Determination of Best Input Factors in Powder-Mixed Electrical Discharge Machining 90CrSi Steel using Multi-Criteria Decision Making Methods

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ABSTRACT

This article outlines the results of a Multi-Criteria Decision Making (MCDM) analysis conducted on the Powder-Mixed Electrical Discharge Machining (PMEDM) process for cylindrical parts fabricated from 90CrSi tool steel, using graphite electrodes. The study aims to identify the optimal input factors to simultaneously minimize Surface Roughness (SR) and Electrode Wear Rate (EWR), while maximizing Material Removal Rate (MRR). Five input factors were selected: powder concentration (C_P), pulse-on time (T_{on}), pulse-off time (T_{off}), pulse current (IP), and servo voltage (SV). Experimental data were generated using the Taguchi method with an L18 design. The optimization process was performed using the Multi-Attributive Border Approximation area Comparison (MABAC), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Evaluation by an Area-based Method of Ranking (EAMR) methods. Criteria weights were calculated utilizing the Entropy and the Multi-Expert Ranking Evaluation with Compensation (MEREC) techniques. The analysis identified the best PMEDM input factor, providing an optimal solution for enhancing the efficiency of machining cylindrically shaped components.

Keywords-PMEDM; MCDM; MABAC; TOPSIS; EAMR; surface roughness; electrode wear rate; material removal rate; 90CrSi tool steel; graphite electrodes

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a widely utilized technique in various industries for machining electrically conductive materials. Nevertheless, the process has notable limitations including low Material Removal Rate (MRR), poor surface quality, and quick tool deterioration. To overcome these challenges, PMEDM has been employed. This technique enhances the EDM process by incorporating metal particles into the dielectric fluid. Much research has explored the

PMEDM to enhance machining performance. These efforts focus on improving key metrics including MRR, SR, and EWR through advanced techniques. Specifically, authors in [1] investigated PMEDM using titanium powder on SKD61, SKD11, and SKT4 die steels. Key parameters, such as pulse on/off time, electric current, and powder concentration, were optimized through the Taguchi method. The results showed a 42.1% increase in MRR with a 20 g/L powder concentration, achieving an optimal MRR of 45.734 mm^3/min. Authors in [2] focused on titanium grade 5 alloy, employing an advanced mixing technique on PMEDM to enhance the MRR. The findings revealed a notable improvement by optimizing gap current, duty factor, powder type, and particle concentration. Meanwhile, authors in [3] examined the impact of SiC powder on the surface roughness of 90CrSi steel, using the Taguchi method. A 30.02% reduction in SR was achieved at a 4g/L powder concentration. Similarly, in [4], it was reported that peak current and powder concentration significantly influenced SR and MRR using a silicon powder in EDM, while in [5], authors employed the TOPSIS approach to minimize surface roughness on AISI 304 stainless steel.

Several researchers have employed optimization techniques to improve PMEDM processes. Authors in [6] studied rotary electrodes with Al_2O_3 powder in machining Inconel 718. A mathematical model corelated input variables, like *IP*, sparking gap (V), T_{on}, and slurry concentration with MRR. In [7], authors used MCDM methods, including TOPSIS, Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS), Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) and MEREC, to optimize PMEDM for 90CrSi tool steel. Authors in [8] similarly employed TOPSIS to enhance MRR and minimize EWR for the same material.

The MCDM method has been widely utilized across various fields to identify the best solutions. Applications included selecting the best airport [9], optimizing the most suitable material [10], ranking top ten universities in Vietnam [11], optimizing solutions in mechanical machining processes, such as turning [12-13], milling and drilling [13], as well as determining the main design factors for a helical gearbox [14]. This paper outlines the results of a MCDM study focused on the processing of 90CrSi tool steel using PMEDM techniques to identify the best input factors achieving minimum SR, EWR, and maximum MRR.

II. METHODOLOGY

This section outlines the steps for implementing MCDM methods, specifically MABAC, TOPSIS, and EAMR, along with criterion weighting techniques including Entropy and MEREC, to address Multi-Objective Optimization Problem (MOOP).

A. TOPSIS Method

It is essential to perform the following steps to employ TOPSIS effectively [15]:

- Making the decision-making matrix by:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

where x_{mn} is the value of criterion *n* in alternatives *m*.

- Calculate the normalized values k_{ij} by:

$$k_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (2)$$

- Determine the weighted normalized decision matrix by:

$$l_{ij} = w_j \times k_{ij} \quad (3)$$

where w_j is the weight of the j^{th} criterion.

- Calculate the best (A^+) and the worst (A^-) alternative by:

$$A^+ = \{l_1^+, l_2^+, \dots, l_j^+, \dots, l_n^+\} \quad (4)$$

$$A^- = \{l_1^-, l_2^-, \dots, l_j^-, \dots, l_n^-\} \quad (5)$$

where l_1^+ and l_1^- denote the best and worst values of the *j* criterion (*j = 1, 2, …, n*).

- Compute the better options D_i^+ and worse options D_i^- by:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(l_{ij} - l_j^+\right)^2} \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(l_{ij} - l_j^-\right)^2} \quad (7)$$

where *i = 1, 2, …, m*.

- Determine the vales of each option by:

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (8)$$

where $0 \leq R_i \leq 1$.

- Ranking the options by maximizing R_i.

B. MABAC Method

The subsequent stages for executing this method are [16]:

- Build the initial decision-making matrix with (1).
- Compute the normalized values r_{ij}^*:

$$r_{ij}^* = \frac{r_{ij} - r_i^-}{r_i^+ - r_i^-} \quad (9)$$

$$r_{ij}^* = \frac{r_{ij} - r_i^+}{r_i^- - r_i^+} \quad (10)$$

where $r_i^+ = max(r_1, r_2, \dots, r_m)$ and $r_i^- = min(r_1, r_2, \dots, r_m)$. Equation (9) is used for MRR criterion, while (10) is used for SR and EWR criterion.

- Determine the weighted matrix elements:

$$v_{ij} = w_j + (w_j \times r_{ij}^*) \quad (11)$$

- Calculate the border approximation area matrix:

$$g_i = \left(\prod_{i=1}^{m} v_{ij}\right)^{1/m} \quad (12)$$

- Find the distance between options and the border approximation area:

$$q_{ij} = v_{ij} - g_i \tag{13}$$

- Calculate the total distances of each option from the approximate border area:

$$S_i = \sum_{j=1}^{n} q_{ij} \tag{14}$$

- Ranking the options by maximizing S_i.

C. EAMR Method

The EAMR method is conducted in the following stages [17]:

- Create the decision-making matrix using (1).
- Compute the mean value of each alternative:

$$\bar{x}_{ij} = \frac{1}{k}\left(x_{ij}^1 + x_{ij}^2 + \cdots + x_{ij}^k\right) \tag{15}$$

where k is the number of decision makers.

- Compute the criteria weights.
- Determine each criterion's weighted average:

$$\bar{w}_j = \frac{1}{k}\left(w_j^1 + w_j^2 + \cdots + w_j^k\right) \tag{16}$$

- Calculate n_{ij} by:

$$n_{ij} = \frac{\bar{x}_{ij}}{e_j} \tag{17}$$

where e_j can be determined by:

$$e_j = \max_i\left(\bar{x}_{ij}\right) \tag{18}$$

- Compute the normalized weigh:

$$v_{ij} = n_{ij} \cdot \bar{w}_j \tag{19}$$

- Calculate the criteria's normalized score:
    i. For MRR objective:

$$G_i^+ = v_{i1}^+ + v_{i2}^+ + \cdots + v_{im}^+ \tag{20}$$

    ii. For SR and EWR objectives:

$$G_i^- = v_{i1}^- + v_{i2}^- + \cdots + v_{im}^- \tag{21}$$

- Determine the ranking's (*RV*) values based on G_i^{++} and G_i^{--}.
- Calculate the options' evaluation score:

$$S_i = \frac{RV(G_i^+)}{RV(G_i^-)} \tag{22}$$

- Ranking the options to find the best choice by maximizing S_i.

D. Entropy Method

The following steps can be applied to perform the Entropy technique [18]:

- Determine the indicator's normalized values:

$$p_{ij} = \frac{x_{ij}}{m + \sum_{i=1}^{m} x_{ij}^2} \tag{23}$$

- Calculate the value of the Entropy for each indicator:

$$me_j = -\sum_{i=1}^{m}\left[p_{ij} \times ln\left(p_{ij}\right)\right] - \left(1 - \sum_{i=1}^{m} p_{ij}\right) \times ln\left(1 - \sum_{i=1}^{m} p_{ij}\right) \tag{24}$$

- Calculate the weight for each indicator:

$$w_j = \frac{1 - me_j}{\sum_{j=1}^{n}\left(1 - me_j\right)} \tag{25}$$

E. MEREC Method

The steps to determine the weights according to the MEREC method are: [19]:

- Create the initial matrix with the same techniques applied in (1).
- Calculate the normalized values:
    a. For MRR objective:

$$h_{ij} = \frac{minx_{ij}}{x_{ij}} \tag{26}$$

    b. For SR and EWR objectives:

$$h_{ij} = \frac{x_{ij}}{maxx_{ij}} \tag{27}$$

- Calculate the overall efficiency of the alternatives:

$$S_i = ln\left[1 + \left(\frac{1}{n}\sum_{j=1}^{n} \left|\ln\left(h_{ij}\right)\right|\right)\right] \tag{28}$$

- Calculate the efficiency of the ith alternative:

$$S'_{ij} = ln\left[1 + \left(\frac{1}{n}\sum_{k,k\neq j}^{n}\left|ln\left(h_{ij}\right)\right|\right)\right] \tag{29}$$

- Calculate the removal effect of the jth criterion:

$$E_j = \sum_{i}^{m}\left|S'_{ij} - S_i\right| \tag{30}$$

- Calculate the criteria weights:

$$w_j = \frac{E_j}{\sum_{k}^{m} E_k} \tag{31}$$

III. EXPERIMENTAL WORK

An experiment was performed to generate the input data for the MCDM problem. The experiment was conducted using the Taguchi method with an L18 ($2^1 + 3^4$) configuration. Table I presents the experimental input process parameters.

TABLE I. INPUT PARAMETERS

No.	Factors	Level		
		1	**2**	**3**
1	Powder Concentration. C_P	0 g/L	0.5 g/L	1 g/L
2	Pulse-on Time, T_{on}	8 µs	12 µs	16 µs
3	Pulse-off Time, T_{off}	8 µs	12 µs	16 µs
4	Peak Current, *IP*	5 A	10 A	15 A
5	Servo Voltage, SV	4 V	5 V	-

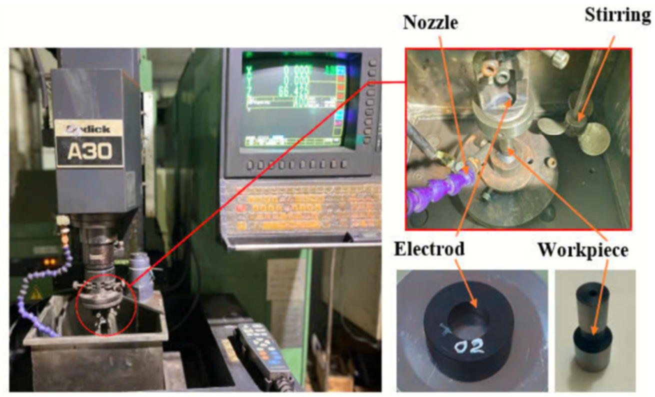

Fig. 1. Experimental setup.

The setup, illustrated in Figure 1, employed a Sodick A30 EDM machine (Japan), graphite electrodes from TOKAI Carbon Co., LTD, (Tokyo, Japan), 90CrSi tool steel workpieces (China), 100 nm SiC powder (China), and Total Diel MS 7000 dielectric fluid (France).

During the experiment, the processing time for each sample was monitored. The mass of the electrodes and samples was measured before and after machining using a WT3003NE electronic balance with a precision of 0.001 g. The SR value for each sample was measured after each test run, while the EWR and MRR values were calculated using the following formulas:

a) EWR:

$$EWR = \sum_{i=1}^{m} \frac{m_{ebi} - m_{eai}}{t_{si}} \quad (32)$$

where:

- m_{ebi}: mass of electrode *i* before machining (mg)
- m_{eai}: mass of electrode *i* after machining (mg)
- t_{si}: processing time for sample *i* (s)
- *m*: number of electrodes used (in this case: *m* = 3).

b) MRR:

$$MRR = \sum_{i=1}^{m} \frac{m_{sbi} - m_{sai}}{t_{si}} \quad (33)$$

where:

- m_{sbi} : mass of sample *i* before processing (mg)
- m_{sai}: mass of sample *i* after processing (mg)
- t_{si}: processing time for sample *i* (s)
- *m*: number of electrodes used (in this case: *m* = 3).

Table II presents the experimental strategy and the outcome's outputs (*SR*, *EWR*, and *MRR*).

TABLE II. EXPERIMENTAL MATRIX AND OUTPUT RESULTS

No.	**Input factors**					***SR*** **(µm)**	***EWR*** **(g/h)**	***MRR*** **(g/h)**
	C_P (g/L)	**T_{on} (µs)**	**T_{off} (µs)**	***IP*** **(A)**	***SV*** **(V)**			
1	0	8	8	5	4	2.041	0.153	0.731
2	0	12	12	10	4	2.928	0.151	1.344
3	0	16	16	15	4	7.704	0.444	3.889
4	0.5	8	8	10	4	2.069	0.030	0.799
5	0.5	12	12	15	4	4.920	0.159	7.070
6	0.5	16	16	5	4	6.930	0.125	0.813
7	1	8	12	5	4	1.965	0.106	1.398
8	1	12	16	10	4	2.771	0.153	3.820
9	1	16	8	15	4	4.563	0.378	4.411
10	0	8	16	15	5	3.568	0.165	6.970
11	0	12	8	5	5	4.841	0.185	1.944
12	0	16	12	10	5	3.723	0.105	1.428
13	0.5	8	12	15	5	2.869	0.055	7.100
14	0.5	12	16	5	5	4.126	0.117	2.328
15	0.5	16	8	10	5	2.909	0.090	1.248
16	1	8	16	10	5	1.674	0.042	2.088
17	1	12	8	15	5	3.565	0.206	7.105
18	1	16	12	5	5	2.952	0.149	2.564

IV. RESULTS AND DISCUSSION

Upon completing the experiment, the output values of SR, EWR, and MRR were processed using the MABAC, TOPSIS, and EAMR methods as input parameters to resolve the MOOP. The criteria weights, essential for addressing the MCDM problem, were calculated using both the Entropy and MEREC techniques and the results are displayed in Table III:

TABLE III. CRITERIA WEIGHTS VALUES

Methods	**Criteria weights**		
	SR **(µm)**	***EWR*** **(g/h)**	***MRR*** **(g/h)**
Entropy	0.3523	0.3140	0.3337
MEREC	0.2422	0.3832	0.3746

The rankings derived from the application of MCDM methods are as follows:

- TOPSIS Method (Table IV): The rankings are based on R_i coefficient with Option 13 identified as the optimal alternative due to its highest $R_i$value of 0.8953.
- MABAC Method (Table V): The rankings are determined by the total distance to the boundary approximation area (S_i) with Option 13 ranked the highest due to its maximum S_i value of.3277.
- EAMR Method (Table VI): The rankings are calculated based on the overall score (S_i), with Option 13 achieving the highest S_i value of 1.4070.

The ranking results of the options, using three MCDM methods and criteria weights calculated through Entropy and MEREC methods, are presented in Table VII. The result is/results are independent of the calculation of the weights, whether using the Entropy or MEREC method. This indicates that the finding of the best alternative is independent of the MCDM method, and the weighting approach employed (or rather, involving the techniques used in this work).

TABLE IV. CALCULATED RESULTS AND RANKING OF ALTERNATIVES BY TOPSIS AND ENTROPY

No.	k_{ij}			l_{ij}			Di^+	Di^-	Ri	Rank
	SR	EWR	MRR	SR	EWR	MRR				
1	0.1201	0.1936	0.0438	0.0423	0.0608	0.0146	0.1369	0.1646	0.5459	13
2	0.1723	0.1907	0.0806	0.0607	0.0599	0.0269	0.1276	0.15323	0.5455	14
3	0.4532	0.5612	0.2333	0.1597	0.1762	0.0779	0.2164	0.06323	0.2261	18
4	0.1217	0.0373	0.0479	0.0429	0.0117	0.0160	0.1265	0.20175	0.6147	7
5	0.2895	0.2010	0.4240	0.1020	0.0631	0.1415	0.0847	0.1795	0.6795	4
6	0.4077	0.1575	0.0488	0.1436	0.0494	0.0163	0.1707	0.12778	0.4281	16
7	0.1156	0.1336	0.0838	0.0407	0.0419	0.0280	0.1183	0.17986	0.6032	8
8	0.1630	0.1930	0.2291	0.0574	0.0606	0.0765	0.0850	0.16626	0.6616	6
9	0.2684	0.4779	0.2646	0.0946	0.1501	0.0883	0.1601	0.10174	0.3886	17
10	0.2099	0.2087	0.4180	0.0739	0.0655	0.1395	0.0667	0.18761	0.7378	2
11	0.2848	0.2337	0.1166	0.1003	0.0734	0.0389	0.1371	0.12118	0.4693	15
12	0.2190	0.1321	0.0857	0.0772	0.0415	0.0286	0.1249	0.15861	0.5594	12
13	0.1688	0.0699	0.4259	0.0595	0.0219	0.1421	0.0268	0.22382	0.8931	1
14	0.2427	0.1473	0.1397	0.0855	0.0462	0.0466	0.1136	0.15302	0.5738	11
15	0.1711	0.1131	0.0749	0.0603	0.0355	0.0250	0.1223	0.17256	0.5852	10
16	0.0985	0.0528	0.1252	0.0347	0.0166	0.0418	0.1005	0.20453	0.6704	5
17	0.2097	0.2608	0.4261	0.0739	0.0819	0.1422	0.0804	0.18038	0.6918	3
18	0.1737	0.1880	0.1538	0.0612	0.0590	0.0513	0.1058	0.15742	0.5980	9

TABLE V. CALCULATED RESULTS AND RANKING OF ALTERNATIVES BY MABAC AND ENTROPY

No.	g_j			q_{ij}			Si	Rank
	SR	EWR	MRR	SR	EWR	MRR		
1	0.5791	0.5252	0.4468	0.1041	0.0091	-0.1131	0.0000	11
2	0.5791	0.5252	0.4468	0.0522	0.0108	-0.0810	-0.0179	13
3	0.5791	0.5252	0.4468	-0.2268	-0.2112	0.0523	-0.3858	18
4	0.5791	0.5252	0.4468	0.1024	0.1028	-0.1095	0.0957	7
5	0.5791	0.5252	0.4468	-0.0642	0.0047	0.2188	0.1593	5
6	0.5791	0.5252	0.4468	-0.1816	0.0307	-0.1088	-0.2596	17
7	0.5791	0.5252	0.4468	0.1085	0.0450	-0.0782	0.0753	8
8	0.5791	0.5252	0.4468	0.0614	0.0094	0.0487	0.1195	6
9	0.5791	0.5252	0.4468	-0.0433	-0.1613	0.0796	-0.1250	16
10	0.5791	0.5252	0.4468	0.0149	0.0000	0.2136	0.2285	2
11	0.5791	0.5252	0.4468	-0.0595	-0.0150	-0.0496	-0.1241	15
12	0.5791	0.5252	0.4468	0.0058	0.0459	-0.0766	-0.0248	14
13	0.5791	0.5252	0.4468	0.0557	0.0832	0.2204	0.3593	1
14	0.5791	0.5252	0.4468	-0.0177	0.0369	-0.0294	-0.0103	12
15	0.5791	0.5252	0.4468	0.0533	0.0573	-0.0860	0.0246	10
16	0.5791	0.5252	0.4468	0.1255	0.0934	-0.0420	0.1769	4
17	0.5791	0.5252	0.4468	0.0150	-0.0312	0.2206	0.2045	3
18	0.5791	0.5252	0.4468	0.0508	0.0125	-0.0171	0.0462	9

TABLE VI. CALCULATED RESULTS AND RANKING OF ALTERNATIVES BY EAMR AND ENTROPY

No.	n_{ij}			v_{ij}			Gi^-	Gi^+	Si	Rank
	SR	EWR	MRR	SR	EWR	MRR				
1	0.2649	0.3450	0.1028	0.0933	0.1083	0.0343	0.2017	0.0343	0.1702	17
2	0.3801	0.3399	0.1892	0.1339	0.1067	0.0631	0.2406	0.0631	0.2624	15
3	1.0000	1.0000	0.5474	0.3523	0.3140	0.1827	0.6663	0.1827	0.2742	14
4	0.2686	0.0664	0.1125	0.0946	0.0209	0.0375	0.1155	0.0375	0.3252	11
5	0.6387	0.3581	0.9951	0.2250	0.1124	0.3321	0.3374	0.3321	0.9841	4
6	0.8995	0.2806	0.1145	0.3169	0.0881	0.0382	0.4050	0.0382	0.0943	18
7	0.2551	0.2381	0.1967	0.0899	0.0747	0.0657	0.1646	0.0657	0.3988	10
8	0.3597	0.3439	0.5377	0.1267	0.1080	0.1795	0.2347	0.1795	0.7646	6
9	0.5923	0.8516	0.6209	0.2087	0.2674	0.2072	0.4760	0.2072	0.4353	8
10	0.4631	0.3718	0.9810	0.1631	0.1168	0.3274	0.2799	0.3274	1.1697	2
11	0.6284	0.4164	0.2736	0.2214	0.1308	0.0913	0.3521	0.0913	0.2593	16
12	0.4832	0.2354	0.2010	0.1702	0.0739	0.0671	0.2441	0.0671	0.2748	13
13	0.3724	0.1245	0.9994	0.1312	0.0391	0.3335	0.1703	0.3335	1.9582	1
14	0.5355	0.2624	0.3277	0.1887	0.0824	0.1094	0.2710	0.1094	0.4035	9
15	0.3776	0.2016	0.1757	0.1330	0.0633	0.0586	0.1963	0.0586	0.2986	12
16	0.2173	0.0941	0.2939	0.0766	0.0296	0.0981	0.1061	0.0981	0.9242	5
17	0.4628	0.4646	1.0000	0.1630	0.1459	0.3337	0.3089	0.3337	1.0803	3
18	0.3832	0.3349	0.3609	0.1350	0.1052	0.1205	0.2402	0.1205	0.5015	7

TABLE VII. RANKING OF OPTIONS BU TOPSIS, MABAC AND EAMR

No.	TOPSIS		MABAC		EAMR	
	Entropy	MEREC	Entropy	MEREC	Entropy	MEREC
1	13	14	11	14	17	17
2	14	13	13	13	15	16
3	18	18	18	18	14	15
4	7	7	7	7	11	11
5	4	3	5	4	4	4
6	16	15	17	17	18	18
7	8	10	8	8	10	10
8	6	6	6	6	6	6
9	17	17	16	16	8	9
10	2	2	2	2	2	2
11	15	16	15	15	16	14
12	12	12	14	12	13	13
13	1	1	1	1	1	1
14	11	8	12	11	9	8
15	10	11	10	10	12	12
16	5	5	4	5	5	5
17	3	4	3	3	3	3
18	9	9	9	9	7	7

Additionally, Spearman's rank correlation coefficient (R) was employed to compare the degree of association between the rankings derived from the different MCDM techniques. This coefficient is calculated as follows [20]:

$$R = 1 - \frac{6\cdot\sum_{i=1}^{m} D_i^2}{n\cdot(n^2-1)} \quad (34)$$

where n is the number of options, while D_i represents the variance between ranks.

Table VIII presents the Spearman's rank correlation coefficient for rankings obtained from different methodologies. The analysis revealed that the highest correlation coefficient is 0.9992, between TOPSIS and MABAC, whereas the lowest is 0.9907, between MABAC and EAMR.

TABLE VIII. SPERARMAN'S RANK CORRELATION COEFFICIENT

MEREC			Entropy		
TOPSIS & MABAC	**TOPSIS & EAMR**	**MABAC & EAMR**	**TOPSIS & MABAC**	**TOPSIS & EAMR**	**MABAC & EAMR**
0.9987	0.9926	0.9933	0.9992	0.9913	0.9907

V. CONCUSIONS

This study presents the findings of a Multi-Criteria Decision Making (MCDM) analysis on Powder-Mixed Electrical Discharge Machining (PMEDM) of cylindrical parts made from 90CrSi tool steel, utilizing graphite electrodes. The analysis employed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Multi-Attributive Border Approximation area Comparison (MABAC), and Evaluation by an Area-based Method of Ranking (EAMR) methods to solve the MCDM problem, while the Entropy and Multi-Expert Ranking Evaluation with Compensation (MEREC) techniques were applied to calculate the criteria weights. The experiment incorporated an 100 nm SiC powder into the Diel MS 7000 dielectric solution and investigated five input process factors: T_{on}, T_{off}, IP, SV, and C_p. The Taguchi method with an L18 (2^1+3^4) design was used for the experiments. Based on the results, the following conclusions were drawn:

- The Multi- Objective Optimization Problem (MOOP) to determine the optimal input factors for the PMEDM of 90CrSi steel using graphite electrodes was successfully solved using the TOPSIS, MABAC, and EAMR method.
- Three single objectives -minimum Surface Roughness (SR), minimum Electrode Wear Rate (EWR), and maximum Material Removal Rate (MRR) were evaluated in relation to the input parameters.
- The optimal input factors for simultaneously achieving the three objectives during the machining of cylindrical parts are: C_p = 0.5 g/L, T_{on} = 8 µs, T_{off} = 12 µs, IP = 15 A, and SV =5 V.

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