Study on Machining Characteristics of Tungsten Carbide in Electro-Discharge Machining Process

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Abstract: **The present study points out a multi-objective optimization problem to determine the optimal process parameters in machining of tungsten carbide in Electro-discharge machining process by applying Grey Relational Analysis coupled with Taguchi method. In this present study, the process parameters are like Pulse current, Pulse on time and Pulse off time have been considered for finding out the desired value of responses like material removal rate (MRR), Electrode wear rate (EWR) and Surface Roughness (Ra). The results obtained are validated by conducting the confirmation experiments.**

Keywords: Grey Relational analysis, Taguchi Method, ANOVA, Surface Roughness

1. INTRODUCTION

Electric discharge machining, commonly known as EDM, is a process that is used to remove metal through the action of an electrical discharge of short duration and high current density between the tool and the work piece (1). The electrical discharge machining process (EDM) is traditionally engaged in the environment of the tooling industry for decades. In particular, EDM is used when geometrically complex shapes-like dies, punches and plastic injection molding tools; have to be produced in difficult to machine materials.

The aim of this project is to study the effect of machining parameters in EDM of tungsten carbide on the machining characteristics. The characteristics of EDM refer essentially to output machining parameters such as material removal rate (MRR), electrode wear rate (EWR) and surface roughness (R_a). The machining parameters are the input parameters of the EDM process, namely pulse-on-time (Ton), pulse-off-time (Toff), and current (I).Literature depicts that C.H. Che Haron et al. (3) has taken copper electrodes of different diameters and done machining in EDM of AISI 1045 tool steel at two current settings and concluded that the material removal rate and the electrode wear rate were not only dependent on the diameter of the electrode but also had close relation with the supply of current. Low current was found suitable for small diameter electrode, high current for big diameter electrode. M. Kiyak (4) has examined the machining parameters on surface roughness in EDM of tool steel and has concluded that surface roughness increases with increase of pulse current and pulse time and increases material removal rate. I. Puertas et al. (5) has concluded the same result in machining WC-Co in EDM. Lau et al. (6) carried out an experiment work to investigate the feasibility of EDM as a means of machining carbon fiber composite materials. The machining was conducted at various currents, pulse durations and with different tool materials and polarities. It was clearly concluded that there exits an optimum material removal rate with peak current and pulse on time. It was again proved that copper electrodes perform better than graphite electrodes in terms of tool wear and surface finish. S.H. Lee (1) studied the influence of operating parameters of EDM of tungsten carbide on the machining characteristics. The effectiveness of the EDM process with WC is evaluated in terms of material removal rate, electrode wear ratio and surface finish. They found that material removal rate and surface finish of the work piece are directly proportional to the discharge current intensity.

2. EXPERIMENTAL SET-UP

During this study, a series of experiments on EDM of tungsten carbide of size 20mm x20mmx5mm was conducted on a ECOWIN MIC-432C electrical discharge machine to examine the effects of input machining parameters such as pulse on time, pulse off time and current, on the material removal rate and electrode wear rate and surface roughness. The electrode taken was 99.9% copper rod of diameter 8 mm. Paraffin was used as dielectric fluid in this experimentation. The machining tests were carried out with a total time of 10 minutes for each experiment. The pressure and temperature of the dielectric fluid was assumed to be constant throughout the experiment. Material is removed during machining from both the work piece and the tool by the erosive action of electrical discharges. The material removed from the work piece and the tool then determined from their respective weight differences before and after undergoing EDM process. This is then divided by respective densities in order to convert it into volumetric term and further divided by the actual time of machining to obtain the material removal rate and electrode wear rate.

The surface roughness is measured by stylus type profilometer (Taylor's Hobson Surtronic +3).

A. MachineTool

The ECOWIN 432C machine is a die-sinking machine manufactured by Ecowin Corporation, Taiwan. It is energized by a 60 a pulse generator. Paraffin was used as dielectric fluid during the experiments.

B. Workpiece & Electrode Material

The work piece material used in this study was tungsten carbide material. The electrode material used during this study was electrolytic copper rod of diameter 8mm.

C. Response Variables Selected

The response variables selected to carry out the present study on EDM performance characteristics are the following:

(i) Material Removal Rate (MRR):

It represents the volume of material removed from the work piece in unit time.

(ii) Electrode Wear Rate (EWR):

It is defined as the volume of material eroded from the tool electrode per unit time divided by the volume of material eroded from the work piece in the same time.

(iii) Centre line average roughness (Ra):

It is defined as the arithmetic mean deviation of the surface height from the mean line through the profile while the mean line is defined so as to have equal areas of the profile above and below it.

3. EXPERIMENTAL DESIGN

In this section, orthogonal array is employed to reduce the number of cutting experiments for determining the optimal cutting parameters. Taguchi's orthogonal arrays were used in engineering analysis and they consist of ranges of EDM process parameters based on three level designs of experiments. In this study, an L9 orthogonal array is chosen for experimentation. This array has eight degrees of freedom and it can handle three- level process parameters. The factors which are to be varied in the experiment, their range and the levels at which runs are to be made are chosen and given in Table 1. The experimental result for the EDM process parameters using the L9 orthogonal array is shown in Table 2.

Table 1 Factors and levels of process parameters

Factors	Symbols	Levels		
		1	2	3
Current (A)	A	20	22	24
Pulse on time(μs)	B	10	50	100
Pulse off time(μs)	C	10	15	20

Table 2 L9 orthogonal array & Experimental Data

Exp No:	A Current (A)	B Pulse on time (μs)	C Pulse off time (μs)	MRR (mm^3/min)	EWR (%)	R_a (μm)
1.	1	1	1	0.4636	0.4844	2.06
2.	1	2	2	0.0662	3.3927	3.74
3.	1	3	3	0.5298	0.1060	5.22
4.	2	1	2	0.3974	0.5651	2.42
5.	2	2	3	0.0662	5.0891	4.16
6.	2	3	1	0.1325	0.8475	5.22
7.	3	1	3	0.1325	1.6950	2.22
8.	3	2	1	0.3974	1.4129	6.10
9.	3	3	2	0.3311	0.1697	2.88

4. RESULTS AND DISCUSSION

A.Grey relational analysis

For better performance of a machining process the material removal rate should be high whereas the surface roughness should be low. Thus, it is a case of multi response optimization, which is different from that of a single performance characteristic. The higher S/N ratio for one performance characteristic may correspond to a lower S/N ratio for another. Therefore, the overall evaluation of the S/N ratio is required for the optimization of multiple performance characteristics.

In the grey relational analysis, data preprocessing is first performed in order to normalize the raw data (Table 3) for analysis. In this study, a linear normalization of the experimental results for material removal rate, electrode wear rate & surface roughness were performed in the range between zero and one, which is also called the grey relational generation.

The normalized processing for MRR corresponding to larger-the-better criterion can be expressed as data

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max\ y_i(k) - \min\ y_i(k)} \quad (1)$$

In this grey relational analysis, the normalized data processing for electrode wear rate and surface roughness corresponding to lower- the-better criterion can be expressed as

$$x_i(k) = \frac{\max\ y_i(k) - y_i(k)}{\max\ y_i(k) - \min\ y_i(k)} \quad (2)$$

where xi(k) is the value after the grey relational generation, min yi(k) is the smallest value of yi(k) for the kth response, and max yi(k) is the largest value of yi(k) for the kth response. An ideal sequence is x0(k) (k=1, 2 and 3 for MRR, EWR & Ra respectively). The grey relational generation has been shown in the Table 3. Basically, the larger normalized results correspond to the better performance and the best-normalized results should be equal to one. Next, the grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results.

Table 3 Data processing of each performance characteristic (Grey relational generation)

Exp. No	MRR	EWR	Ra
Ideal Sequence	1		1
1	0.857204	0.075937	0
2	0.001294	0.659569	0.415842
3	1	0	0.782178
4	0.714409	0.092131	0.089109
5	0	1	0.519802
6	0.143011	0.148803	0.782178
7	0.143011	0.318878	0.039604
8	0.714409	0.262266	1
9	0.571398	0.012783	0.20297

The grey relational coefficient $\xi_i(k)$ can be calculated as

$$\xi_i(k) = \frac{\Delta_{\min} + \psi\,\Delta_{\max}}{\Delta_{oi}(k) + \psi\,\Delta_{\max}} \quad (3)$$

where $\Delta_{0i} = \left\| x_0(k) - x_i(k) \right\|$ = difference of the absolute value between x0(k) and xi(k), $\Delta_{\min}$ and $\Delta_{\max}$ are respectively the minimum and maximum values of the absolute differences (Δ_{0i} as shown in Table 4) of all comparing sequences. ψ is a distinguishing coefficient, $0 \le \psi \le 1$, the purpose of which is to weaken the effect of $\Delta_{\max}$ when it gets too big and thus enlarges the difference significance of the relational coefficient. In the present case, ψ = 0.5 is used. After averaging the grey relational coefficients, the grey relational grade γ_i can be calculated as follows:

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

where n = number of process responses. The higher value of grey relational grade is considered as the stronger relational degree between the ideal sequence x0(k) and the given sequence xi(k). It has already been mentioned that the ideal sequence x0(k) is the best process response in the experimental layout. Thus the higher relational grade implies that the corresponding parameter combination is closer to the optimal.

Table 4 Grey relational grade of performance characteristic

Exp. No	Grade
1	0.487431
2	0.463247
3	0.676628
4	0.448665
5	0.614478
6	0.478352
7	0.878054
8	0.680143
9	0.720046

The higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized value. In other words, optimization of the complicated multiple performance characteristics can be converted into optimization of a single grey relational grade. The grey relational grade is shown in the Table 4. Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels. Basically, the larger the grey relational grade, the better is the multiple performance characteristics. However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known so that the optimal combinations of the machining parameter levels can be determined more accurately.

B.Analysis of variance for grey relational grade

The purpose of the analysis of variance (ANOVA) is to investigate which machining parameters significantly affect the performance characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions by each machining parameter and the error (Nalbant et al., 2007). In addition, the Fisher's F-test can also be used to determine which machining parameters have a significant effect on the performance characteristic. Usually, the change of the machining parameter has a significant effect on the performance characteristic when F is large is shown in Table 5.

Table 5 ANOVA for Grey relational grade

Source	DF	SS	MS	F	P
A	2	0.108209	0.054104	2027.61	0.000
B	2	0.002289	0.001144	42.89	0.023
C	2	0.062506	0.031253	1171.24	0.001
Error	2	0.000053	0.000027		
Total	8	0.173057	0.054104	2027.61	

In the grey relational grade graph (Fig.1), it is clearly mentioned that first level of current, second level of pulse on time, first level of pulse off time (A1B2C1) are the optimal combination of process parameters for multiple performance characteristics.

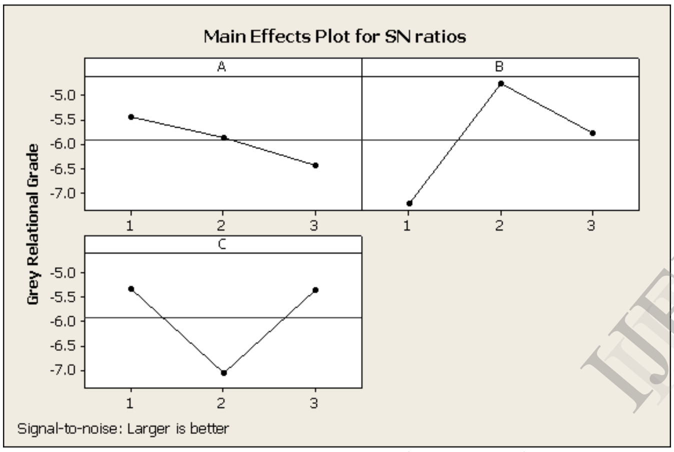

Figure 1 Grey relational grade graphs of multiple performance characteristics

C. Confirmation tests

After the optimal level of machining parameters has been identified, a verification test needs to be carried out in order to check the accuracy of analysis. The estimated grey relational grade, $\hat{\gamma}$, using the optimal level of the process parameters can be calculated as:

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{o} (\bar{\gamma}_i - \gamma_m) \qquad (5)$$

where γ_m is the total mean grey relational grade, $\bar{\gamma}_i$ is the mean grey relational grade at the optimal level, and o is the number of the main design parameters that significantly affect the machining characteristics of EDMed surfaces. Table 6 shows the comparison of the estimated grey relational grade with the actual grey relational grade obtained in experiment using the optimal cutting parameters. It may be noted that there is good agreement between the estimated value (0.67784) and experimental value (0.70860). The improvement of grey relational grade from initial parameter combination (A1B1C1) to the optimal parameter combination (A1B2C1) is 0.2211. This is about 28% of the mean grey relational grade and thus there is significant improvement. Here, it may conclude that the multiple performance characteristic of the EDM process such as material removal rate and surface finish are improved together by using this approach.

Table 6 Results of the confirmation experiment

	Initial cutting parameters	Optimal cutting parameters	
		Prediction	Experiment
Setting Level	A1B1C1	A1B2C1	A1B2C1
MRR	0.4636		0.5524
EWR	0.4844		0.3521
Surface Roughness	2.0600		1.8672
Grey relational grade	0.48743	0.67784	0.7086
Improvement of grey relational grade = 0.2211			

5 CONCLUSION

The use of the orthogonal array with grey relational analysis to optimize the EDM process with the multiple performance characteristics has been reported here. A grey relational analysis of the experimental results of material removal rate and surface roughness can convert optimization of a single performance characteristic called the grey relational grade. As a result, optimization of the complicated multiple performance characteristics can be greatly simplified through this approach. It is shown that the performance characteristics of the EDM process such as material removal rate and surface roughness are improved together by using this approach.

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