Manufacturing Rev. 9, 19 (2022)

https://doi.org/10.1051/mfreview/2022018

Manufacturing Review
Available online at:
https://mfr.edp-open.org

Research Article
Open Access

Multi-objects optimization in μ-EDM using AlCrN coated tungsten carbide electrode by Deng's method

Dong Pham Van[1], Shailesh Shirguppikar[2], Phan Nguyen Huu[1,*], Minh Nguyen Duc[1], Tai Bui Tien[1], Thanh Le Thi Phuong[1], and Ly Nguyen Trong[1]

[1] Hanoi University of Industry, No. 298, CauDien Street, Bac TuLiem District, Hanoi, Vietnam
[2] Department of Mechanical Engineering Department, RIT, Rajaramnagar affiliated to SUK, Maharashtra, India

Received: 9 January 2022 / Accepted: 26 May 2022

Abstract. In machining, the use of appropriate optimization method will significantly contribute in improving the economic and technical efficiency. Currently, there are many techniques used for multi-objective decisions in electrical discharge machining (EDM) and micro-EDM. This may create mistakes in choosing the optimal solution for each problem and mislead the optimum solution. Therefore, it is necessary to have research directions to be able to come up with a reasonable optimal method. In this study, the author has studied multi-targeting decisions in micro-EDM using coated electrode. Experiments were performed using Ti-6Al-4V as a workpiece material and AlCrN coated Tungsten carbide (WC) micro tool electrode. Deng's method was used to decide the optimized level of depth of machining (Z Co-Ordinate) and overcut (OC) in micro-EDM using the coated electrode. Research results are analyzed and evaluated with several other multi-objective decision methods. The results indicated that Deng's method was the suitable method for this study and the machined surface quality of the coated electrode was also analyzed.

Keywords: Micro-EDM / coated electrode / Deng' / s method

1 Introduction

Micro-sized products play an important role in many modern industries in fields such as medical, electro-electronics, aerospace, etc. Several traditional and non-communicative technological solutions have been used. Micro-EDM is the most used non-traditional technology solution, so the study of improving machining efficiency in micro-EDM is very important in the field of micro machining [1]. Improving machining productivity, machining accuracy and machining quality are the main current research directions in this field [2]. Several technical solutions have been introduced to achieve these goals, but the technical complexity of use and application costs are high and this has affected their application in practice [3–5]. Currently, research on optimizing technological parameters in micro-EDM and micro-EDM using coated electrodes is a promising research path with high potential [6–8]. Currently, micro-EDM using coated electrode is a technical solution that is of great interest. Therefore, studies to clarify this solution are very necessary.

Research results about EDM using coated electrodes have shown that proper use of coating materials will contribute to a significant improvement in electrode wear and this will lead to improved machining accuracy [9]. The Cu, brass and Cu-W electrodes in the EDM were coated with Nickel and Diamond, the results showed that the tool wear rate (TWR) of the coated electrode was significantly improved compared to that of the uncoated electrode [10]. Compared with the electrode coated with Nickel coated material, the Diamond coated electrode was able to produce better wear resistance of the electrode. Quality indicators in EDM for Ti-6Al-4V with Al_2O_3-TiO_2 coated electrode have been significantly improved, and TWR and overcut (OC) of the coated electrode are smaller than Cu electrode by 92% and 62.5%, respectively [11]. Three types of electrode materials including Al, Cu and Cu coated Al electrodes have been used in EDM, and EDM using coated electrode will bring high economic efficiency [12]. The results show that the Cu electrode has the highest machining efficiency, and the smallest is that of the Al electrode. In EDM, the use of silver coating on the surface of the Cu electrode resulted in a significant reduction of electrode wear [13]. Similar results were obtained when ZinC coating was used on the surface of the brass electrode in micro-EDM [14]. Surface roughness was also improved

* e-mail: nguyenhuuphan@haui.edu.vn

using MWCNT coated thin film micro tool electrodes. The use of coated electrodes has considerably enhanced the machining productivity and wear resistance of electrodes in EDM; the coating material is copper-based MWCNT composite. [15]. Compared to the Cu electrode, MRR is increased by 99.52% and TWR is reduced by 57.11%. Similar results were obtained in the study with EDM using nichroloy coated Cu electrode [16]. The coating material will directly affect the machining improvement efficiency in EDM [17]. In addition, the applicability of this method shall determine the optimal technological parameters and the quality of the coating on the electrode surface. Although the economic efficiency of Cu coated Gr electrode in EDM is improved compared to EDM using Cu electrode, the TWR of the coated electrode is smaller than that of the uncoated electrode. The machining productivity with Cu electrode is higher, and the difference between the machined surface quality of coated and uncoated electrode is not significant [18]. The mathematical model of SR in EDM using AlCrNi coated electrode has been determined [19]. However, the effectiveness of EDM using AlCrNi coated electrodes has not been evaluated. Compared with Cu electrode, the economic efficiency of EDM using coated Ak12 electrode has been improved by approximately 35% [20]. Surface quality is greatly enhanced following micro-EDM machining with a Boron – CVD diamond coated electrode. [21]. The dimensional accuracy in the micro-EDM with the Cu-ZrB2 coated electrode is much higher than that of the Cu electrode [22]. This shows that the TWR of the coated electrode is better. The TWR and OC of the micro-EDM using TiN coated WC electrode were reduced by 16.32% and 26%, respectively [23] and the machining productivity of the coated electrode is also improved. From the above research and survey results, it has been shown that EDM with coated electrodes can bring good economic efficiency in this machining field.

With the use of different coating materials, it will also change the spark formation conditions which will affect the EDM machining process. Therefore, research in order to determine the optimal technology parameters suitable for each type of coating material is very necessary. Many single and multi-item optimization techniques have been commonly used in EDM, and these techniques can also be suitable for micro-EDM. The computational technique of the Genetic Algorithm Method (GA) was used to build mathematical models of material removal rater (MRR), TWR and surface roughness (SR) in EDM for hybrid 7075Al [24]. The quality parameters at optimal conditions have been significantly improved. Similar results were obtained in the multi-objective problem of EDM for Al7075/B4C/Gr by Response surface methodology (RSM) – Technique for Order Preference by Similarity to Ideal Solution (Topsis) [25]. However, the number of experiments in empirical research determined through the RSM technique is quite large. Some research results have shown the effectiveness of the combination of the Taguchi method with some multi-objective decision techniques. And the simplicity of the combination of Taguchi – Utility in the multi-objective decision in EDM has contributed to overcome the above limitations [26]. The single-objective and multi-objective optimization problems in EDM are solved by Taguchi method and Taguchi – Grey relational analysis (GRA) [27]. The results show that they can be effective optimization tools in EDM. The number of experiments in the multi-objective optimization study of green EDM has been significantly reduced by the combined Taguchi – Topsis technique [28]. Using Topsis, the machining efficiency at optimal conditions is improved by 14.3% [29]. The quality parameters at the optimum condition of the Topsis method are higher than those optimized by some other methods (GRA, Preference selection index (PSI), etc.) [30]. Several quality parameters in EDM with coated and uncoated electrodes are simultaneously determined by multiple optimization methods [31]. The research results of each optimization problem depend on the input of each type of problem and the optimization method. Some research results have shown that Deng's method can produce higher multi-objective optimization than Topsis [32,33]. Therefore, it is necessary to have studies to determine the optimal results for each specific problem.

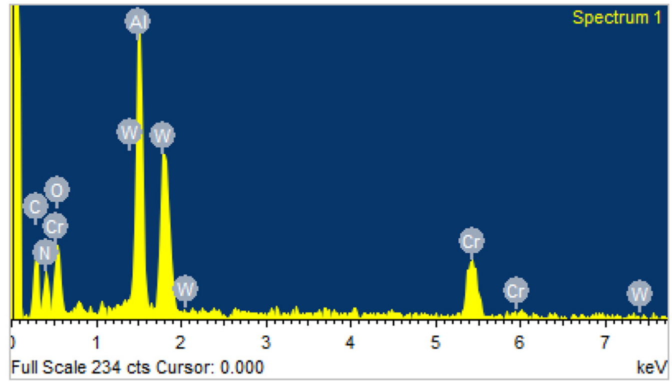

Fig. 1. EDX of aluminum chromium nitride thin film coating.

In this study, the author will study multi-target optimization in micro-EDM using coated electrode for Ti-6Al-4V workpiece. Taguchi – Deng's method is used for multi-objective decision making. The quality indicators used in this study include Z and Overcut (OC). Research results will be compared with some commonly used solutions in EDM and micro-EDM. Surface quality after micro-EDM with AlCrN coated electrode at optimal conditions is also analyzed and evaluated

2 Materials and experimental matrix

2.1 Experimental setup

The Tungsten carbide (WC) electrode is coated with Aluminum Chromium Nitride (AlCrN), and the coating thickness is 3385 μm. The coating characteristics are shown in Figure 1 and the diameter size of the coated electrode is 496.77 μm. Titanium alloy (Ti-6Al-4V) is widely used in several fields such as medical, aviation and nuclear, and it is chosen as the workpiece. The dielectric fluid is EDM oil, HD-1 dielectric fluid was used in this study and its properties are listed in Table 1. The micro EDM machine is the Hyper 10 Micro EDM. The technological

Table 1. Properties of HD-1 dielectric fluid.

Dielectric EDM Colour	Property Colourless
Viscosity at 40 °C (cSt)	2.25
Density at 15 °C(kg/l)	0.773
Flash point gap (^{0}c)	108
Pour point (^{0}c)	–27
Aromatics(%m)	<0.0

parameters are selected according to Table 2. The quality criteria including Z Co-ordinate (Z) and overcut (OC) were selected in the study. Z is directly related to machining productivity and OC will characterize machining accuracy. The Z Co-Ordinate was the reading related to the depth of the electrode in the drilled hole cavity which was shown on the screen by the machine. OC was determined through a SEM image analyzer.

2.2 Experimental matrix

Taguchi is used to set up the experimental matrix. This will reduce the time and cost of the experimental research process, because the number of experiments in Taguchi's matrix is minimal. The choice of the experimental matrix depends on the input parameter and the number of levels of the input parameter. Because they will determine the degrees of freedom of the matrix. In this study, the number of input parameters and the level of each parameter are equal to 3, so the degrees of freedom of the matrix is 8. Therefore, the suitable empirical matrix will be Taguchi's L9, Table 3. Experimental results are shown in Table 2 and Figure 2.

2.3 Deng's method for multi-criteria decision making

This method was proposed by Hepu Deng in 2007 and is said to be an appropriate solution that can overcome the limitations of the Topsis method. The steps to perform the calculation according to Deng's method are described in Figure 3 and as follows [33]:

Step 1. Sort the selected indicators in the matrix form:

$$X = \begin{bmatrix} x_{11} & x_{12} & . & x_{1j} & . & x_{1n} \\ x_{21} & x_{22} & . & x_{2j} & . & x_{2n} \\ . & . & . & . & . & . \\ x_{i1} & x_{i2} & . & x_{ij} & . & x_{in} \\ . & . & . & . & . & . \\ x_{m1} & x_{m2} & . & x_{mj} & . & x_{mn} \end{bmatrix} \tag{1}$$

x_{ij} – is the experimental value of the selected evaluation indicators (j – The number of indicators (j = 1–n), i – The number of experimental values of an indicator (i = 1–m).

Step 2. Normalize the determination matrix, convert the responses to nondimensional form to make comparisons between response values. The standardized matrix is established through standardized values $x'_{ij}\left(0 \le x'_{ij} \le 1\right)$.

Determine the normalized determination matrix with the normalized value x_{ij}' as (3).

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

$$X' = \begin{bmatrix} x' & x' & . & x' & . & x' \\ x' & x' & . & x'_{2j} & . & x' \\ . & . & . & . & . & . \\ x' & x' & . & x' & . & x' \\ . & . & . & . & . & . \\ x' & x' & . & x' & . & x' \end{bmatrix} \tag{3}$$

Step 3. Determine the weighted values of selected indicators (W_j). W_j is determined by the AHP method.

Step 4. Calculate the performance matrix by assigning the weight of quality indicators to the normalized matrix. The quality matrix is defined as follows:

$$A_{ij} = w_j.x'_{ij}$$

$$A = \begin{bmatrix} W_1 \times x_{11} & W_2 \times x_{12} & . & W_j \times x_{1j} & . W_n \times x_{1n} \\ W_1 \times x_{21} & W_2 \times x_{22} & . & W_j \times x_{2j} & . W_n \times x_{2n} \\ . & . & . & . & . \, . \\ W_1 \times y_{i1} & W_2 \times x_{i2} & . & W_j \times x_{ij} & . W_n \times x_{in} \\ . & . & . & . & . \, . \\ W_1 \times y_{m1} & W_2 \times x_{m2} & . & W_j \times x_{mj} & . W_n \times x_{mn} \end{bmatrix}$$

$$= \begin{bmatrix} y_{11} & y_{12} & \cdot & y_{1j} & \cdot \, y_{1n} \\ y_{21} & y_{22} & \cdot & y_{2j} & \cdot \, y_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \, \cdot \\ y_{i1} & y_{i2} & \cdot & y_{ij} & \cdot \, y_{in} \\ \cdot & \cdot & \cdot & \cdot & \cdot \, \cdot \\ y_{m1} & y_{m2} & \cdot & y_{mj} & \cdot \, y_{mn} \end{bmatrix} \tag{4}$$

A_{ij} – Value of quality indicator j in ith experiment; W_j – Weightage of the indicators; A – Quality matrix.

Step 5. Positive ideal solution (PIS) and negative ideal solution (NIS) are determined as follows:

PIS:

$$A^+ = \left\{\left(\max_i y_{ij}\middle|\in J\right), \left(\min_i y_{ij}\right)\middle| j \in J' | i = 1, 2, ..., n)\right\} \quad \text{(Best criteria)}$$

$$A^+ = \left\{y_1^+, y_2^+, , ...y_j^+, ..., y_n^+\right\} \tag{5}$$

NIS:

$$A^- = \left\{\left(\min_i y_{ij}\middle|\in J\right), \left(\max_i y_{ij}\middle| j \in J' | i = 1, 2, ..., n)\right\} \quad \text{(Worst criteria)}$$

Table 2. Process Parameters and Their Levels for Final Experiments.

Process parameters	Symbol	Units	Levels 1	2	3
Voltage	V	V	120	140	160
Capacitance	C	F	100 pF	1000 pF	10 nF
Spindle Rotation	RPM	rpm	200	400	600
Defreedom			2	2	2

Table 3. Experimental results with AlCrN coated micro tool electrode.

Expt. No.	Process parameters Voltage (V)	Capacitance (F)	RPM (rpm)	Response variables Z (mm)	Overcut (µm)
1	120	100 pF	200	0.66	58.37
2	120	1000 pF	400	1.42	27.71
3	120	10 nF	600	2.20	53.71
4	140	100 pF	400	0.95	62.45
5	140	1000 pF	600	1.43	32.97
6	140	10 nF	200	2.92	45.19
7	160	100 pF	600	1.72	74.12
8	160	1000 pF	200	1.49	60.93
9	160	10 nF	400	2.47	73.7

$$A^- = \left\{ y_1^-, y_2^-, , ..., y_j^-, ..., y_n^- \right\} \quad (6)$$

where $y_j^+ = \{\max_{j=1,2,3,...m}, y_m^{'}\}$ is the best value of x_j; $y_j^- = \{\min_{j=1,2,3,...m}, y_j^{'}\}$ is the worst value of x_j and and $A_i = \{y_1^{'}, y_2^{'}, ..., y_n^{'}\}$ $J^{'}$ is combined with good indicators; $J\prime$ is combined with bad indicators.

Step 6. Calculate the degree of conflict between each alternative: The degree of conflict between each alternative and positive ideal solution and the negative ideal solution can be calculated as follow:

$$A_j, A^{\pm} = |A_i||A^{\pm}|\cos\theta_i^{\pm}$$

$$A_j, A^{\pm} = \sum_{i=1}^{n} y_{\mathrm{ij}}^{'} y_i^{\pm}$$

$$|A_j| = \left(\sum_{i=1}^{n} y_{\mathrm{ij}}^{'2} \right)^{0.5}$$

$$A^{\pm} = \left(\sum_{i=1}^{n} y_{\mathrm{ij}}^{\pm 2} \right)^{0.5}$$

The conflict between the alternative and positive ideal solution can be obtained as:

$$\mathrm{Cos}\theta_i^+ = \frac{\sum_{i=1}^{n} y_{ij}.y_i^+}{\sqrt{\left[\sum_{i=1}^{n} y_{ij}^2\right]}\sqrt{\left[\sum_{i=1}^{n} y_{ij}^{+2}\right]}} \quad (7)$$

The conflict between the alternative and negative ideal solution can be obtained as:

$$\mathrm{Cos}\theta_i^- = \frac{\sum_{i=1}^{n} y_{ij}.y_j^-}{\sqrt{\left[\sum_{i=1}^{n} y_{ij}^2\right]}\sqrt{\left[\sum_{i=1}^{n} y_{ij}^{-2}\right]}} \quad (8)$$

Step 7. The degree of similarity and conflict between the alternative and the positive and negative ideal solutions are calculated as follows:

A degree of conflict:

$$|C_i| = \cos\theta_i^{-+} \times |A_i| \quad (9)$$

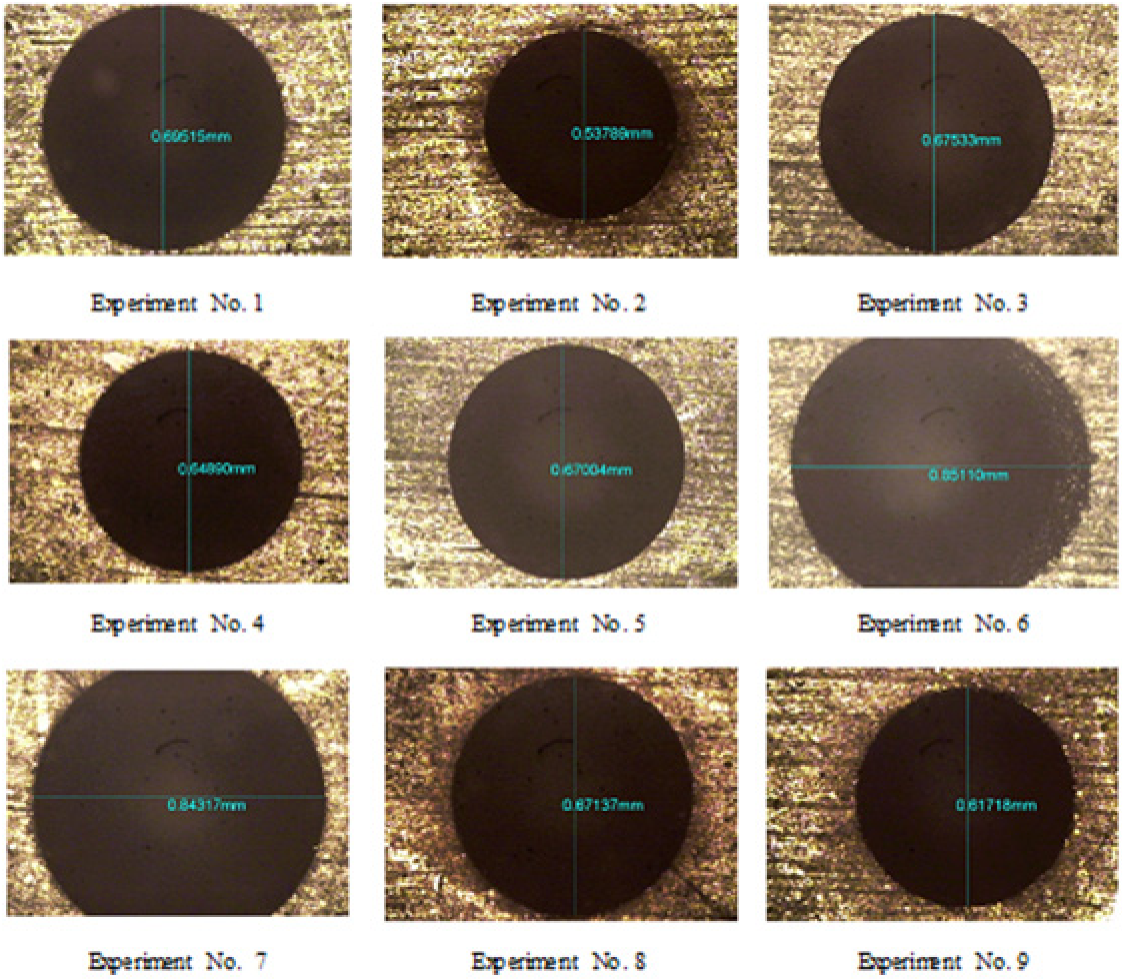

Fig. 2. Microscopic Images showing hole diameter.

A degree of similarity:

$$S_i^{-+} = \frac{|C_i|}{|A^{-+}|} = \frac{\cos\theta^{-+} \times |A_i|}{|A^{-+}|} = \frac{\cos\theta^{-+} \times \sqrt{\left(\sum_{i=1}^{n} y_{ij}^2\right)}}{\sqrt{\left(\sum_{i=1}^{n} y_j^{-+2}\right)}} \tag{10}$$

Step 8. Calculate the overall performance index:

The overall performance index for each alternative is calculated as follows:

$$P_i = \frac{S_i^+}{S_i^+ + S_i^-}, \quad i = 1, 2, ..., n; 0 \leq P_i \leq 1 \tag{11}$$

The larger the index value is, the more priority it will have.

Step 9: Rank according to Deng's similarity-based method. Higher Pi values will give good quality Ai solutions.

3 Results and discussion

3.1 Determine the best value by ranking of Deng's method

The steps and calculation formulas using Deng's method are described in detail in the document [33]. Applied with multi-target optimization in EDM using AlCrN coated electrode for Ti-6Al-4V with Z and OC quality criterias. The calculation steps are as follows:

Step 1: Build a matrix of quality indicators, according to the formula (1):

$$X = \begin{bmatrix} Z_1 & OC_1 \\ Z_2 & OC_2 \\ . & . \\ . & . \\ . & . \\ Z_9 & OC_9 \end{bmatrix}$$

Step 2: Data Normalization: The quality criteria decided in optimization problems are very different and they differ in both properties and units. Therefore, it is

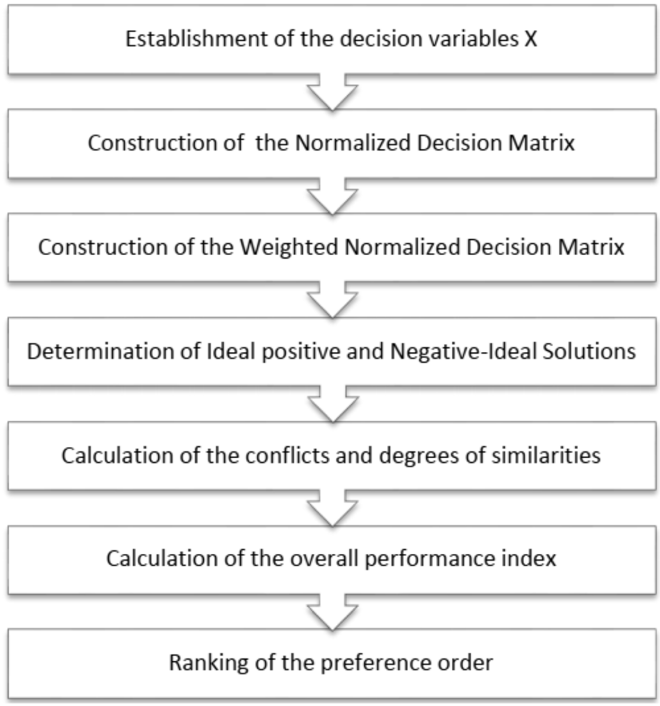

Fig. 3. The calculation steps of the multi-objective problem using Deng's method [33].

Table 4. Transformation matrix of quality criteria.

Exp. No	V	C	RPM	X'	
				z	OC
1	120	100 pF	200	0.120	0.344
2	120	1000 pF	400	0.259	0.163
3	120	10 nF	600	0.401	0.317
4	140	100 pF	400	0.173	0.368
5	140	1000 pF	600	0.261	0.195
6	140	10 nF	200	0.533	0.267
7	160	100 pF	600	0.314	0.437
8	160	1000 pF	200	0.272	0.359
9	160	10 nF	400	0.451	0.435

necessary to perform a normalization step to bring them to unitless quantities for calculation. Conversion values are determined according to formulas (2) and (3). The results of normalization in this problem are as shown in Table 4.

Step 3: The weight of the quality parameters (W_j): In the micro-EDM study, machining productivity and machining dimensional accuracy are important parameters. However, the significance level of Z is more important than that of OC in this study. W_j is determined by the AHP method. The weight values are $W_Z = 0.673$ and $W_{OC} = 0.327$.

Step 4: Assign the weight of the selected quality criteria to the normalized matrix and the values of the indicators are determined according to (4), Table 5.

Step 5: Identify the best solution and the worst solution: Positive ideal solution and the farthest from the negative ideal solution. Regarding formulas (5) and (6), determine the best solutions and the worst solutions, Table 6.

Step 6. Calculate the degree of conflict between each alternative: Its value is determined according to (7) and (8), and the received results are given in Table 7.

Step 7. The degree of similarity and conflict between the alternative and the positive and negative ideal solutions are calculated according to (9) and (10). The values are shown in Table 7.

Step 8. Calculate the overall performance index: The value of Pi is determined according to formula (11), and the value is given in Table 7.

Step 9. Ranking index by Deng's method: The results show that the 6th experiment received the largest Pi.

Table 5. Normalization matrix of quality criteria with weights.

Exp. No	V	C	RPM	y'	
				Z	OC
1	120	100 pF	200	0.081	0.113
2	120	1000 pF	400	0.174	0.053
3	120	10 nF	600	0.270	0.104
4	140	100 pF	400	0.117	0.120
5	140	1000 pF	600	0.176	0.064
6	140	10 nF	200	0.359	0.087
7	160	100 pF	600	0.211	0.143
8	160	1000 pF	200	0.183	0.118
9	160	10 nF	400	0.303	0.142

$W_Z = 0.673$ $W_{OC} = 0.327$.

Table 6. Positive ideal solution and negative ideal solution.

Solution	Quality criterion	
	Z	OC
A^+	0.359	0.053
A^-	0.081	0.143

Table 7. Calculating the conflict index and ranking the alternatives.

Exp. No	Cos θ^+	Cos θ^-	C^+	C^-	S^+	S^-	Pi	Rank
1	0.697	0.994	0.097	0.138	0.267	0.839	0.241	9
2	0.989	0.726	0.180	0.132	0.497	0.806	0.382	2
3	0.976	0.772	0.282	0.223	0.779	1.359	0.364	4
4	0.794	0.968	0.133	0.162	0.367	0.988	0.271	8
5	0.980	0.760	0.183	0.142	0.505	0.863	0.369	3
6	0.996	0.685	0.367	0.253	1.014	1.537	0.397	**1**
7	0.902	0.896	0.233	0.229	0.675	1.390	0.327	7
8	0.912	0.885	0.200	0.192	0.582	1.171	0.332	6
9	0.958	0.816	0.323	0.273	0.938	1.662	0.361	5

Therefore, the 6th experiment will give optimum efficiency is best, optimal process parameter (Tab. 3) will be $V = 140$ V, $C = 10$ nF, RPM = 200 rpm. The best quality characteristics are $Z = 2.92$ mm and OC = 45.19 μm.

3.2 Optimization of technological parameters by analysis of $S/NS/N$ ratio

The economic effect of using Taguchi method to design the experimental matrix is very clear. However, the number of experiments studied is very small, so the optimal result is most likely not within the value of 9 experiments in the matrix. Therefore, determining the optimal value by S/N analysis is very necessary. The results of the S/N analysis are shown in Figure 4. The results showed that the optimal set of technological parameters $V = 140$ V, $C = 10$ nF, RPM = 600 rpm, and it is different from them by the ranking of Pi. The analytical optimization parameter of S/N did not overlap with any of the 9 experiments of Taguchi's L9 matrix. The value of the quality criteria will be determined by formula (12) [12], Table 8. Experimental verification shows that the experimental value differs the most from the calculated value by 6.15%, which indicates that the calculated formula is appropriate. Comparison with the rating results shows that the results of the analysis by S/N have lower efficiency than those determined by the rating of Pi. Compared to the results of the Pi rating, the Z of the S/N analysis is reduced by 7.87% and the OC is increased by 9.09%.

(Z,OC)optimal=V2+C1+RPM3−2T (12)

Z: The value of Z at the optimum condition; OC: The value of OC at the optimum condition; T: Average of all observations; V_2: Average of all the value under columns having voltage value 140 V; C_1: Average of all the value

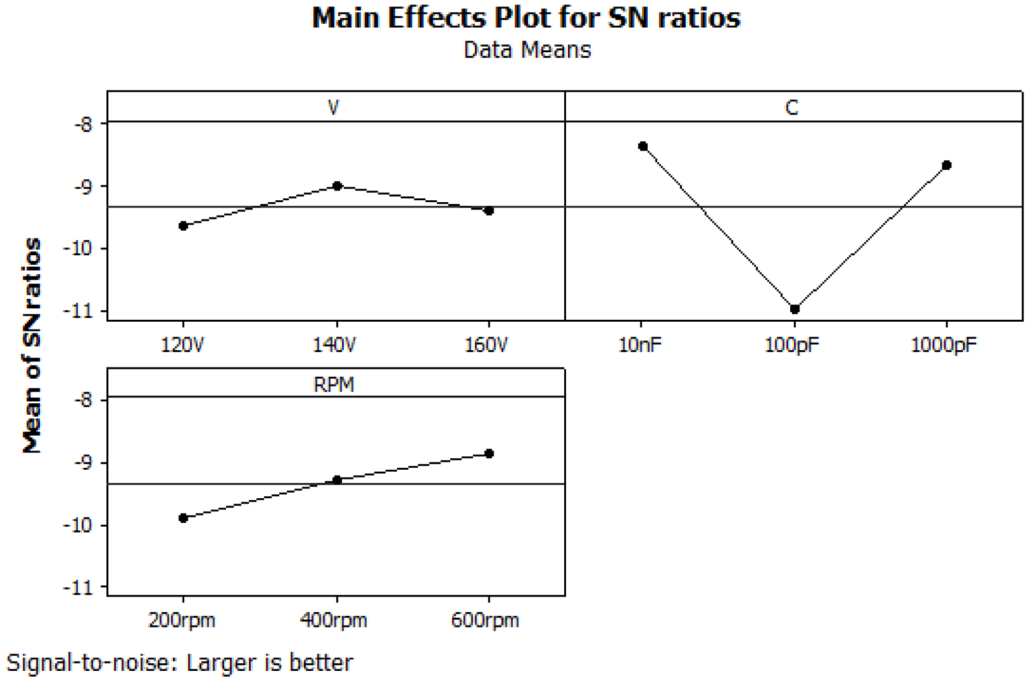

Fig. 4. S/N analysis of Pi ratio.

Table 8. Experimental results.

Qualify indicator	Optimal paramter	Optimal value Caculation	Experiment	Deviation (%)
Z (mm)	V =140 V, C = 10 nF, RPM = 600 rpm	2.69	2.71	0.74%
OC (μs)		49.30	52.33	6.15%

Table 9. Optimal results of methods by ranking.

Methods	Best exp.	Optimal value Z	OC
Deng's method	6st	2.92	45.19
GRA	1st	0.66	58.37
MOORA	5st	1.43	32.97
PSI	9st	2.47	73.7
TOPSIS	3st	2.20	53.71
VIKOR	1st	0.66	58.37
COPARS	5st	1.43	32.97

under columns having capacitance value 10 nF; RPM_3: Average of all the value under columns having spindle rotation value 600 rpm.

3.3 Analysis and assessment of the suitability of Deng's method

To evaluate the effectiveness of Deng's method used in this study, the author compared the results of several multi-objective decision methods commonly used in EDM with the results calculated by Deng's method, Table 9. Research results have shown that different multi-objective decision methods can give the same or different results. The results for MOORA and COPARS were the same, and the best results were obtained in the 5st experiment. The best results for GRA and VIKOR are similar, it is 1st experiment, and PSI and TOPSIS results are 9st and 3st experiment, respectively. Evaluation of the optimal results showed that

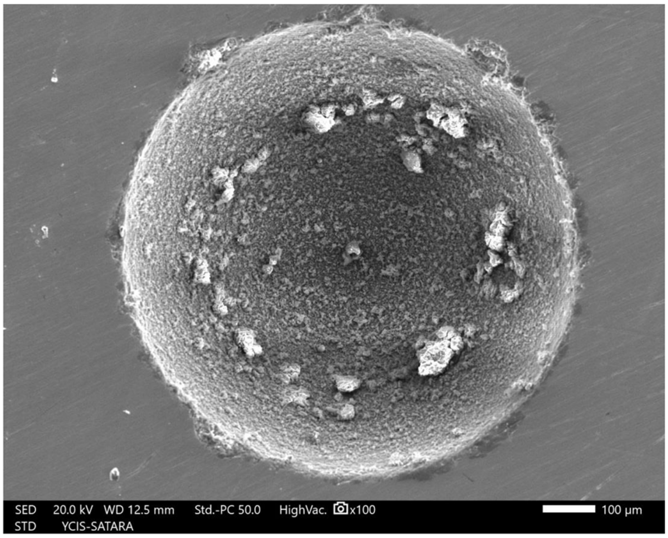

Fig. 5. SEM of hole after micro-EDM using AlCrN coated electrode

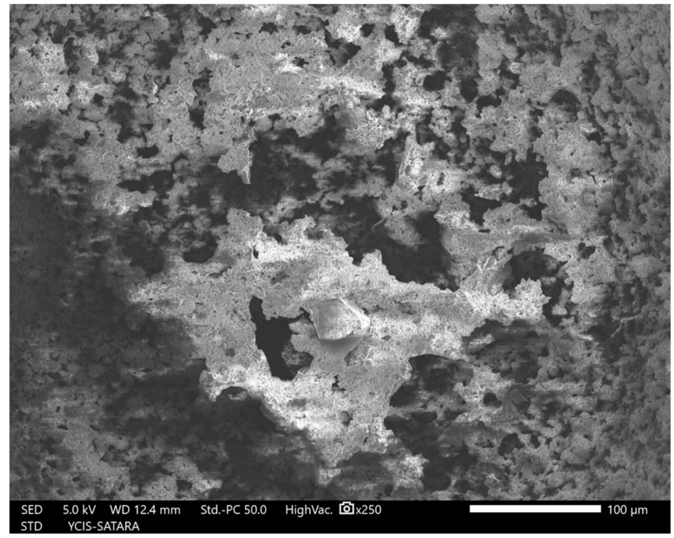

Fig. 7. SEM of structure of the machined surface after micro-EDM using AlCrN coated electrode.

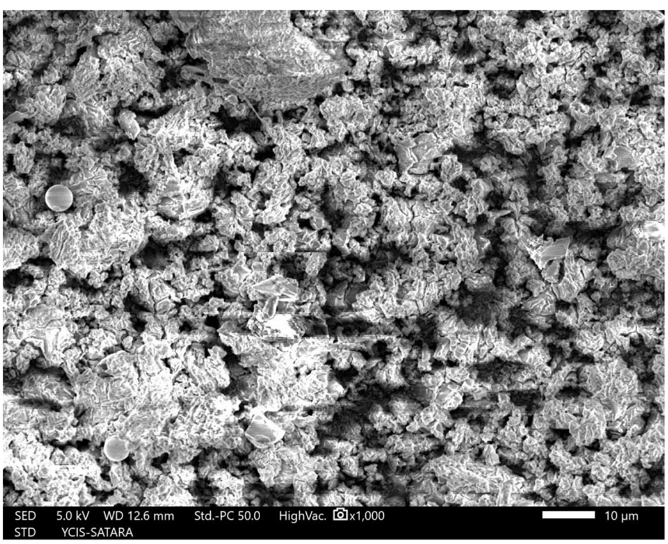

Fig. 6. SEM of Machined surface after micro-EDM using AlCrN coated electrode.

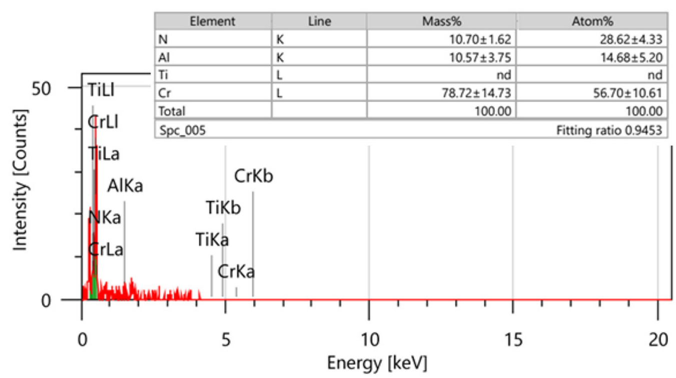

Fig. 8. EDX of machined surface after micro-EDM using AlCrN coated electrode.

the results in the 6th experiment would give higher machining efficiency, and this shows that Deng's method used in this study is appropriate.

3.4 Surface quality analysis after micro-EDM

The shape of the hole after machining is shown in Figure 5. The random appearance of sparks on the electrode surface and the energy of each spark is different, hence the edge of the hole is flawed which will affect the roundness of the machined surface [7]. There are many particles on the machined surface, and this will affect the surface texture after machining. The cause of the appearance of adherent particles on the machined surface is that the electrode and workpiece materials are melted and evaporated, and they are rapidly cooled by the dielectric solution [3]. However, they were not pushed out of the discharge gap by the dielectric solution. The shape and size of the adhesion particles are very different on the machined surface, and the density of the particles at different positions on the machined surface is uneven, Figure 6. The SEM image of the machined surface also shows that the number of particles adhering to the surface is very large. The microstructure of the machined surface is porous, and there are many voids above the machined surface, Figure 7. In addition, the EDX analysis of the machined surface also shows that the composition of the chemical elements of the machined surface layer is changed compared to the base layer, and electrode materials created a coating on the machined surface, Figure 8. The cause may be that the worn electrode material has penetrated into the machined surface, and this causes a change in the chemical composition of the machined surface [3]. The above changes will directly affect the working condition of the machined surface.

4 Conclusion

The results of the multi-target optimization study of the technological parameters in the micro-EDM for Ti-6Al-4V with AlCrN coated WC electrode gave the following conclusions:

– Taguchi combined with Deng's method is used in the research to find a suitable optimal set of technological parameters and this leads to reduced empirical research costs.
– Optimal technological parameters include V = 140 V, C = 10 nF, RPM = 200 rpm and quality characteristics at optimal conditions Z = 2.92 mm and OC = 45.19 μm.
– The selection of the optimal set of technological parameters should be based on the analysis and comparison of the effectiveness of the two ranking methods and the analysis of the S/N coefficient. This will aid in producing the greatest results.
– In comparison with the other multi-objective decision methods (GRA, MOORA, PSI, VIKOR, TOPSIS, COPARS), the results of Deng's method in this study are good. This shows that using Deng's method for multi-objective decision in this study is the most appropriate.
– It is necessary to compare and evaluate between methods to choose the reasonableness in using the optimal tool, and this will help choose the most reasonable set of optimal technology parameters possible.
– The quality of the machined surface after micro-EDM was analyzed, and the machined surface layer was significantly changed compared to the base material. In addition, the condition of the machined surface layer is also significantly changed which is necessary for further studies to clarify this change.

The work described in this paper was supported by Hanoi University of Industry (HAUI), Hanoi, Vietnam.

References

1. P.J. Liew, C.Y. Yap, J. Wang, T. Zhou, J. Yan, Surface modification and functionalization by electrical discharge coating: a comprehensive review, Int. J. Extrem. Manuf. **2** (2020) 012004
2. M.A. Ilani, M. Khoshnevisan, Mathematical and physical modeling of FE-SEM surface quality surrounded by the plasma channel within Al powder-mixed electrical discharge machining of Ti-6Al-4V, Int. J. Adv. Manuf. Technol. **112** (2021) 3263–3277
3. A. Taherkhani, M.A. Ilani, F. Ebrahimi et al., Investigation of surface quality in cost of goods manufactured (COGM) method of μ-Al2O3 powder-mixed-EDM process on machining of Ti-6Al-4V, Int. J. Adv. Manuf. Technol. **116** (2021) 1783–1799
4. M.A. Ilani, M. Khoshnevisan, Powder mixed-electrical discharge machining (EDM) with the electrode is made by fused deposition modeling (FDM) at Ti-6Al-4V machining procedure, Multiscale Multidiscip. Model. Exp. Des. **3** (2020) 173–186
5. M.A. Ilani, M. Khoshnevisan, Study of surfactant effects on intermolecular forces (IMF) in powder-mixed electrical discharge machining (EDM) of Ti-6Al-4V, Int. J. Adv. Manuf. Technol. **116** (2021) 1763–1782
6. J. George, R. Chandan, R. Manu et al., Experimental investigation of silicon powder mixed EDM using graphene and CNT nano particle coated electrodes, Silicon **13** (2021) 3835–3851
7. N.H. Phan et al., Material removal rate in electric discharge machining with aluminum tool electrode for Ti-6Al-4V titanium alloy, Adv. Eng. Res. Appl. (2020). https://doi.org/10.1007/978-3-030-64719-3_58
8. N.H. Phan et al., Tool wear rate analysis of uncoated and AlCrNi coated aluminum electrode in EDM for Ti-6Al-4-V titanium alloy, Adv. Eng. Res. Appl. (2020). https://doi.org/10.1007/978-3-030-64719-3_91
9. U.A. Danade, S.D. Londhe, R.M. Metkar, Machining performance of 3D-printed ABS electrode coated with copper in EDM, Rapid Prototyp. J. **25** (2019) 1224–1231
10. Y. Liu, W. Wang, W. Zhang, F. Ma, D. Yang, Z. Sha, S. Zhang, Experimental study on electrode wear of diamond-nickel coated electrode in EDM small hole machining, Adv. Mater. Sci. Eng. (2019) ID 7181237
11. J. Prasanna, S. Rajamanickam, Investigation of die sinking electrical discharge machining of Ti-6Al-4V using copper and AlO-TiO coated copper electrode, Middle-East J. Sci. Res. **24** (2016) 33–37
12. T.R. Ablyaz, E.S. Shlykov, S.S. Kremlev, Copper-coated electrodes for electrical discharge machining of 38X2H2MA steel, Russian Eng. Res. **37** (2017) 910–911
13. K. Karunakaran, M. Chandrasekaran, Investigation of machine-ability of Inconel 800 in EDM with coated electrode, IOP Conf. Series: Mater. Sci. Eng. **183** (2017) 012014
14. H. Hanizam, N. Mohamad, U.A.A. Azlan, M. Qamaruddin, Process optimization of EDM cutting process on tool steel using zinc coated electrode, MATEC Web Conf. **97** (2017) 01073
15. P. Mandal, S. Chandra Mondal, Performance analysis of copper-based MWCNT composite coated 316L SS tool in electro discharge machining, Mach. Sci. Technol. **25** (2021) 422–437
16. Sathyamangalam, T. Nadu, Effect of nichroloy coated electrode on machining performance of electrical discharge machining using Inconel 625, Mater. Today: Proc. **45** (2021) 7894–7900
17. A. Arthur, P. Dickens, C. Bocking, R. Cobb, Wear & failure mechanisms for SL EDM electrodes, International Solid Freeform Fabrication Symposium (1996) 175–190
18. N. Chindaladdha, D. Kaewdook, Performance of electro-plated copper coating on graphite electrode in EDM process, TNI J. Eng. Technol. **8** (2020)
19. N.H. Phan, P.V. Dong, T. Mthuramalingam, N.V. Thien, H.T. Dung, T.Q. Hung, N.V. Duc, N.T. Ly, Experimental investigation of uncoated electrode and PVD AlCrNi coating on surface roughness in electrical discharge machining of Ti-6Al-4V, Int. J. Eng. Trans. A: Basics **34** (2021) 928–934
20. T. Ablyaz, K. Muratov, S.B. Preetkanwal, S.S. Sarabjeet, Experimental investigation of wear resistance of copper coated electrode-tool during electrical discharge machining, IOP Conf. Series: Mater. Sci. Eng. **510** (2019) 012001
21. E. Uhlmann, S. Rosiwal, K. Bayerlein, M. Röhner, Influence of grain size on the wear behavior of CVD diamond coatings in micro-EDM, Int. J. Adv. Manuf. Technol. **47** (2010) 919–922
22. W. Yuangang, Z. Fuling, W. Jin, Wear-resist electrodes for micro-EDM, Chin. J. Aeronaut. **22** (2009) 339–342

23. S.S. Shirguppikar, M.S. Patil, Experimental investigation on micro-electro discharge machining process using tungsten carbide and titanium nitride-coated micro-tool electrode for machining of Ti-6Al-4V, S Adv. S Mater. S Process. Technolog. (2020) DOI: 10.1080/2374068X. 2020. 1833399
24. K. Ponappa, K.S.K. Sasikumar, M. Sambathkumar, M. Udhayakumar, Multi-objective optimization of EDM process parameters for machining of hybrid aluminum metal matrix composites (AL7075/TiC/B4C) using genetic algorithm, Surf. Rev. Lett. **26** (2019) 1950071
25. M. Kolli, A.V.S. Ram Prasad, D.S. Naresh, Multi-objective optimization of AAJM process parameters for cutting of B4C/Gr particles reinforced Al 7075 composites using RSM-TOPSIS approach, SN Appl. Sci. **3** (2021) 711
26. I. Nayak, J. Rana, Multi-response optimization in wire electrical discharge machining (WEDM) of D2 steel using utility approach, Manufactur. Rev. **8** (2021) 16
27. P. Antil, S.K. Antil, C. Prakash, G. Królczyk, C. Pruncu, Multi-objective optimization of drilling parameters for orthopaedic implants, Measur. Control **53** (2020) 1902–1910
28. R. Manivannan, M. Pradeep Kumar, Multi-response optimization of Micro-EDM process parameters on AISI304 steel using TOPSIS, J. Mech. Sci. Technol. **30** (2016) 137–144
29. R. Manivannan, M. Pradeep Kumar, Multi-attribute decision-making ofcryogenically cooled micro-EDM drilling process parameters using TOPSIS method, Mater. Manufactur. Processes **32** (2017) 209–215
30. H.-P. Nguyen, N.V. Ngo, Q. Nguyen, Optimizing process parameters in EDM using low frequency vibration for material removal rate and surface roughness, J. King Saud Univ. Eng. Sci. (2020). https://doi.org/10.1016/j.jksues.2020.05.002
31. N.H. Phan, P. Van Dong, H. Tien Dung, N. Van Thien, T. Muthuramalingam, S. Shirguppikar, N. Chi Tam, N. Trong Ly, Multi-object optimization of EDM by Taguchi-DEAR method using AlCrNi coated electrode, Int. J. Adv. Manuf. Technol. **116** (2021) 1429–1435
32. S.O.N. Raj, S. Prabhu, Analysis of multi objective optimisation using TOPSIS method in EDM process with CNT infused copper electrode, Int. J. Mach. Machinabil. Mater. **19** (2017) 76–94
33. H. Deng, A similarity-based approach to ranking multicriteria alternatives, in *Advanced Intelligent Computing Theories and Applications. With Aspects of Artificial Intelligence. ICIC 2007. Lecture Notes in Computer Science*, edited by D.S. Huang, L. Heutte, M. Loog (Springer, Berlin, Heidelberg, 2007), **4682**

Cite this article as: Dong Pham Van, Shailesh Shirguppikar, Phan Nguyen Huu, Minh Nguyen Duc, Tai Bui Tien, Thanh Le Thi Phuong, Ly Nguyen Trong, Multi-objects optimization in μ-EDM using AlCrN coated tungsten carbide electrode by Deng's method, Manufacturing Rev. **9**, 19 (2022)