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Using EAMR Method to Find Best Input Parameters for PMEDM SKD11 Tool Steel

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Abstract
The paper shows the findings of a study that utilized Multi-Criteria Decision-Making (MCDM) to determine the best input parameters for machining cylindrical parts made of SKD11 tool steel using Powder-Mixed Electrical Discharge Machining (PMEDM). The experiment consisted of six input elements: Powder concentration (C_p), powder size (S_p), pulse on time (T_{on}), pulse off time (T_{off}), pulse current (IP), and servo voltage (SV). Moreover, the Taguchi methodology was utilized for the experimental design. The EAMR methodology was utilized to address the MCDM problem, employing the Entropy method for estimating the criteria weights. The objective was to achieve a high rate of material removal speed (MRS) while limiting the rate of electrode wear (EWR). The solution for the MCDM problem in the PMEDM of cylindrically shaped components was found based on the discovered results.

Keywords: MCDM, EAMR Method, PMEDM, SKD11, Electrode Wear Rate, Material Removal Speed

1. Introduction

Electrical discharge machining (EDM) is a non-traditional machining technique. It is used to remove substances from the surfaces of machine parts made of difficult-to-cut materials or to create complex geometric shapes. This machining technology has been widely utilized in several industries including as automotive, aerospace, and mold and die manufacture, irrespective of the physical properties of the materials being machined, as long as they possess conductivity. Nevertheless, it has been noted that the effectiveness of the EDM process is greatly impeded by the sluggish rate at which materials are eliminated, also known as the low material removal rate (MRR), subpar surface quality, and rapid deterioration of the tool. To overcome the constraints of EDM, researchers have proposed a method known as powder-mixed electrical discharge machining (PMEDM) [1-5].

In order to enhance the PMEDM process, a study was conducted in [6] to develop a more sophisticated mixing technique for PMEDM. The aim of the study is to enhance the MRR from titanium grade 5 alloy. The considered process factors encompass gap current, duty factor, powder mixed dielectric fluid pressure, powder type, and particle concentration. A research investigation [7] was carried out to assess MRR and tool wear rate (TWR) of EN-8 steel using PMEDM. Also, the Response Surface Methodology has been utilized to design and assess the experiments. The essential determinants that impact the selected performance indicators have been identified, and the most favorable circumstances for the process have been established. The work in [8] presents an experimental inquiry with the objective of identifying the optimal process factors for cutting cylindrical components constructed of 90CrSi utilizing graphite electrodes in PMEDM. The study investigated two parameters: The maximum material removal speed (MRS) and the lowest surface roughness (SR). The input factors utilized were the servo current IP, servo voltage SV, powder concentration C_p, pulse on time Ton, and pulse off time T_{off}. The influence of the input elements on the multi-criteria objective was presented. The research conducted in reference [9] investigates the influence of PMEDM parameters on the machining time of cylindrical shaped parts from 90CrSi alloy steel. The inquiry examines the influence of five parameters, specifically pulse on time, powder concentration, pulse off time, pulse current, and server voltage, on the duration of machining. The Taguchi method is utilized to do eighteen experiments using an orthogonal array L18. An optimal model for the machining time was obtained by ANOVA analysis. In [10], the response surface method was utilized to design and assess experiments with the goal of optimizing process parameters. These factors include pulse-on time, duty cycle, peak current, and concentration of the silicon powder. The aim of this study is to minimize SR and enhance MRR. The findings suggest that the peak current factor and concentration exert the most significant influence on both the MRR and SR. The reliability of the suggested method is confirmed by the minimal discrepancy noticed between the forecasts and experimental findings.

Several studies have been carried out on the optimization or multi-criteria decision making (MCDM) of PMEDM processes. The study on MCDM has shown the results of employing the PMEDM technique with titanium powder on the machining of SKD11 tool steel. The Preferred Selection Index (PSI) approach was used for evaluation. Reference [11] contains the detailed findings. The selection criteria for this study were the lowest SR and the highest MRR. J. Jayaraj *et al*. [12] showcased the selection process for the most efficient technique to cut Inconel 718. They achieved this by employing PMEDM using titanium powder. This study adopted the MCDM approach called Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), using two criteria: SR and MRR. The MCDM challenge in PMEDM, namely the manufacture of EN-31 tool steel using mixed Si powder, was addressed by employing the TOPSIS technique in [13].

The paper describes the findings of a study that employed MCDM to find the best input parameters for machining cylindrical parts made of SKD11 tool steel using Powder-Mixed Electrical Discharge Machining (PMEDM). The experiment consisted of six input components: Powder concentration (C_p), powder size (S_p), pulse on time (T_{on}), pulse off time (T_{off}), pulse current (IP), and servo voltage (SV). Moreover, the Taguchi methodology was utilized for the experimental design. The EAMR methodology was utilized to address the MCDM problem, employing the Entropy method for estimating the criteria weights. The objective was to achieve a high rate of material removal while limiting the rate of electrode wear. The solution for the MCDM problem in the PMEDM of cylindrically shaped parts was found based on the discovered results.

2. Methodology

2.1 Method to solve MCDM problem

This study employed the EAMR technique to address the issue of Multiple Criteria Decision Making (MCDM). To utilize this approach, it is crucial to strictly stick to the subsequent procedures [14]:

- **Step 1:** Create the decision-making matrix:

$$X_d = \begin{bmatrix} x_{11}^d & \cdots & x_{1n}^d \\ x_{21}^d & \cdots & x_{21}^d \\ \vdots & \cdots & \vdots \\ x_{m1}^d & \cdots & x_{mn}^d \end{bmatrix} \quad (1)$$

In which, 1 ≤d ≤ k; k denotes the decision maker's number; d is the decision maker's indication.

- **Step 2:** Calculate the mean value of each option by:

$$\bar{x}_{ij} = \frac{1}{k}\left(x_{ij}^1 + x_{ij}^2 + \cdots + x_{ij}^k\right) \quad (2)$$

- **Step 3:** Compute the creation weights;
- **Step 4:** Determine each criterion's weighted average by:

$$\bar{w}_j = \frac{1}{k}\left(w_j^1 + w_j^2 + \cdots + w_j^k\right) \quad (3)$$

- **Step 5:** Find n_{ij} by:

$$n_{ij} = \frac{x_{ij}}{e_j} \quad (4)$$

Where e_j is found by:

$$e_j = max_{i\in\{1,\ldots,m\}}\left(\bar{x}_{ij}\right) \quad (5)$$

- **Step 6:** Calculate the normalized weight by:

$$v_{ij} = n_{ij} \cdot \bar{w}_j \quad (6)$$

- **Step 7:** Compute the criteria's normalized score.

+) For MRS target:

$$G_i^+ = v_{i1}^+ + v_{i2}^+ + \cdots + v_{im}^+ \quad (7)$$

+) For SR target:

$$G_i^- = v_{i1}^- + v_{i2}^- + \cdots + v_{im}^{-+} \quad (8)$$

- **Step 8:** Calculate the ranking's (SR) values from G_i^+ and G_i^-:

- **Step 9:** Determine the options' evaluation score by:

$$S_i = \frac{RV(G_i^+)}{RV(G_i^-)} \quad (9)$$

- Rank the order of options by maximizing S_i.

2.2 Method to calculate criteria weights

In this work, the Entropy method has been used to find the criteria weights. The following steps are required to apply the technique [15]:

Step 1: Calculate the indicator's normalized values by:

$$p_{ij} = \frac{x_{ij}}{m + \sum_{i=1}^{m} x_{ij}^2} \quad (10)$$

Step 2: Determine the Entropy for each indicator by:

$$me_j = -\sum_{i=1}^{m}[p_{ij} \times ln(p_{ij})] - (1 - \sum_{i=1}^{m} p_{ij}) \times ln(1 - \sum_{i=1}^{m} p_{ij}) \quad (11)$$

Step 3: Compute the weight of each indicator by:

$$w_j = \frac{1 - me_j}{\sum_{j=1}^{m}(1 - me_j)} \quad (12)$$

3. Experimental Work

An empirical investigation was undertaken to support the process of solving the MCDM. Table 1 displays the constituent elements involved in the input procedure of the experiment. The experiment was conducted using the Taguchi technique, specifically employing an L18 ($1^6 + 5^3$) design. Fig 1 illustrates the arrangement of the experiment. The experiment utilized a Sodick A30 EDM machine, copper electrodes, SKD11 tool steel samples, SiC powder, and Total Diel MS 7000 dielectric solution. Before and after processing the samples, the weight of each electrode and sample was determined using an electronic balance WT3003NE, which has a precision of 0.001 (g). Moreover, the exact duration of the operation on the EDM machine had been recorded. The EWR and MRS can be calculated using Equations (13) and (14), which utilize these parameters. Table 2 presents the experimental matrix and the accompanying output, which includes the values for EWR and MRS.

Fig 1: Experimental setup

- For finding EWR:

$$EWR = \sum_{i=1}^{n} \frac{m_{ebi} - m_{eai}}{t_{si}} \quad (13)$$

- For finding MRS:

$$MRR = \sum_{i=1}^{n} \frac{m_{pbi} - m_{pai}}{t_{si}} \quad (14)$$

In which, m_{ebi} and m_{eai} represent the mass of i^{th} electrode before and after processing (mg); m_{pbi} and m_{pai} are the mass of i^{th} samples before and after processing (mg); t_{si} is the machining time (min.); n=3 is the electrode number.

Table 1: Input parameters

No	Parameters	Code	Level					
			1	2	3	4	5	6
1	Powder concentration (g/l)	C_p	0	2	3	4	5	6
2	Powder size (nm)	S_p	100	500	1000	-	-	-
3	Pulse on time (µs)	T_{on}	10	20	30	-	-	-
4	Pulse off time (µs)	T_{off}	10	20	30	-	-	-
5	Peak current (A)	IP	4	8	12	-	-	-
6	Servo voltage (V)	SV	3	5	7	-	-	-

Table 2: Experimental plan and output results

No.	Input parameters						EWR (mg/min.)	MRS (mg/min.)
	C_p	S_p	T_{on}	T_{off}	IP	SV		
1	0	100	10	10	4	3	29.692	9.877
2	0	500	20	20	8	5	10.285	16.098
3	0	1000	30	30	12	7	99.834	49.645
4	2	100	10	20	8	7	13.533	6.725
5	2	500	20	30	12	3	16.922	15.886
6	2	1000	30	10	4	5	35.934	41.983
7	3	100	20	10	12	5	11.359	32.487
8	3	500	30	20	4	7	24.706	12.425
9	3	1000	10	30	8	3	32.871	11.826
10	4	100	30	30	8	5	24.111	28.270
11	4	500	10	10	12	7	67.676	8.199
12	4	1000	20	20	4	3	10.498	5.289
13	5	100	20	30	4	7	10.715	5.329
14	5	500	30	10	8	3	18.969	15.200
15	5	1000	10	20	12	5	64.615	7.373
16	6	100	30	20	12	3	85.497	30.868
17	6	500	10	30	4	5	55.694	5.650
18	6	1000	20	10	8	7	15.250	5.293

4. Finding Best Input Process Parameters

After the experiment is finished, the outcomes of MRS and EWR will be transmitted to the EAMR program as input parameters to address the MCDM problem. In order to address the MCDM problem, the criteria weights were determined utilizing the Entropy technique, as outlined in Section 2.2, in the subsequent manner: The values p_{ij} are normalized using Equation (10). The entropy value for each indicator me_j was computed using Equation (11). Determine the weight of the criteria, w_j, by applying Equation (12). The weights allocated to MRS and EWR were computed as 0.4826 and 0.5174, respectively. Section 2.1 provides suggestions on the optimal utilization of the EAMR technique for overcoming the MCDM challenge. The first matrix is formed with Formula (1). Calculate the average value of the options for each criterion using Equation (2). Formula (3) can be used to calculate the average weighted values. Determine the value of n_{ij} using Equation (4), taking into account that e_j is determined by Equation (5). Next, apply Formula (6) to compute the value of v_{ij}. Utilize Equation (7) to compute the normalized score of the criterion for the MRR target, and subsequently employ Equation (8) to derive the values of G_i for the EWR target. Finally, get the S_i value by use Formula (9). Table 3 presents a variety of computed outcomes and the order of choices.

According to the information provided in Table 3, alternative 7 is the most advantageous option because it has the highest S_i value (S_i=6.1659). The best input dressing parameters are as follows: C_p=3 (g/l), S_p=100 (nm), T_{on}=20 (µs), T_{off}=10 (µs), IP=12 (A), and SV=5 (V).

Table 3: Calculated results and ranking of options

S. No	n_{ij}		v_{ij}		G_i		S_i	Rank
	EWR	**MRS**	EWR	**MRS**	EWR	**MRS**		
1	0.2974	0.1990	0.1435	0.1029	0.1435	0.103	0.7171	15
2	0.1030	0.3243	0.0497	0.1678	0.0497	0.168	3.3743	2
3	1.0000	1.0000	0.4826	0.5174	0.4826	0.517	1.0720	10
4	0.1356	0.1355	0.0654	0.0701	0.0654	0.07	1.0713	11
5	0.1695	0.3200	0.0818	0.1656	0.0818	0.166	2.0238	5
6	0.3599	0.8457	0.1737	0.4375	0.1737	0.438	2.5188	4
7	0.1138	0.6544	0.0549	0.3386	0.0549	0	6.1659	1
8	0.2475	0.2503	0.1194	0.1295	0.1194	0.129	1.0842	8
9	0.3293	0.2382	0.1589	0.1232	0.1589	0.123	0.7756	13
10	0.2415	0.5695	0.1166	0.2946	0.1166	0.295	2.5277	3
11	0.6779	0.1651	0.3272	0.0854	0.3272	0	0.2612	16
12	0.1052	0.1065	0.0508	0.0551	0.0508	0.055	1.0861	7
13	0.1073	0.1073	0.0518	0.0555	0.0518	0.056	1.0721	9
14	0.1900	0.3062	0.0917	0.1584	0.0917	0.158	1.7274	6

15	0.6472	0.1485	0.3124	0.0768	0.3124	0	0.2460	17
16	0.8564	0.6218	0.4133	0.3217	0.4133	0.322	0.7783	12
17	0.5579	0.1138	0.2692	0.0589	0.2692	0.059	0.2187	18
18	0.1528	0.1066	0.0737	0.0552	0.0737	0.055	0.7482	14

5. Conclusions

This article describes the results of a MCDM study on cylindrical components made of SKD11 tool steel for PMEDM procedures, using copper electrodes. The EAMR methodology was used to solve the MCDM problem, while the Entropy method was used to determine the weights of the criterion. In addition, the analysis took into account six input process parameters: C_p, S_p, T_{on}, T_{off}, IP, and SV. The experiment was carried out utilizing the Taguchi technique with an L18 ($1^6 + 5^3$) design. The study's findings suggest that the most effective input process parameters for obtaining the lowest RS and the highest MRS are as follows: C_p=3 (g/l), S_p=100 (nm), T_{on}=20 (µs), T_{off}=10 (µs), IP=12 (A), and SV=5 (V).

6. Acknowledgement

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