

Article

Multi-Criteria Decision Making in the PMEDM Process by Using MARCOS, TOPSIS, and MAIRCA Methods

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Abstract: Multi-criteria decision making (MCDM) is used to determine the best alternative among various options. It is of great importance as it hugely affects the efficiency of activities in life, management, business, and engineering. This paper presents the results of a multi-criteria decision-making study when using powder-mixed electrical discharge machining (PMEDM) of cylindrically shaped parts in 90CrSi tool steel. In this study, powder concentration, pulse duration, pulse off time, pulse current, and host voltage were selected as the input process parameters. Moreover, the Taguchi method was used for the experimental design. To simultaneously ensure minimum surface roughness (RS) and maximum material-removal speed (MRS) and to implement multi-criteria decision making, MARCOS (Measurement of Alternatives and Ranking according to Compromise Solution), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), and MAIRCA (Multi-Attributive Ideal–Real Comparative Analysis) methods were applied. Additionally, the weight calculation for the criteria was calculated using the MEREC (Method based on the Removal Effects of Criteria) method. From the results, the best alternative for the multi-criteria problem with PMEDM cylindrically shaped parts was proposed.

Keywords: PMEDM; multi-criteria decision making; MARCOS; TOPSIS; MAIRCA; MEREC; taguchi; 90CrSi; surface roughness; material-removal speed



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1. Introduction

Multi-criteria decision making (MCDM) is a common problem in practice when it is necessary to analyze different options to come up with the best alternative. This problem is posed not only for engineering but also for medicine, business, social sciences, and everyday life. In particular, it has been widely applied in mechanical processing because the machining process is often required to meet many criteria, such as the minimum machined surface roughness (SR), maximum material-removal rate (MMR), minimum cutting force, maximum tool life, or minimum machining cost. In fact, the criteria of a machining process often contradict each other. The requirement to increase the MMR will involve an increase in the depth of the cut and the feed rate, and it will lead to a growth in the surface roughness and a decrease in tool life. In addition, the requirement for a minor surface roughness will lead to a reduction in the depth of the cut and feed rate, and in turn, it will reduce the MMR. Therefore, solving MCDM problems through different methods has attracted many researchers.

The TOPSIS method is one of the most widely used MCDM methods [1]. Besides its simplicity and practicality [2], it can be applied to problems covering a lot of criteria and alternatives [1]. This method was first proposed by Hwang et al. [3], and it has been used

in many mechanical machining processes, such as grinding [4,5], turning [6–8], electrical discharge machining [9–11], waterjet machining [12,13], etc. For the PMEDM process, it has been used to implement MCDM when machining Al_2O_3 ceramics [14], Inconel 718 [15], Inconel X-750 [16], etc.

The MAIRCA (Multi-Attributive Ideal–Real Comparative Analysis) method was proposed in 2014 [17] for the selection of railway crossings for investment in safety equipment. This method has the advantage that the objective function can be both qualitative and quantitative [6]. In [18], the MAIRCA method was used to rank and select the appropriate location for the construction of ammunition depots. Recently, it has been applied to MCDM in the turning process [6].

The MARCOS approach was recently proposed by Stević, Ž. et al. [19] when choosing sustainable suppliers in the healthcare industry in Bosnia and Herzegovina. This method is used for supplier selection in steel production [20]. It has been used for MCDM for three methods of processing, including milling, grinding, and turning [21]. In [22], this method was used to select suitable gear material and cutting fluid.

A PMEDM process is understood as an EDM process with a dielectric solution mixed with metal powder in order to limit some disadvantages of the EDM process, such as low machined surface quality and small MMR. Like EDM, this type of machining is very effective when processing difficult-to-machine conductive materials and concave parts such as stamping dies and plastic molds. Therefore, there have been many studies on optimization or MCDM of PMEDM processes. The results of MCDM when PMEDM using titanium powder when machining SKD11 tool steel using the Preferred Selection Index (PSI) method have been shown in [23], in which the minimum SR and maximum MRR are selected as criteria. J. Jayaraj et al. [15] presented the selection of the best option when machining Inconel 718 using PMEDM with titanium powder. In this study, two criteria were SR and MRR, and the MCDM method was the TOPSIS method. The TOPSIS method was also applied in [24] when solving the MCDM problem in PMEDM with mixed Si powder when processing EN-31 tool steel.

From the above analysis, it is obvious that there have been quite a few studies on MCDM for mechanical machining processes, including PMEDM, so far. Nevertheless, all of the studies on PMEDM have been carried out when machining concave parts or holes. Up to now, there has been no research on MCDM when machining cylindrically shaped parts, which are commonly used in shaped punches for stamping steel plates or tablet-shaped punches.

This paper introduces the results of an MCDM study when using PMEDM cylindrically shaped parts. In the study, minimum RS and maximum MRS were selected as the criteria for the investigation since RS and MRS are the two most important output parameters and the most popular subjects for the optimization study of mechanical machining processes [25]. Additionally, three methods, including MARCOS, TOPSIS, and MAIRCA, were used for MCDM, and the MEREC method was used to determine the weights for the criteria. The evaluation of the results when solving the MCDM problem with different methods was performed. In addition, the best alternative to obtain minimum RS and maximum MRS simultaneously was suggested.

2. Methods of MCDM

2.1. MARCOS Method

Multi-criteria decision making using the MARCOS method is carried out according to the following steps [19]:

Step 1: Forming an initial decision-making matrix:

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

In which m is the alternative number, n is the criteria number, and x_{mn} is the value of the criterion n in the alternative m .

Step 2: Making an extended initial matrix by adding an ideal (AI) and anti-ideal solution (AAI) into the initial decision-making matrix.

$$X = \begin{matrix} & \begin{matrix} AAI \\ A_1 \\ A_2 \\ \vdots \\ A_m \\ AI \end{matrix} & \begin{bmatrix} x_{aa1} & \cdots & x_{aan} \\ x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mn} \\ x_{ai1} & \cdots & x_{ain} \end{bmatrix} \end{matrix} \quad (2)$$

In the above equation, $AAI = \min(x_{ij})$ and $AI = \max(x_{ij})$ if the criterion j is bigger is better; $AAI = \max(x_{ij})$ and $AI = \min(x_{ij})$ if the criterion j is smaller is better; $i = 1, 2, \dots, m; j = 1, 2, \dots, n$.

Step 3: Normalizing the extended initial matrix (X). The normalized matrix $N = [n_{ij}]_{m \times n}$ can be determined by:

$$u_{ij} = x_{AI} / x_{ij} \text{ if the criterion } j \text{ is smaller is better.} \quad (3)$$

$$u_{ij} = x_{ij} / x_{AI} \text{ if criterion } j \text{ is bigger is better.} \quad (4)$$

Step 4: Determining the weighted normalized matrix $C = [c_{ij}]_{m \times n}$ by using the following equation:

$$c_{ij} = u_{ij} \cdot w_j \quad (5)$$

where w_j is the weight coefficient of criterion j .

Step 5: Determining the utility degree of alternatives K_i^- and K_i^+ by:

$$K_i^- = S_i / S_{AAI} \quad (6)$$

$$K_i^+ = S_i / S_{AI} \quad (7)$$

In (6) and (7), S_i is determined by:

$$S_i = \sum_{j=1}^m c_{ij} \quad (8)$$

Step 6: Calculating the utility function of alternatives $f(K_i)$ by:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}} \quad (9)$$

where $f(K_i^-)$ is the utility function related to the anti-ideal solution; $f(K_i^+)$ is the utility function related to the ideal solution. These functions can be found by:

$$f(K_i^-) = K_i^+ / (K_i^+ + K_i^-) \quad (10)$$

$$(K_i^+) = K_i^- / (K_i^+ + K_i^-) \quad (11)$$

Step 7: Ranking the alternatives based on the final values of the utility functions to find an alternative with the highest possible value of the utility function.

2.2. TOPSIS Method

To apply this method, the following steps need to be taken [3]:

Step 1: Using step 1 of the MARCOS method.

Step 2: Determining the normalized values k_{ij} by using the following equation:

$$k_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (12)$$

Step 3: Identifying the weighted normalized decision matrix by:

$$l_{ij} = w_j \times k_{ij} \quad (13)$$

Step 4: Finding the best alternative A^+ and the worst alternative A^- by the following equations:

$$A^+ = \{l_1^+, l_2^+, \dots, l_j^+, \dots, l_n^+\} \quad (14)$$

$$A^- = \{l_1^-, l_2^-, \dots, l_j^-, \dots, l_n^-\} \quad (15)$$

where l_j^+ and l_j^- are the best and worst values of the j criterion ($j = 1, 2, \dots, n$).

Step 5: Determining the values of better options D_i^+ and worse options D_i^- by:

$$D_i^+ = \sqrt{\sum_{j=1}^n (l_{ij} - l_j^+)^2} \quad i = 1, 2, \dots, m \quad (16)$$

$$D_i^- = \sqrt{\sum_{j=1}^n (l_{ij} - l_j^-)^2} \quad i = 1, 2, \dots, m \quad (17)$$

Step 6: Calculating values R_i of each alternative by:

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \quad i = 1, 2, \dots, m; \quad 0 \leq R_i \leq 1 \quad (18)$$

Step 7: Ranking the order of alternatives by maximizing the value of R .

2.3. MAIRCA Method

To apply the MAIRCA method, it is necessary to perform the following steps [17]:

Step 1: Forming the initial matrix in the same way as in the MARCOS method.

Step 2: Calculating the preferences according to alternative selection P_{A_j} . It is assumed that there is no preference for alternatives. Then, the priority for the criteria remains the same and it can be found as follows:

$$P_{A_j} = \frac{1}{m}, \quad j = 1, 2, \dots, n \quad (19)$$

Step 3: Determining the elements t_{pij} of the theoretical rating matrix by:

$$t_{pij} = P_{A_j} \cdot w_j, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots \quad (20)$$

in which w_j is the weight of the j th criterion.

Step 4: Determining the elements of real rating matrix t_{rij} by:

$$t_{rij} = t_{pij} \cdot \left(\frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \right) \quad \text{if the criterion } j \text{ is bigger is better.} \quad (21)$$

$$t_{rij} = t_{pij} \cdot \left(\frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \right) \quad \text{if the criterion } j \text{ is smaller is better.} \quad (22)$$

Step 5: Calculating the total gap matrix g_{ij} by using the following equation:

$$g_{ij} = t_{pij} - t_{rij} \quad (23)$$

Step 6: Determining the final values of the criterion functions (Q_i) using the alternatives. These values are found by the sum of the gaps (g_{ij}) according to alternatives or by the following formula:

$$Q_i = \sum_{j=1}^m g_{ij} \quad (24)$$

3. Calculating the Weights of Criteria

In this work, the MEREC method was employed to find the weights of the criteria through the following steps [26]:

Step 1: Forming the initial matrix as in the MARCOS method.

Step 2: Determining the normalized matrix elements by:

$$h_{ij} = \frac{\min x_{ij}}{x_{ij}} \text{ if the criterion } j \text{ is bigger is better.} \quad (25)$$

$$h_{ij} = \frac{x_{ij}}{\max x_{ij}} \text{ if the criterion } j \text{ is smaller is better.} \quad (26)$$

Step 3: Finding the performance of the alternatives S_i according to the following equation:

$$S_i = \ln \left[1 + \left(\frac{1}{n} \sum_j |\ln(h_{ij})| \right) \right] \quad (27)$$

Step 4: Calculating the performance of i th alternative S'_{ij} concerning the removal of the j th criterion by using the following equation:

$$S'_{ij} = \ln \left[1 + \left(\frac{1}{n} \sum_{k, k \neq j} |\ln(h_{ik})| \right) \right] \quad (28)$$

Step 5: Calculating the removal effect of the j th criterion E_j by:

$$E_j = \sum_i |S'_{ij} - S_i| \quad (29)$$

Step 6: Determining the weight for the criteria by using the following equation:

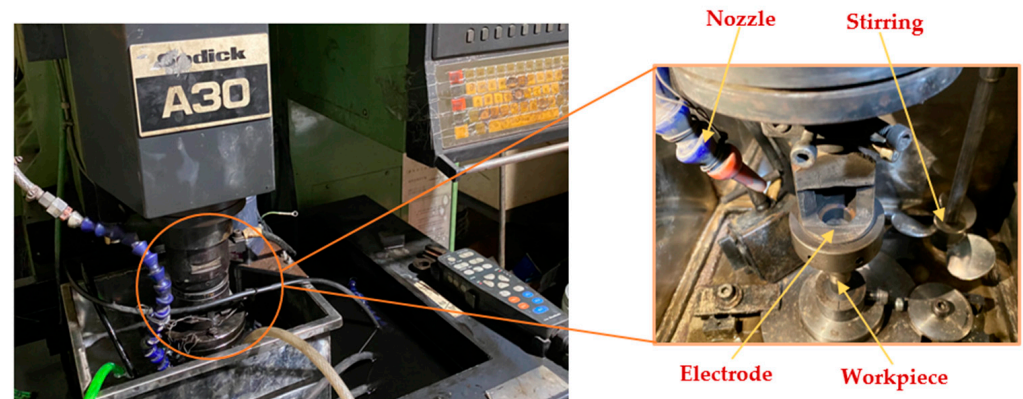
$$w_j = \frac{E_j}{\sum_k E_k} \quad (30)$$

4. Experimental Setup

To solve the proposed MCDM problem, an experiment was performed. The input process parameters of this experiment are given in Table 1. In addition, the Taguchi method with L18 ($2^1 + 3^4$) design was chosen for the experiment. Figure 1 depicts the experimental setup using a Sodick A30 EDM machine (Japan), graphite electrodes (TOKAI Carbon Co., LTD, Tokyo, Japan), workpieces with 90CrSi tool steel (China), 100 nm SiC powder (China), and Total Diel MS 7000 dielectric solution (France). After conducting experiments, the surface roughness (Ra) was measured, and the material-removal speed (MRS) was calculated. The experimental plan, the measurement values of workpieces SR, and the calculated values of the material-removal speed (MRS) (the average result of three measurements) are given in Table 2.

Table 1. Input parameters and their levels.

No.	Input Parameters	Code	Unit	Level		
				1	2	3
1	Powder concentration	C_p	g/l	0	0.5	1
2	Pulse on time	T_{on}	μs	8	12	16
3	Pulse off time	T_{off}	μs	8	12	16
4	Peak current	I_p	A	5	10	15
5	Servo voltage	SV	V	4	5	-

**Figure 1.** Experimental setup.**Table 2.** Experimental plan and output results.

No.	Input Parameters					Output Results	
	C_p	S_p	T_{on}	T_{off}	SV	Ra (μm)	MRS (g/h)
1	0.0	8	8	5	4	2.0410	0.7306
2	0.0	12	12	10	4	2.9280	1.3441
3	0.0	16	16	15	4	7.7040	3.8894
4	0.5	8	8	10	4	2.0690	0.7992
5	0.5	12	12	15	4	4.9203	7.0694
6	0.5	16	16	5	4	6.9297	0.8136
7	1.0	8	12	5	4	1.9653	1.3978
8	1.0	12	16	10	4	2.7713	3.8204
9	1.0	16	8	15	4	4.5630	4.4114
10	0.0	8	16	15	5	3.5677	6.9694
11	0.0	12	8	5	5	4.8410	1.9435
12	0.0	16	12	10	5	3.7227	1.4282
13	0.5	8	12	15	5	2.8693	7.1003
14	0.5	12	16	5	5	4.1257	2.3283
15	0.5	16	8	10	5	2.9090	1.2479
16	1.0	8	16	10	5	1.6743	2.0881
17	1.0	12	8	15	5	3.5653	7.1046
18	1.0	16	12	5	5	2.9523	2.5645

5. Multi-Criteria Decision Making

In this section, the MCDM problem is performed using the MARCOS, TOPSIS, and MAIRCA methods, where the weights of the criteria are determined by the MEREC method.

5.1. Calculating the Weights for the Criteria

The determination of the weights for the criteria according to the MEREC method is carried out according to the steps mentioned in Section 3. Accordingly, the normalized values h_{ij} are determined by Equations (25) and (26). Additionally, the alternative performance S_i can be found using Equation (27). Next, S_i and S'_{ij} are calculated by (28). The criterion-removal effect is then obtained by Equation (29). Finally, the weight of the criteria w_j is determined by Equation (30). It is reported that the weights of R_a and MRR are 0.5692 and 0.4308, respectively.

5.2. Using MARCOS Method

The application of the MARCOS method to multi-objective decision-making is carried out according to the steps outlined in Section 2.1. First, the ideal solution (AI) and the anti-ideal solution (AAI) are determined by Formula (2). The obtained values of R_a and MRR are 1.6743 (μm) and 7.1046 (g/h) with AI , and 7.704 (μm) and 0.7306 (g/h) with AAI , respectively. Then, the normalized values u_{ij} are determined according to Formulas (3) and (4). Additionally, the normalized value taking the weight c_{ij} into account is found by Formula (5). In addition, coefficients K_i^- and K_i^+ are determined by Equations (6) and (7). The values of $f(K_i^-)$ and $f(K_i^+)$ are determined by Equations (10) and (11). It was found that $f(K_i^-) = 0.49$ and $f(K_i^+) = 0.51$. Finally, the values of $f(K_i)$ are calculated by Formula (9). Table 3 shows the calculated results of several parameters and the ranking of the alternatives. From this table, it is obviously recognizable that alternative A_{13} is the best alternative.

Table 3. Calculated results and ranking of alternatives by MARCOS method.

Trial	K^-	K^+	$f(K^-)$	$f(K^+)$	$f(K_i)$	Rank
A1	0.060611	0.058234	0.49	0.51	0.0396	8
A2	0.048251	0.046359	0.49	0.51	0.0315	12
A3	0.042628	0.040956	0.49	0.51	0.0278	15
A4	0.060355	0.057989	0.49	0.51	0.0394	9
A5	0.073787	0.070893	0.49	0.51	0.0482	5
A6	0.022154	0.021285	0.49	0.51	0.0145	18
A7	0.06754	0.064892	0.49	0.51	0.0441	7
A8	0.068236	0.06556	0.49	0.51	0.0446	6
A9	0.056476	0.054261	0.49	0.51	0.0369	11
A10	0.081773	0.078567	0.49	0.51	0.0534	4
A11	0.037312	0.035848	0.49	0.51	0.0244	17
A12	0.040619	0.039026	0.49	0.51	0.0265	16
A13	0.090423	0.086877	0.49	0.51	0.0591	1
A14	0.044125	0.042394	0.49	0.51	0.0288	14
A15	0.047812	0.045937	0.49	0.51	0.0312	13
A16	0.082495	0.07926	0.49	0.51	0.0539	3
A17	0.082767	0.079521	0.49	0.51	0.0541	2
A18	0.056708	0.054484	0.49	0.51	0.0370	10

5.3. Using TOPSIS Method

The application of TOPSIS method to multi-objective decision making is guided in Section 2.2. Accordingly, the normalized values of k_{ij} are calculated by Equation (12), and the normalized weighted values l_{ij} are determined by Equation (13). Similarly, the A^+ and A^- values of R_a and MRS are achieved by Equations (14) and (15). It is noted that R_a and MRS are equal to 0.0583 and 0.2058 for A^+ and 0.2681 and 0.0212 for A^- . In addition, the D_i^+ and D_i^- values were found according to Formulas (16) and (17). Finally, the ratio R_i was calculated by Equation (18). Table 4 illustrates the results of the calculation of several

parameters and the ranking of the alternatives when using the TOSIS method. It was found that alternative A13 is the best alternative among the given options.

Table 4. Calculated results and ranking of alternatives by TOPSIS method.

Trial	k_{ij}		l_{ij}		D_i^+	D_i^-	R_i	Rank
	Ra	MRS	Ra	MRS				
A1	0.1248	0.0492	0.0710	0.0212	0.1851	0.1971	0.5157	11
A2	0.1790	0.0904	0.1019	0.0390	0.1725	0.1672	0.4922	12
A3	0.4710	0.2617	0.2681	0.1127	0.2296	0.0916	0.2851	17
A4	0.1265	0.0538	0.0720	0.0232	0.1832	0.1961	0.5171	10
A5	0.3008	0.4756	0.1712	0.2049	0.1130	0.2077	0.6477	5
A6	0.4237	0.0547	0.2412	0.0236	0.2582	0.0271	0.0948	18
A7	0.1202	0.0941	0.0684	0.0405	0.1656	0.2006	0.5478	8
A8	0.1694	0.2570	0.0964	0.1107	0.1025	0.1936	0.6540	4
A9	0.2790	0.2968	0.1588	0.1279	0.1272	0.1527	0.5456	9
A10	0.2181	0.4689	0.1242	0.2020	0.0660	0.2311	0.7779	3
A11	0.2960	0.1308	0.1685	0.0563	0.1857	0.1057	0.3626	16
A12	0.2276	0.0961	0.1296	0.0414	0.1792	0.1400	0.4386	15
A13	0.1754	0.4777	0.0999	0.2058	0.0416	0.2498	0.8573	1
A14	0.2522	0.1567	0.1436	0.0675	0.1625	0.1329	0.4498	14
A15	0.1779	0.0840	0.1012	0.0362	0.1750	0.1675	0.4891	13
A16	0.1024	0.1405	0.0583	0.0605	0.1453	0.2135	0.5951	6
A17	0.2180	0.4780	0.1241	0.2059	0.0658	0.2343	0.7807	2
A18	0.1805	0.1725	0.1027	0.0743	0.1388	0.1737	0.5559	7

5.4. Using MAIRCA Method

Multi-objective decision-making under the MAIRCA method is carried out based on the steps outlined in Section 2.3. After the initial matrix is set up, the priority or the criteria P_{A_j} is calculated by Formula (19). Since the criteria are considered equal, the priority for both Ra and MRS is equal to $1/18 = 0.0556$. In addition, the value of parameter $t_{p_{ij}}$ is found by Equation (20), with the note that the weight of the criterion is determined in Section 3. The $t_{p_{ij}}$ values of Ra and MRS obtained are 0.0316 and 0.0239, respectively. Then, the values of $t_{r_{ij}}$ is calculated by Equations (21) and (22), and the values of g_{ij} is determined by Equation (23). Finally, the values of criterion functions Q_i can be found using Formula (24). Table 5 shows the calculated parameters and ratings of the rating options when using the MAIRCA method. From this table, it can be seen that option A13 is the best alternative.

5.5. Results and Remarks

Table 6 presents the ranking results of options when applying three methods, MARCOS, TOPSIS, and MAIRCA. Moreover, Figure 2 shows a chart used for comparing the results of MCDM by using different methods. The vertical axis represents the values of the quantities when ranking the alternatives by different methods. Specifically, these methods include $f(K_i)$ (when using the MARCOS method), R_i (the TOPSIS method), and Q_i (the MAIRCA method). From the results, the following observations are proposed:

1. The ranking order of alternatives is different when using the three methods, MARCOS, TOPSIS, and MAIRCA.
2. All the three above-mentioned methods lead to the same result, i.e., A13 is the best option, which indicates that determining the best alternative does not depend on the decision-making method used. This observation is also consistent with the results when applying these MCDM methods to the turning process [6].
3. The MAIRCA and TOPSIS methods have up to 14/18 alternatives rated the same (except for options A5, A7, A8, and A18), which proves that these two methods have given quite similar results and can be used interchangeably.

4. To achieve “minimum” Ra and “maximum” MRS simultaneously, the proposed optimum process parameters include the following values: $C_p = 0.5$ (g/l), $T_{on} = 8$ (μ s), $T_{off} = 12$ (μ s), $IP = 15$ (A), and $SV = 5$ (V).

Table 5. Calculated results and ranking of alternatives by MAIRCA method.

Trial	k_{ij}		l_{ij}		Q_i	Rank
	Ra	MRS	Ra	MRS		
A1	0.0297	0.0000	0.0019	0.0239	0.0259	11
A2	0.0250	0.0023	0.0066	0.0216	0.0282	12
A3	0.0000	0.0119	0.0316	0.0121	0.0437	17
A4	0.0296	0.0003	0.0021	0.0237	0.0257	10
A5	0.0146	0.0238	0.0170	0.0001	0.0171	4
A6	0.0041	0.0003	0.0276	0.0236	0.0512	18
A7	0.0301	0.0025	0.0015	0.0214	0.0230	7
A8	0.0259	0.0116	0.0058	0.0123	0.0181	5
A9	0.0165	0.0138	0.0151	0.0101	0.0253	9
A10	0.0217	0.0234	0.0099	0.0005	0.0104	3
A11	0.0150	0.0046	0.0166	0.0194	0.0360	16
A12	0.0209	0.0026	0.0107	0.0213	0.0321	15
A13	0.0254	0.0239	0.0063	0.0000	0.0063	1
A14	0.0188	0.0060	0.0129	0.0179	0.0308	14
A15	0.0251	0.0019	0.0065	0.0220	0.0285	13
A16	0.0316	0.0051	0.0000	0.0188	0.0188	6
A17	0.0217	0.0239	0.0099	0.0000	0.0099	2
A18	0.0249	0.0069	0.0067	0.0170	0.0237	8

Table 6. Ranking of alternatives by different methods of multi-criteria decision making.

Trial	Rank		
	MARCOS	TOPSIS	MAIRCA
A1	8	11	11
A2	12	12	12
A3	15	17	17
A4	9	10	10
A5	5	5	4
A6	18	18	18
A7	7	8	7
A8	6	4	5
A9	11	9	9
A10	4	3	3
A11	17	16	16
A12	16	15	15
A13	1	1	1
A14	14	14	14
A15	13	13	13
A16	3	6	6
A17	2	2	2
A18	10	7	8

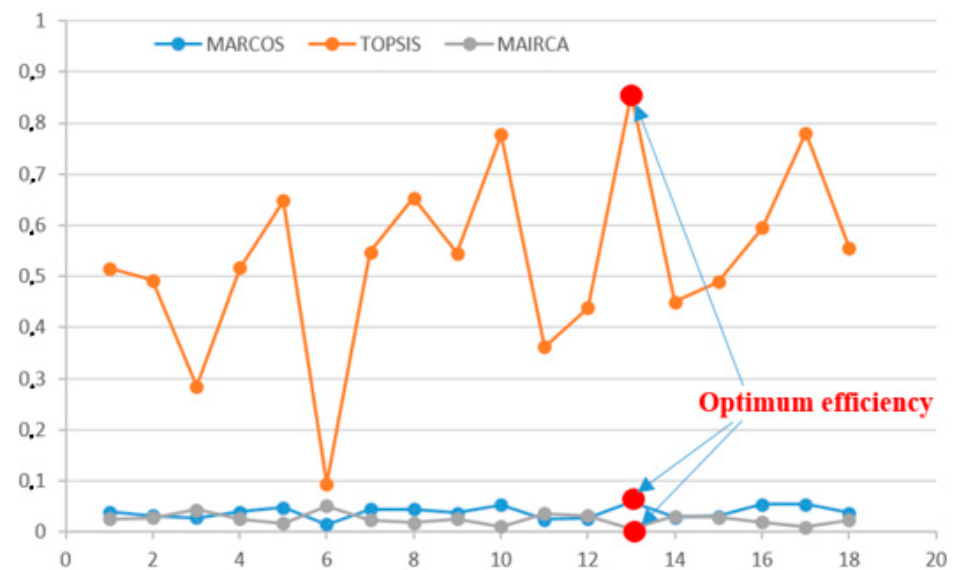


Figure 2. Comparison graph of MARCOS, TOPSIS, and MAIRCA.

6. Conclusions

This article shows the results of a multi-criteria decision-making study when using PMEDM cylindrically shaped parts. In this work, 90CrSi tool steel was chosen as the workpiece material, and 100 nm SiC powder was mixed into the Diel MS 7000 dielectric. Moreover, five process factors, including the powder concentration, the pulse-on-time, the pulse-off-time, the pulse current, and the server voltage, were investigated. Additionally, the Taguchi method with the L18 ($2^1 + 3^4$) design was used to design the experiment, and three methods, including MARCOS, TOPSIS, and MAIRCA, were applied for multi-criteria decision making. Moreover, the determination of the weights for the criteria was performed using the MEREC method. The following conclusions were drawn from the research results:

1. This is the first time that MARCOS, TOPSIS, and MAIRCA methods have been used for the MCDM of a PMEDM process when processing cylindrically shaped parts.
2. Using all three above-mentioned methods identified the same best alternative.
3. The MAIRCA and the TOPSIS methods give quite similar ratings, proving that these two methods can be used interchangeably for MCDM when using PMEDM.
4. It was noted that the optimum set of the input factors for obtaining the minimum Ra and the maximum MRS simultaneously when processing cylindrically shaped parts was $C_p = 0.5$ (g/l), $T_{on} = 8$ (μ s), $T_{off} = 12$ (μ s), $IP = 15$ (A), and $SV = 5$ (V).
5. To further strengthen the reliability of the conclusions of this study, it is necessary to conduct multi-criteria decision-making studies with different weighting methods.

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