} u_{ij} \middle| j \in J \right), \left(\sum_i^{\max} \middle| j \in J \middle| i = 1,2...m \right) \right\} \qquad (6.2)$$

$$= \left\{ u_1^-, u_2^-, u_3^- ....u_n^- \right\}$$

Step 5: Separation between alternatives were determined from the "ideal" solution and is given by:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(u_{ij} - u_j^+ \right)^2} \qquad i=1.2,3..........m \qquad (7.1)$$

Separation of alternatives from "negative-ideal" solution is expressed as:

$$S_i^- = \sqrt{\sum_{j=1}^{n}\left(u_{ij} - u_j^-\right)^2} \qquad i=1.2,3.........m \qquad (7.2)$$

Step 6: Relative nearness of the distinct alternative to the positive ideal solution is calculated which is given as:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \qquad i=1.2,3.........m \qquad (8)$$

Step 7: The Pi value was ranked in descending order to identify the set of alternatives having the most preferred and the least preferred solutions. These are shown in table 7

7. RESULTS

Effect of process parameters on MRR: The average values of MRR, TWR, and SR for each trial (run) and their values are presented in Table 6. A main effects plot is a plot of the means at each level of a factor, all main effects plots of means for MRR, TWR, and SR are drawn by using MINITAB 16 software. Figure 1 presents main effects plot for means of MRR,

From Figure 1 it has been observed that MRR increases with increasing in peak current. The increase in peak current causes increase in spark energy resulting in higher current density. This rapidly over heats the work piece and increases MRR with peak current. Further as current increases, discharge strikes the surface of work piece intensively which creates an impact force on the molten material in the molten puddle and this results into ejection of more material out of the crater (V.V Reddy et al, 2014). Since it is always desirable to maximize the MRR larger the better option is selected.

Effect of process parameters on TWR: The average values of TWR for each trial values are presented in Table 6. Figure 2 presents main effects plot for means of TWR.

It is observed from Figure 2 the increase in tool wear rate with increase in peak current as well as pulse on time. This can be explained as increase in peak current causes increase in spark energy resulting in increase in TWR. Further spark energy and the period to transfer this energy in to the electrodes increases with increase in pulse on time which results in increase in TWR. However slight increase in TWR is noticed with increase in pulse off time due to overshoot effect for some time. Since it is always desirable to minimize the TWR smaller the better option is selected.

Effect of process parameters on SR: The average values of SR for each trial values are presented in Table 6. Figure 3 presents main effects plot for means of SR.

It is observed from the Figure 3 that there is increase in surface roughness with increase in peak current. This can be recognized to the fact that increase in peak current causes increase in spark energy resulting in the formation of deeper and larger craters result in increase in surface roughness. It is also noticed that surface roughness increases with the increase in pulse on time. However decrease in surface roughness value is observed with increasing in pulse off time. This may be due to proper removal of debris from the discharge channel. Since it is always desirable to minimize the SR smaller the better option is selected.

TOPSIS Analysis: Using "TOPSIS" Optimization of EDM with multi attributes like MRR, TWR, EWR and SR was performed With the results obtained after the experimental runs, the preference value for each experimental combination can be achieved using equations(3to8).The preference value for each substitute can be calculated considering the relative closeness to the best solution which is computed as the "ratio of negative ideal separation measure divided by the sum of negative ideal separation measure and the positive ideal separation measure" using equation (8). All the output responses are assigned equal weightage considering the performance parameters equally important when machined under ideal conditions. Multi-attribute optimization is thus converted into single objective optimization using a combined approach of Taguchi's design and TOPSIS. The preference values for TOPSIS obtained from each experimental run with the rank order are furnished in Table 7.The relative closeness to the ideal solution with respect to the optimal performance measure achieves the maximum preference value and highest rank and is thus considered as the best value for the performance measure. It can be seen that experimental run*9 is the best multiple performance characteristics having the highest preference order, hence it is the optimal setting followed by run*7 and *8.The optimal parametric combination can be determined by considering the higher values of preference order. The optimal setting obtained is I3 (peak current, 28A), $T_{on}1$ (pulse on time, 100µs), $T_{off}2$ (pulse off time, 125µs).

8. SUGGESTIONS

The confirmation test for the optimal parameters with its levels was conducted to evaluate quality characteristics for EDM of Titanium alloy. Table 8 shows the comparison of the experimental results for the optimal conditions (A3B1C2) with predicted results for optimal (A3B1C2) EDM parameters. The comparison again shows the good agreement between the predicted and the experimental values.

9. CONCLUSIONS

1. Titanium super alloy can easily be machined on EDM with reasonable speed and surface finish. It is difficult to machine Titanium super alloy on conventional machining because of shorter tool life and severe surface abuse due to its high hardness and strength.
2. All the chosen responses namely MRR, TWR, and SR are increased with increase in peak current and pulse on time. However MRR and SR decrease with increase in pulse off time.
3. Peak current pulse on time and pulse off time are significant parameters affecting MRR, TWR and SR. While pulse off time has no significant affect on TWR.
4. TOPSIS method represents selection of optimal process parameters. It shows the optimum conditions at (A3B1C2). The results obtained were MRR=2.26 mm^3/min, TWR=1.38 mm^3/min and SR=7.1 µm.

10. FIGURES AND TABLE

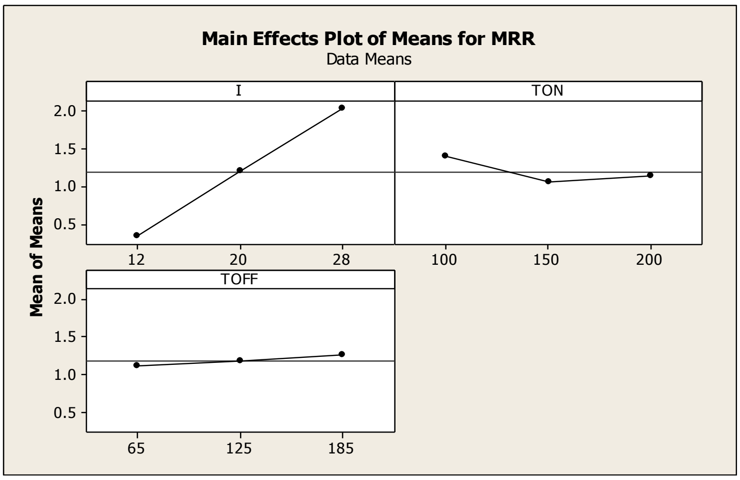

Figure 1: Effect of process parameters on mean data of MRR

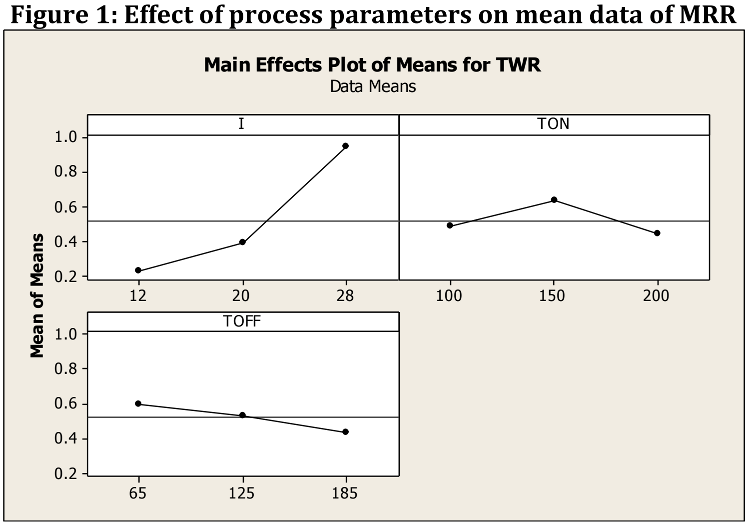

Figure 2: Effect of process parameters on mean data of TWR

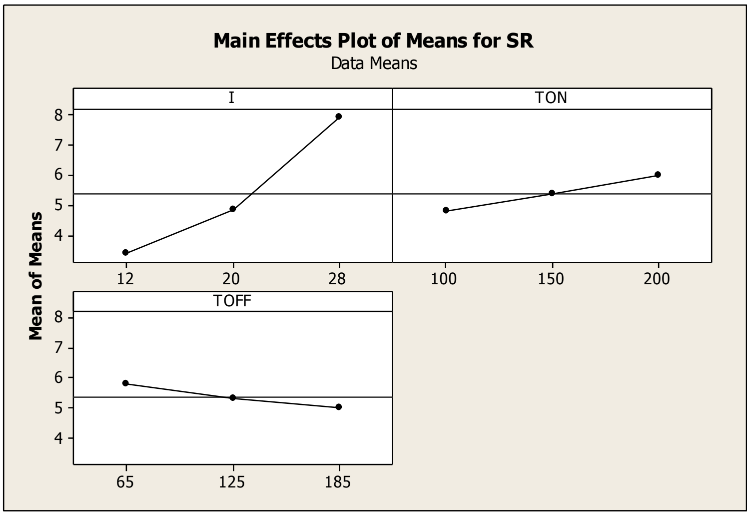

Figure 3: Effect of process parameters on mean data of SR

Table 1: Properties of Titanium alloy (Ti-6Al-4V)

Property	Value and units
Structure	Face entered cubic
Magnetic ordering	Diamagnetic
Electrical resistivity	(20 °C) 16.78 nΩ·m
Thermal conductivity	401 $W \cdot m^{-1} \cdot K^{-1}$
Thermal expansion	(25 °C) 16.5 $\mu m \cdot m^{-1} \cdot K^{-1}$
Speed of sound(thin rod)	(annealed), 3810 $m \cdot s^{-1}$
Young's modulus	110–128 GPa
Shear modulus	48 GPa
Bulk modulus	140 GPa
Poisson ratio	0.34

Table 2: Properties of electrolyte copper

Density	8.95 (g/cm^3)
Specific capacity	383 (J/kg °C)
Thermal conductivity	394 (W/m °C)
Electrical resistivity	1.673×10^{-8} Ω m
Melting point	1083°C

Table 3: Process parameters and corresponding levels

Input Parameters	Peak Current I ,(amp)	Pulse on Time T_{on} ,(μs)	Pulse off Time T_{off},(μs)
Level 1	12	100	65
Level 2	20	150	125
Level 3	28	200	185

Table 4: Experimental conditions

Working conditions	Description
Work piece	Titanium alloy (100mm×18mm×8mm)
Electrode	Electrolyte copper Ø 14mm and length 60 mm
Dielectric	Commercial EDM Oil grade SAE 240
Flushing	Side flushing with pressure 0.5Mpa
Polarity	Positive
Supply voltage	240 V
Machining time	5 minutes

Table 5: Experimental layout using an L_9 (3^4) OA

S.No	Peak current I	Pulse on time T_{on}	Pulse off time T_{off}
1.	12	100	65
2.	12	150	125
3.	12	200	185
4.	20	100	125
5.	20	150	185
6.	20	200	65
7.	28	100	185
8.	28	150	65
9.	28	200	125

Table 6: Average experimental results and S/N ratios of MRR, TWR, and SR

Exp No	Performance measures		
	MRR (mm^3/min)	TWR (mm^3/min)	SR (µm)
1	0.49661	0.29423	3.3505
2	0.18811	0.36872	3.38
3	0.35365	0.0149	3.48
4	1.36945	0.32402	3.986
5	1.15124	0.4432	4.57238
6	1.06847	0.40596	5.91125
7	2.30248	0.84544	7.023
8	1.81339	1.0838	8.16675
9	1.97141	0.9013	8.556

Table 7: Pi values Ranks for considered conditions

Exp. No	P	Ranks
1	0.162003	7
2	0.1448731	8
3	0.0595114	9
4	0.4200225	5
5	0.4015192	6
6	0.4206151	4
7	0.8411842	2
8	0.8284189	3
9	0.8588491	1

Table 8: Comparison of Predicted values with Experiment values

Level	Optimal process parameters		% of error
	Experiment	Predicted	
	A3B2C1	A3B2C1	
MRR (mm^3/min)	2.26	2.21386	2.04155
TWR (mm^3/min)	1.38	1.39417	-1.0265
SR (µm)	7.1	7.2477	-2.0814

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