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Experimental investigation of machining parameter for micro hole drilling on titanium wrought alloy

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Abstract

This paper presents an investigation of micro holes drilling using electrical discharge machining (Micro- EDM) on titanium wrought alloy, difficult to machine conventionally. EDM is a thermal machining process that utilizes spark discharges to erode a conductive material. In the present study, attempt is made to find the optimal machining conditions with metal removal rate (MRR) and electrode wear rate (EWR) as objective. It was observed that with increase in discharge energy MRR and EWR increases. Grey relational analysis was used to determine the optimal machining parameters, among which the discharge current and the capacitance are found to be the most significant. The obtained optimal machining conditions are capacitance of 0.30 pF, current of 32 A, pulse-on time of 20 µs and a pulse-off time of 12 µs. It was observed that MRR mainly depend on discharge energy while longer pulses increases EWR.

Keywords: *Micro-EDM, Response Surface Methodology, Grey Relational Analysis, Material removal rate, Electrode wear rate.*

1. Introduction

Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. Its unique feature, that is, the use of thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in the manufacture of moulds, dies, automotive, as well as aerospace and surgical components. The growing popularity of micro-EDM can be attributed to advantages including low set-up cost, high-aspect-ratio parts, enhanced precision, and significant design freedom [1]. Another characteristic of EDM is the lack of direct contact between the electrode and the workpiece, thus eliminating mechanical stress, chatter and vibration during machining [2].

T. Masuzawa et al. [3] fabricated micro pins, micro nozzles and micro pipes using EDM. D. M. Allen et al. [4] used micro-EDM technology to manufacture ink jet nozzles. B. H. Yan et al. [5] described the characteristics of micro-hole of carbide produced by micro-EDM using copper tool electrode and investigated the effects various machining parameters on the quality of micro-holes. M. P. Jahan et al. [6] investigated the influence of major operating parameters on the performance of micro-EDM with an electrode of WC in producing quality micro-holes in both transistor- and RC-type generators. S. Son et al. [7] investigated the influence of EDM parameters especially pulse duration, on micro-EDM characteristics such as material removal rate and machining accuracy. Y.Y. Tsai and T. Masuzawa [8] observed that the TWR in brass electrode is higher than the tungsten electrode material, due to the higher melting and boiling point of tungsten material which possess high thermal capability with excellent wear resistance. Natarajan N. et al. [9] done optimization using grey relational analysis with input parameters as current, voltage, pulse on time and pulse off time while the response are material removal rate (MRR), electrode wear rate (EWR), diameteral overcut (DOC) and taper (T).

Micro-EDM is an efficient machining process for the fabrication of a micro hole with various advantages. Although most micro EDM machine today have process control, but selecting and maintaining optimal setting is still an extremely difficult job which must be addressed. The goal of the present study is to determine the optimal machining parameters for formation of micro-holes with minimum electrode wear rate and maximum metal removal rate. The response surface methodology was employed to elucidate the effect of the machining parameters on the characteristics of the EDM process. Grey relational analysis was used to find the optimal machining parameters satisfying the multiple characteristics of the EDM process.

2. Machining of micro-hole using EDM

2.1 Experimental set-up

Experiments of micro hole machining have been conducted using charmills robdrill machine. The EDM machine is shown in Fig. 1. Rotary brass hollow tubular electrode of diameter ϕ 500 µm is fed downward into the workpiece under servo control. The EDM oil is circulated as a dielectric fluid and it is injected through the tubular electrode. The electro-conductive titanium wrought alloy (VT-20) is selected as workpiece of size 35×25×15 mm. Positive polarity machining by means of a negative electrical source connected to the electrode and a positive electrical source connected to the work material, was utilized. This type of machining allowed higher machining rate along with lesser electrode wear.

Fig 1: Micro-EDM machine

2.1 Experimental design

The experiments were designed using response Surface Methodology. Total 30 runs were conducted designed with central composite design having 16 factorial points, 6 center points and 8 star points. The experiments has been conducted with four controllable factors namely capacitance, current, pulse-on time and pulse-off time. On the basis of preliminary experiments conducted by using one variable at a time approach the range of input parameters was selected. Machining parameters and their level chosen for this study are shown in Table 1. Experiments were carried out in single block. Weighing machine with least count 0.1 mg was used to measure the electrode and workpiece weight.

Table 1: Machining Parameters and their levels

	-2	-1	0	+1	+2
Capacitance	0.15	0.22	0.26	0.32	0.38
Current	8	15	19	26	32
Pulse-on time	8	12	16	20	24
Pulse-off time	8	12	16	20	24

3. Analysis and result

The analysis was made using the popular software specifically used for design of experiment applications known as MINITAB 16. In present study, it is desirable to maximize MRR and to minimize EWR. The MRR and EWR for each run was calculated by weight difference of specimen and electrode before and after the machining of each hole respectively.

$$MRR = \frac{W_1 - W_2}{T_m} \text{ gm/min} \quad \ldots\ldots\ldots\ldots (1)$$

$$EWR = \frac{W_{t1} - W_{t2}}{T_m} \text{ gm/min} \quad \ldots\ldots\ldots\ldots (2)$$

Where W1 and Wt1 are initial weight of work piece and electrode respectively; W2 and Wt2 are final weight of work piece and electrode respectively and Tm is the machining time.

3.1 Analysis of MRR

The MRR is calculated as the workpiece removal weight over the machining time, which is expressed as grams per minute. Fig 2 shows that the MRR is directly proportional to the capacitance, current and pulse-on time. But the MRR is lower, whenever there is increase in pulse-off time. MRR mainly depend on discharge energy, long pulse energy results in higher MRR.

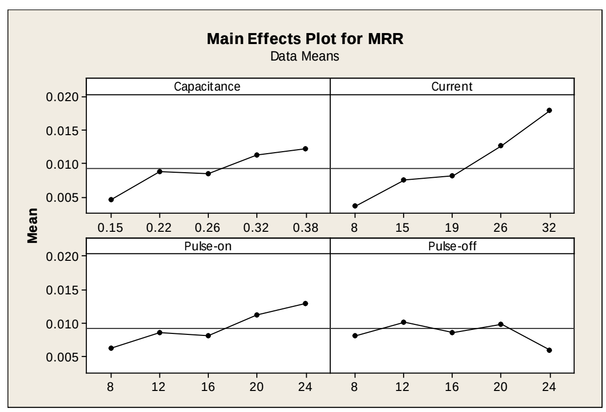

Fig 2: Main Effect Plot for MRR

3.2 Analysis of EWR

EWR is calculated as the ratio of tool wear weight to the machining time, which is expressed as grams per minute. Fig 3 shows that the EWR is directly proportional to the capacitance, current and pulse-on time. But the EWR is lower, whenever there is increase in pulse-off time. EWR increases with pulse on time with respect to discharge energy.

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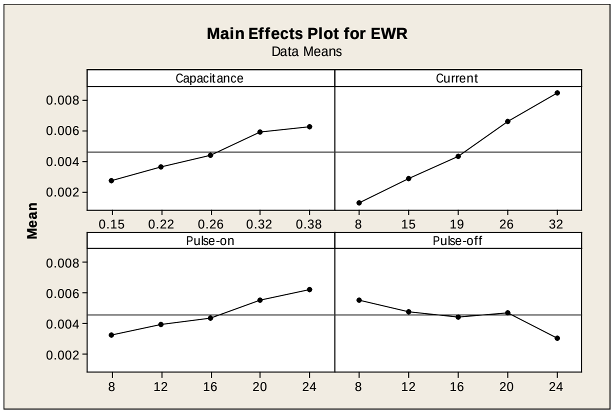

Fig 3: Main Effect Plot for EWR

4. Grey Relational Analysis (GRA)

The grey relational analysis is a widely used analyzing system even when a model is uncertain or the information is incomplete. It provides an efficient solution to complicated interrelationships among multiple performance characteristics. Based on the normalized experimental data, the grey relational coefficient is calculated representing the correlation between the desired and actual experimental data. Then, the overall grey relational grade is determined by averaging the grey relational coefficient corresponding to the selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. In the grey relational analysis, the normalized MRR value corresponding to the larger-the-better (LB) criterion can be calculated using:

$$x_i(k) = \frac{y_i - min\ y_i(k)}{max\ y_i(k) - min\ y_i(k)} \quad \text{………………………..…… (3)}$$

And the normalized EWR values corresponding to the smaller-the-better (SB) criterion can be calculated Using:

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad \text{……………...……….…… (4)}$$

Where x_i (k) is the value after the grey relational gene ration, min x_i (k) is the smallest value of x_i(k) for k^{th} response, and max x_i(k) is the largest value of x_i(k) for the k^{th} response.

The grey relational coefficient (ξ_i (*k*)) for the normalized *S/N* ratio values is computed using:

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - min\ y_i(k)} \quad \text{……….……….……….. (5)}$$

where Δ is the absolute difference, Δ_{oi}(k) = $\|x_o(k) - x_i(k)\|$ is the difference in the absolute values between x_o(k) and x_i(k), ξ_i is the distinguishing coefficient (0–1), Δ min is the smallest value of Δ_{oi} and Δ max is the largest value of Δ_{oi} . After averaging the grey relational coefficients, the grey relational grade γ_i can be obtained:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad \text{……………...…………… (6)}$$

Where, *n* is the number of the process responses.

The higher value of grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence x_i (*k*). The reference sequence $x_0(k)$ represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

The response table for grey relational grade at each level of machining parameter is shown in Table 2. It is observed that factor B, the current is the most significant controlled parameter for the EDM operation followed by capacitance, pulse-on time and pulse-off time with maximum of the MRR and minimum of the EWR.

Table 2: Response table for the Grey Relational Grade

Symbol	Parameter	Levels					MAX-MIN	RANK
		-2	-1	0	1	2		
A	Capacitance	0.5162	0.5250	0.5318	0.5511	0.5918	0.0756	2
B	Current	0.5910	0.5279	0.5223	0.5482	0.6317	0.1094	1
C	Pulse-on	0.5180	0.5349	0.5364	0.5412	0.5351	0.0232	3
D	Pulse-off	0.5384	0.5436	0.5353	0.5325	0.5280	0.0156	4

5. Conclusions

The micro-hole drilling experiments were successfully performed on titanium wrought alloy using brass electrode. The material removal rate and electrode wear rate are evaluated. It is observed that increase in discharge energy drastically reduces the machining time to machine a hole on the workpiece at the same time EWR is high due to large amount of electrons removed from cathode surface, during the matching process. The optimal parameters for performance are calculated from grey relational analysis and the result are Capacitance (C5) = 0.38 Pf, Current (I5) = 32 A, Pulse-on time (Ton) = 20 µsec and Pulse-off time (Toff) = 12 µsec. It was observed that current is most significant among all parameters followed by capacitance, pulse on time and pulse off time.

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