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Optimization of Micro-EDM Process Parameters using Grey Relational Analysis on Tungsten Carbide

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Abstract

Micro-electrical discharge machining (Micro-EDM) is a proven technology for the manufacturing of miniaturized parts and components than conventional machining processes. The objective of the present work is to optimize the process parameters, including pulse on time, pulse off time, gap voltage and current, which influence the EDM drilling process of Tungsten carbide (WC) on material removal rate, tool wear rate, over cut and taper. An experimental plan of a central composite design (CCD) based on the response surface methodology (RSM) was employed to carry out the experiments. Grey relational analysis is used to optimize the process parameters of Micro-EDM using multi-performance characteristics such as material removal rate (MRR), electrode wear rate (EWR), overcut and taper angle of the tool.

Keywords: Micro-EDM, RSM, GRA, Tungsten Carbide

1.Introduction

Tungsten carbide is widely used as the material for tools and mechanical parts because of its high hardness and wear resistance. Tungsten carbide is considered as difficult to machine material because of its super hardness and high brittleness. It has tendency to undergo brittle fracture during machining with conventional machining method. To overcome the above difficulties special machining techniques are used among which electrical discharge machining (EDM) is most favorable [1-2]. EDM playing vital role in modern industries for machining of various materials such as alumina particle reinforced material, titanium alloy, nickel-based super alloy, high-speed tool steel, various metal matrix composites (MMC) and ceramics, etc. which cannot be machined easily by the conventional machining processes [3]. Gianluca D'Urso et al [4] studied the sustainability of Micro-EDM drilling process on effect of electrode tool and work piece materials. They concluded that EDM technology is more sustainable in manufacturing area in the view of tool wear and machining. S Gopalakannan et al. [5] investigated the influence of process parameters on Al7075 B_4C metal matrix composite. They concluded that surface roughness increases with increase in pulse current and pulse on time, whereas the voltage surface roughness decreases up to 50 volts and further increase in voltage the surface roughness increases and optimal process parameters also developed using response surface methodology. Nun-Ming Liu et al. [6] investigated process parameters of EDM process on cobalt-bonded tungsten carbide. The experiments are designed using quadratic model of RSM associated with a sequential approximation optimization (SAO) method to find the optimum settings of processing parameters on the disintegration characteristics in the EDM drilling process. They concluded that disintegration factor is generally increases with increase in discharge current, pulse on time and duty factor within the lower value of discharge, but the disintegration factor decreases within high discharge current. Rajesh Khanna et al. [7] investigated the use Taguchi approach for better tool wear rate in EDM drilling of Al7075 and optimal process parameters also developed using grey relational analysis to reduce the tool wear rate. They concluded that the combination of maximum pulse on-time and minimum pulse off-time gives maximum material removal rate. Zhiping Xie et al. [8] investigated the machining parameters of EDM on Ti-6Al-4V using combined approach of Taguchi method and grey relational analysis. They developed optimal process parameters with improved electrode wear ratio of 2.8%, material removal rate of 45.8% when the Taguchi method and grey relational analysis are used. Othman Belgassim et al. [9] investigated EDM process parameters on AISI D3 tool steel to determine the optimal parameters using Taguchi method and grey relational analysis. They concluded that optimal process parameters simultaneously leading to a higher material removal rate, lower surface roughness, and lower overcut are then verified through a confirmation experiment.

In this paper, the optimization of parameters considering multiple performance characteristics of the EDM process to tungsten carbide using the Taguchi method and grey relational analysis is reported. The multiple responses including material removal rate (MRR), overcut (OC) and taper angle. The machining parameters are discharge current, voltage, pulse on time and pulse off time.

2. Experimentation and design of experiments

In order to carry out the experiments SPARTANICS EDM drilling machine is used. It is capable to made drilling diameter of 0.3mm to 3mm. The work piece used in this study was tungsten carbide, composition of 50% tungsten and 50% carbide and dimension of 30 mm × 30 mm x 3 mm. The tool electrode material used in this study was copper of diameters 0.5 mm having high melting point and high wear resistance. The dielectric fluid used in this study was commercially available “Total FINA ELF EDM 3” oil having relatively high flash point, high auto-ignition temperature and high dielectric strength. The Central Composite Design (CCD) was used to implement the response models using Response surface methodology (RSM). A total of 30 experiments was performed which incorporates of 8 cube points, 6 centre points in a cube, 6 Axial points, and the alpha value is 1. The range of the process parameters was set by taking into consideration of the tool or inserts specification and even by performing the trial experiments in order to achieve the desired responses.

Table 1 Machining parameters and their levels

Machining Parameters	Level 1	Level 2	Level 3
GAP Voltage(v)	30	40	50
Current(Amp)	8	10	12
Pulse ON(μs)	3	5	7
Pulse OFF(μs)	4	6	8

3. Mathematical calculations of response parameters

The time taken for machining each hole was recorded. After completion of machining the corresponding responses such as the multiple responses including material removal rate (MRR), overcut (OC) and taper angle are calculated. The following mathematical equations are used to find the response parameters [10].

3.1 Material removal rate

$$MRR = \frac{\frac{\pi}{3}[R_t^2 + R_b R_t + R_b^2] * h}{t}$$

Where

R_t= Radius of the hole at top surface in mm

R_b= Radius of the hole at bottom surface in mm

h=depth of the hole in mm

t= Machining time in minets

3.2 Overcut (OC)

$$OC = \frac{D}{d}$$

Where

D is the average diameter of the hole after machining in mm and

d is the diameter of the tool in mm

3.3 Taper angle (θ)

$$\boldsymbol{\theta} = \tan^{-1}(\frac{D_1 - D_0}{2L})$$

Where

D_1=Diameter of the micro hole at entry in mm

D_0=Diameter at exit in mm and

L = length of micro-hole in mm

4. Grey Relational Analysis and results

This method is used to analyze the multiperformances in experimental studies and has some advantages than statistical methods [11]. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, gray analysis helps to compensate for the shortcoming in statistical regression. Gray relation analysis is an effective means of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method [12]. The processing steps are listed below.

The original sequence can be normalized as following:

$$\boldsymbol{x_i^*(\mathbf{k})} = \frac{x_i^0(\mathbf{k}) - \min x_i^0(\mathbf{k})}{max x_i^0(\mathbf{k}) - \min x_i^0(\mathbf{k})} \qquad (1)$$

Where i=1… m; k=1, n. m is the number of experimental data items and n is the number of parameters. x_i^o (k) denotes the original sequence, $\boldsymbol{x_i^*(\mathbf{k})}$ denotes the sequence after the data preprocessing, max $\boldsymbol{x_i^0(\mathbf{k})}$ denotes the largest value of $x_i^{(o)}(k)$, min $\boldsymbol{x_i^0(\mathbf{k})}$denotes the smallest value of

$\boldsymbol{x_i^0(\mathbf{k})}$,and x^o is the desired value.When the “lower is better” is a characteristic of the original sequence, the original sequence should be normal-ized as following:

$$\boldsymbol{x_i^*(\mathbf{k})} = \frac{max x_i^0(\mathbf{k}) - x_i^0(\mathbf{k})}{max x_i^0(\mathbf{k}) - \min x_i^0(\mathbf{k})} \qquad \mathbf{(2)}$$

In gray relational analysis, the measure of the relevancy between two systems or two sequences is defined as the gray relational grade. When only one sequence, $x_0(k)$, is available as the reference sequence and all other sequences serve as comparison sequences; it is called a local gray relation measurement. After data preprocessing is carried out, the gray relation coefficient $\xi_i(k)$ for the kth performance characteristics in the ith experiment can be expressed as following:

$$\boldsymbol{\xi}_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}} \qquad \mathbf{(3)}$$

Here, Δ_{0i} is the deviation sequence of the reference sequence and the comparability sequence.

$$\boldsymbol{\Delta_{0i} = \|x_0^*(k) - x_i^*(k)\|} \qquad \mathbf{(8)}$$

$$\boldsymbol{\Delta_{min}} = \min_{\forall j \in i} \min_{\forall k} \boldsymbol{\|x_0^*(k) - x_i^*(k)\|} \mathbf{(9)}$$

$$\boldsymbol{\Delta_{max}} = \max_{\forall j \in i} \max_{\forall k} \boldsymbol{\|x_0^*(k) - x_i^*(k)\|} \qquad \mathbf{(10)}$$

x_0*(k) denotes the reference sequence and

$x_i^*(k)$ denotes the comparability sequence.
ζ is distinguishing or identification coefficient:
$\zeta \in [0,1]$ (the value may be adjusted based on the actual system requirements).

A value of ζ is the smaller and the distinguished ability is the larger. ζ=0.5 is generally used.After the gray relational coefficient is derived, it is usual to take the average value of the gray relational coefficients as the gray relational grade [18–20]. The gray relational grade is defined as following:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \qquad (4)$$

However, in a real engineering system, the importance of various factors to the system varies. In the real condition of unequal weight being carried by the various factors, the gray relational grade was extended and defined as follows :

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} w_k \xi_i(k) \sum_{k=1}^{n} w_k = 1 \qquad (5)$$

Where w_k denotes the normalized weight of factor k.

The gray relational grade γ_i represents the level of correlation between the reference sequence and the comparability sequence. The value of gray relational grade is equal to 1 if the two sequences are identically coincidence.

Table 2 Design of experiments and results

S.No	Gap Voltage (V)	Current (A)	Pulse on Time (µs)	Pulse off Time (µs)	Material Removal Rate(MRR) (mm^3/s)	Over cut (OC) (mm)	Taper Angle(Θ) (degree)	Grey relational grade	Rank
1	30	8	3	8	0.0031	0.052	0.159	0.776664	1
2	50	8	7	8	0.0028	0.088	0.127	0.624052	8
3	40	10	3	6	0.0034	0.097	0.541	0.519021	24
4	40	10	5	6	0.0038	0.100	0.222	0.604293	10
5	40	8	5	6	0.0031	0.093	0.318	0.56391	16
6	50	12	3	4	0.0024	0.080	0.222	0.601262	11
7	30	12	7	8	0.0036	0.100	0.413	0.544484	20
8	30	8	7	8	0.0056	0.165	1.718	0.542671	21
9	40	10	5	8	0.0037	0.110	0.668	0.491467	26
10	30	8	3	4	0.0042	0.085	0.127	0.68979	3
11	50	10	5	6	0.0026	0.075	0.350	0.585586	13
12	50	8	7	8	0.0028	0.075	0.095	0.671664	4
13	40	10	5	6	0.0028	0.078	0.445	0.56158	17
14	40	10	7	6	0.0031	0.083	0.190	0.623967	9
15	30	12	3	8	0.0033	0.072	0.286	0.634145	6
16	40	10	5	6	0.0033	0.095	0.827	0.478248	28
17	40	10	5	6	0.0042	0.135	0.254	0.572216	15
18	50	8	3	8	0.0032	0.105	0.954	0.445752	29
19	50	12	7	4	0.0024	0.061	0.127	0.708329	2
20	50	8	3	4	0.0030	0.111	0.209	0.40886	30
21	30	12	7	4	0.0036	0.084	0.350	0.594072	12
22	50	12	3	8	0.0026	0.071	0.254	0.626256	7
23	40	12	3	6	0.0037	0.099	0.604	0.516165	25
24	40	10	5	6	0.0032	0.085	0.095	0.654445	5
25	50	8	7	4	0.0029	0.102	0.350	0.532648	23
26	40	10	5	6	0.0038	0.101	0.891	0.483592	27
27	30	12	3	4	0.0047	0.097	0.859	0.549636	19
28	30	8	7	4	0.0039	0.085	0.445	0.584232	14

29	40	10	5	4	0.0035	0.092	0.541	0.53347	22
30	30	10	5	8	0.0054	0.130	0.432	0.556199	18

Grey relational coefficients for each experimental run based on uniform rotatable central composite design. These Grey relational coefficients have been calculated as discussed in the previous section. In Table 2, the highest value of Grey relational coefficient observed is 0.776664, corresponding to experiment No.30 at parametric setting of T_{on} 3 µs, T_{off} 8 µs, IP 8 A, and V_g 30V. Hence, the parametric setting, corresponding to experiment No. 1 is the optimal process parameter for EDM process during machining of tungsten carbide among the thirty experiments as this has yielded the best multi performance characteristics.

Table 3 The response table for grey relational grade

Process Paramete	Average closeness coefficients			Maximum-minimum
	Level 1	Level 2	Level 3	
v_g	0.639912	0.589821	0.5262075	0.1137045
IP	0.649013	0.606564	0.498738	0.150275
T_{on}	0.570420	0.598955	0.5219586	0.0769964
T_{off}	0.557967	0.562408	0.569885	0.011918

5. Conclusion

GRA based on Taguchi method's response table has successfully evaluated feasibility in the EDM of Tungsten carbide. Optimal machining parameters have been determined by GRA for multi performance characteristics (MRR, Taper angle and OC). From response table of average GRA, following largest value of GRA was found for: T_{on} 3 µs, T_{off} 8 µs, IP 8 A, and V_g 30V. These are the recommended levels of controllable process factors when greatest MRR, lesser taper angle and OC are simultaneously obtained.

References