Application of multi-criteria decision making technique in wire-cut EDM tool steel

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ABSTRACT

The findings of a study on the application of the MCDM technique to select the best input parameters in wire-cut electrical discharge machining (wire-cut EDM) 90CrSi tool steel are presented in this paper. The TOPSIS method was used in the study to solve the MCDM problem, and the Entropy method was used to compute the weights of the criteria. In this work, six input parameters including the cutting voltage VM, the pulse on time ton, the pulse off time toff, the servo voltage SV, the wire feed WF, the feed speed SPD, and the workpiece cutting radius R were investigated. Also, a 27-2 design experiment was performed and a total of 32 experimental runs were conducted. The MCDM problem was solved. According to the findings of this study, the best experimental setup is experiment No. 7 with the following input parameters: VM=9 (V), T_{on}=12 (s), T_{off}=13 (s), SV=25 (V), WF=8 (mm/min), SPD=4.5 (mm/min), and R=9 (mm).

Từ khoá: WEDM; MCDM; TOPSIS method; Surface Roughness; Cutting Speed; 90CrSi tool steel.

1. INTRODUCTION

To improve the performance of a mechanical machining process, it is necessary to determine the best process input parameters to satisfy multi-criteria at the same time, which often conflicts with each other. For example, to achieve the smallest surface roughness (SR), the depth of the cut and the feed rate must be reduced, resulting in a small material removal rate (MMR). Similarly, obtaining the maximum MMR will require increasing the depth of cut and the feed rate, as well as increasing SR. Solving the MCDM problem to choose the best solution for a machining process is very common in this case.

WEDM is a novel machining technique used to create conductive materials and parts with narrow slots. Due to a large number of input parameters such as VM, ton, toff, SV, WF, SPD, and so on, determining the best cutting mode for WEDM is difficult. As a result, the MCDM problem has been used in many studies to solve this problem.

Various MCDM methods have been used in the past to determine the best alternative in WEDM. P. Sreeraj et al. [1] conducted research on optimizing process parameters to enhance machining performance by combining MOORA and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) with Principal Component Analysis (PCA). The authors in [2] used the Multi-Objective Optimization Ratio Analysis (MOORA) method to determine the best input factors for wire-EDM Inconel 718. The MOORA was also used in [3] to cut D3 die steel. The authors in [4] applied the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method to find the best cutting factors when processing magnesium AZ91 alloy. The Weighted

Aggregates Sum Product Assessment (WASPAS) method was applied to solve the MCDM problem when processing Inconel 718 [5]. In this work, the kerf width, the material removal rate, and the tool wear rate were selected as three criteria. In [6] used the Operational competitiveness rating analysis (OCRA) method to obtain the optimum process parameters for cutting aluminium metal matrix.

Based on the above analysis, a number of studies have been conducted on the use of MCDM methods to figure out the best experimental setup when wire-EDMing with various materials. However, no studies have been conducted with 90CrSi tool steels. This paper presents the results of using the TOPSIS method to determine the best set of input parameters for wire-EDM 90CrSi tool steel. The TOPSIS technique was selected because it is the most commonly used MCDM method in mechanical machining process research. It has been used in EDM [7, 8], PMEDM [9], turning [10], milling, internal grinding [11], and others.

2. METHODOLOGY

2.1. Method for MCDM

The TOPSIS method was used to solve the MCDM problem in this study. The following steps must be taken in order to use this method [12]:

Step 1: Constructing a decision matrix:

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

In which, x_{mn} of the decision matrix shows the performance of m alternative with respect to n criteria.

Step 2: Calculating the normalized values k_{ij}:

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

Step 3: Finding the weighted normalized decision matrix by the following Equation:

$$l_{ij} = w_j \times k_{ij} \tag{3}$$

Step 4: Determining the best and the worst solutions (A+ and A-) by:

$$A^+ = \{l_1^+, l_2^+, \ldots, l_j^+, \ldots, l_n^+\} \tag{4}$$

$$A^- = \{l_1^-, l_2^-, \ldots, l_j^-, \ldots, l_n^-\} \tag{5}$$

In which, l_j^+ and l_j^- are the best and worst values of the j criterion (j=1,2, ..., n).

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

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

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

In (6) and (7) i = 1, 2, …, m.

Step 6: Determining the coefficient R_i of each solution by:

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

Wherein, i = 1, 2, …, m; $0 \leq R_i \leq 1$

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

2.2. Method for calculation of the weight of criteria

In this work, the Entropy method was used to calculate the weights of the criteria.

The steps outlined below can be used to put this method into action [13].

Step 1: Determining indicator normalized values:

$$p_{ij} = \frac{x_{ij}}{m + \sum_{i=1}^{m} x_{ij}^2} \quad (9)$$

Step 2: Finding the Entropyfof each indicator:

$$me_j = -\sum_{i=1}^{m} [p_{ij} \times \ln(p_{ij})] - \left(1 - \sum_{i=1}^{m} p_{ij}\right) \times \ln\left(1 - \sum_{i=1}^{m} p_{ij}\right) \quad (10)$$

Step 3: Finding the weight of each indicator:

$$w_j = \frac{1 - me_j}{\sum_{j=1}^{m}(1 - me_j)} \quad (11)$$

3. EXPERIMENTAL SETUP

An experiment was conducted for wire-EDMing 90CrSi steel to find the best solution that satisfied two criteria simultaneously time: minimum surface roughness SR and maximum cutting speed CS. Seven input parameters were specifically chosen for this experiment (table 1). A 2-level 1/4 factorial experimental design with two levels was also chosen. As a result, 27-2=32 test runs will be carried out. The experimental setup included the following items: a Fanuc Robocut -1 iA EDM machine (figure 1); brass wire with a diameter of 0.25 (mm) (Taiwan); workpiece material 90CrSi; 22x22 (mm2) samples; dielectric fluid: deionized water; surface roughness tester: Mitutoyo 178-923-2A, SJ-201 (Japan).

Following the experiment, the workpieces' surface roughness was measured and the cutting speed was calculated. Table 2 shows the various levels of input factors along with the output response results (Ra and CS). These are the most basic parameters of the wire_EDM process.

***Table 1.** Input factors and their levels.*

Factor	Code	Unit	Low	High
Cutting voltage	VM	V	3	9
Pulse on time	T_{on}	μs	8	12
Pulse off time	T_{off}	μs	13	18
Server voltage	SV	V	25	35
Wire feed	WF	mm/minute	8	12
Feed speed	SPD	mm/minute	2.5	4.5
Workpiece cutting radius	R	mm	3	9

Figure 1. *WEDM machine for experiment.*

Table 2. *Experimental plan and output results.*

Run Order	VM	T_{on}	T_{off}	SV	WF	SPD	R	Ra (μm)	CS (mm/min.)
1	9	8	18	35	12	2.5	3	3.877	2.08
2	9	8	13	25	8	2.5	3	3.412	2.18
3	9	8	18	25	8	4.5	3	3.410	1.98
4	9	8	13	35	8	4.5	9	2.800	1.81
5	3	8	13	35	12	2.5	9	3.453	1.34
6	3	8	18	35	8	4.5	3	3.962	1.63
7	9	12	13	25	8	4.5	9	3.067	2.50
8	3	8	13	25	8	4.5	9	3.066	1.51
...									
31	3	8	13	35	8	2.5	3	3.992	1.83
32	9	8	18	25	12	4.5	9	2.870	1.68

4. DETERMINING THE BEST ALTERNATIVE IN WEDM 90CrSi TOOL STEEL

This section explains determining the best experimental setup for the MCDM problem using the TOPSIS method and calculating the criteria weights using the Entropy method.

4.1. Determining the weights for the criteria

The weights of criteria are calculated using the Entropy method as follows (see section 2.2): The normalized values p_{ij} are calculated using Equation 19. Calculate the Entropy value for each indicator me_j using Equation 10. Finally, determine the weight of the criteria wj using Equation 141). Ra and CS weights were determined to be 0.4664 and 0.5336, respectively.

4.2. Determining the best experimental setup using TOPSIS method

Section 2.1 describes how to use the TOPSIS method to solve the MCDM problem. As a consequence, Equation (2) is used to calculate normalized k_{ij} values, while Equation (3) is used to determine normalized weighted l_{ij} values (3). Equations (4) and (5) calculate the A^+ and A^- values of R_a and MRR (5). R_a and MRR are 0.0982 and

0.1829 for A^+, respectively, and 0.1389 and 0.0854 for A^-. Furthermore, the D_{i+} and D_{i-} values were calculated using formulas (6) and (7). (7). Finally, Equation was used to quantify the ratio R_i (8). Table 3 shows the results of using the TOSIS method to determine and rank several parameters. Besides, figure 2 describes the relation between the values of R_i and the solutions.

From table 3 and figure 2, it was found that option 7 is the best choice. This is because it has the highest utility function value (R_i=0.9081). As a result, the optimal solution includes the parameters listed below.: VM = 9 (V); T_{on} = 12 (s); T_{off} = 13 (s); SV = 25 (V); WF = 8 (mm/min.); SPD = 4.5 (mm/min.); R = 9 (mm).

Table 3. *Several calculated results and ranking of alternatives.*

Trial	kij		lij		Di+	Di-	Ri	Rank
	Ra	MRR	Ra	MRR				
1	0.2915	0.2796	0.1360	0.1492	0.0506	0.0639	0.5580	13
2	0.2565	0.2931	0.1196	0.1564	0.0341	0.0736	0.6831	9
3	0.2564	0.2659	0.1196	0.1419	0.0463	0.0597	0.5635	11
4	0.2105	0.2433	0.0982	0.1298	0.0531	0.0603	0.5319	15
5	0.2596	0.1795	0.1211	0.0958	0.0901	0.0207	0.1865	32
6	0.2979	0.2191	0.1389	0.1169	0.0776	0.0316	0.2892	28
7	0.2306	0.3361	0.1075	0.1793	0.0100	0.0991	0.9081	1
31	0.30014	0.24537	0.13998	0.13093	0.06672	0.04557	0.40585	21
32	0.21576	0.22612	0.10063	0.12066	0.06232	0.05208	0.45528	18

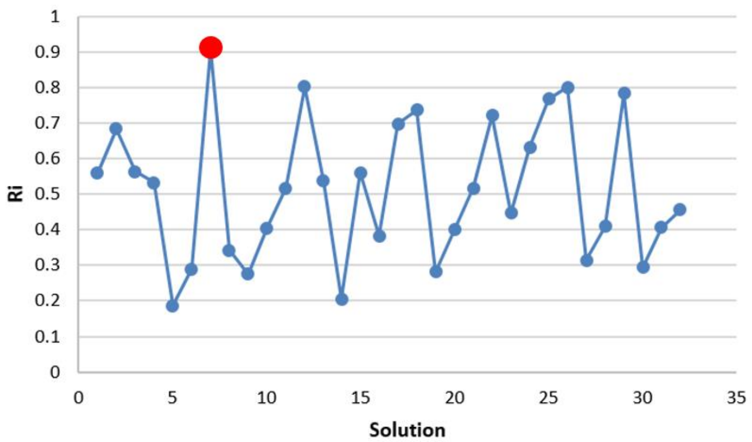

Figure 2. *Relation between solution and the value of R_i.*

5. CONCLUSIONS

The TOPSIS method was used in this paper to optimize the various input factors of the wire-EDM process when cutting 90CrSi tool steel. According to the study's findings, using alternative 7 can achieve the lowest surface roughness and highest cutting speed at the same time. Experiment 7 had the best performance feature of the 32 trials, with the highest utility function value (f(Ki)=0.1205). The TOPSIS technique determined that the best experimental setup for obtaining the lowest SR and highest CS is as follows: VM = 9 (V); T_{on} = 12 (s); T_{off} = 13 (s); SV = 25 (V); WF = 8 (mm/min.); SPD = 4.5 (mm/min.); R = 9 (mm). This result is suitable for selecting wire cutting mode for batch processing.

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TÓM TẮT

Ứng dụng kỹ thuật ra quyết định đa tiêu chí trong gia công cắt dây thép dụng cụ 90CrSi

Kết quả của một nghiên cứu về việc áp dụng kỹ thuật ra quyết định đa tiêu chí (MCDM) để lựa chọn các thông số đầu vào tốt nhất trong gia công cắt dây (EDM cắt dây) thép dụng cụ 90CrSi được trình bày trong bài báo này. Phương pháp TOPSIS được sử dụng trong nghiên cứu để giải bài toán MCDM và phương pháp Entropy được sử dụng để tính trọng số của các tiêu chí. Trong nghiên cứu này, sáu thông số đầu vào bao gồm điện áp xung VM, xung thời gian phát xung t on, thời gian ngắt xung t off, điện áp séc-vô SV, cường độ dòng điện xung WF, tốc độ tiến dao SPD và bán kính cắt phôi R đã được nghiên cứu. Ngoài ra, một thí nghiệm với thiết kế 2 7-2 với tổng cộng 32 lần chạy thử nghiệm đã được thực hiện. Bài toán MCDM đã được giải. Theo kết quả của nghiên cứu này, thiết lập thí nghiệm tốt nhất là thí nghiệm số 7 với các tham số đầu vào sau: VM = 9 (V), T_{on} = 12 (s), T_{off} = 13 (s), SV = 25 (V), WF = 8 (mm/phút), SPD = 4,5 (mm/phút) và R = 9 (mm).

Từ khóa: WEDM; MCDM; Phương pháp TOPSIS; Độ nhám bề mặt; Tốc độ cắt; Thép dụng cụ 90CrSi.