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RESEARCH TO DETERMINE THE BEST VALUE OF BOTH Z AND OVC IN MICRO-EDM USING CARBON COATED ELECTRODE USING TOPSIS METHOD

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Abstract

In the machining process, it is difficult to solve problems due to the relationship between productivity and quality, for example, as the productivity increases, the quality of reprocessing may decrease. Some methods only address specific objectives, such as the quality of the machining method, the machining productivity, the quality, or even the cost. Electrical discharge machining (EDM) and micro-EDM are most commonly used for processing the surfaces of die and moulds. The amount of electrode wear in micro-EDM has a direct effect on the dimensional accuracy of the machined hole. Therefore, improving the corrosion resistance of electrodes in micro-EDM is still of great interest. The effective coating of thin film for the micro tool electrodes in the case of micro-EDM can lead to minimize the electrode wear which eventually improve the productivity and machining quality. In the present study, experiments were performed on micro-EDM using carbon coated tool electrode and optimized using Taguchi-Topsis to investigate optimum levels of Depth of cut (*Z*) and overcut (*OVC*). It was concluded that optimum conditions had improved significantly using carbon coated micro tool electrode. Optimal levels of technological parameters include $V = 160$ V, $C = 10000$ pF, $RPM = 400$ rpm, and $Zopt = 2.525$ mm, $OVCopt = 61.718$ µm. The quality of the machined surface with the coated electrode at optimal conditions is analyzed and evaluated. The Topsis method is a suitable solution to this problem, and the steps to perform the calculation in this technique are simple.

Keywords: Micro, EDM, coated, electrode, Topsis, Al, OVC, Z, Carbon, Taguchi.

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1. Introduction

A crucial component in engineering sectors like aerospace and implant biomedicine is titanium alloy (Ti-6Al-4V). The most used technique for machining titanium alloys (Ti-6Al-4V) is EDM, specifically micro-EDM. In micro-EDM machining, productivity and dimensional accuracy are crucial quality factors technical specialists are very interested in the simultaneous development of these quality metrics. Coated electrode micro-EDM is a fairly new method, and it shows great promise for increasing micro-EDM machining efficiency. However, various materials have distinct impacts on the machining quality parameters when utilized to cover the electrode surface in micro-EDM. Currently, the number of studies of micro-EDM with coated electrode is very small. Therefore, research results in micro-EDM with coated electrode are published, and it will contribute to clarifying the influence of coating material on the micro-EDM machining process.

Recently published research results in micro-EDM with coated electrode have shown that the coating material used in micro-EDM has a significant influence on the spark discharge process during material removal process. At the same time, the economic efficiency in using electrode materials has also been significantly improved. The Cu coated Al electrode resulted in a reduction in the cost of the electrode material by approximately 2.85 times [1]. Even though, the cost of the electrode coating process also needs to be evaluated for the economic viability of this technique. MRR, TWR, HV and topography of machined surface in EDM with Cu coated electrode – MWCNT base is significantly improved [2]. Materials of coating alloys including Cu and MWCNT have been found on the machined surface layer, and this will affect the mechanical, physical and chemical properties of the workpiece surface. Cu electrode with Ag-coated material in EDM resulted in increased MRR, and decreased TWR and SR [3]. This contributes to improve machining performance in EDM. Comparing the performance of Cu and Ag electrode coating materials in micro-EDM machining with WC electrode has shown that the MRR of Cu coated WC is the largest, MRR of Ag coated WC electrode is the 2nd smallest, and the MRR and TWR of the WC electrode are the smallest [4]. The results were compared with the WC electrode, the TWR of the TiN coated electrode is reduced by 16.32 % and the OVC of the coated electrode is reduced by 26 %, and the machining efficiency of coated electrode is improved by approximately 18.9 % [5]. The research articles were published on coated electrode which focused on comparing the efficiency of TiN, Ag and ZrN coated electrodes in micro-EDM showed that TiN coated electrode is the most suitable [6]. The EWR and OVC of the TiN coated electrode are the smallest, and they are the largest with the Ag coated electrode. The characteristics of melting, electrical and thermal conductivity of different materials, will affect the EDM process with coated electrodes differently [7]. The effective layer of Cu coating with Gr electrode by plating method, it provided to a improvement in the SR values of the machined surface, and this solution can be effectively used in finishing machining processes [8]. The values of TWR and overcut (OVC) in EDM with Al_2O_3-TiO_2 coated Cu electrode were significantly reduced, and the comparison between coated and uncoated electrodes showed that the TWR of the coated electrode decreased by 92 % and the OVC of the coated electrode decreased by 62.5 % [9]. The TWR of the Cu-ZrB_2 coating electrode is much smaller than that of the uncoated electrode [10]. Parallel results were obtained with the ZniC coated Cu electrode in the EDM for Inconel alloy IN718 [11]. Results with the TiAlN coated electrode were compared and it was observed that the machining efficiency of TiN coated electrode was higher [12, 13]. However, the number of optimal research results in this area is still very small [14]. Research using multi-objective decision in micro-EDM is very necessary, it will promote the application of this technology in practice.

In this study, Simultaneous determination of Z and OVC in micro-EDM using carbon coated electrode for Ti-6Al-4V was performed. Optimal technological parameters were determined in this multi-objective problem, and the surface quality after the micro-EDM with the coated electrode at optimal conditions was analyzed and evaluated. Topsis is combined with Taguchi to solve multi-objective problems.

2. Materials and methods

The carbon coated WC electrode was used in the study, and the coating thickness of the electrode is approximately 10 microns. The micro-EDM machine used in the experimental study is the Hyper 10 micro-EDM, and the rotating speed of the main shaft of the machine is in the range of 300–3000 rpm. The dielectric fluid is EDM oil, and the workpiece material is titanium alloy (Ti-6Al-4V). Quality indicators including Z and OVC were used in the study. The table of technological parameters in the micro-EDM selected in the study is as **Table 1**.

Table 1
Experimental results with carbon coated micro tool electrode

Ex. No.	Process parameters			Response variables	
	Voltage (V)	Capacitance (pF)	*RPM* (rpm)	*Z* (mm)	*OVC* (μm)
1	120	100	200	0.6521	60.079
2	120	1000	400	1.232	30.344
3	120	10000	600	2.072	59.237
4	140	100	400	0.791	89.322
5	140	1000	600	1.399	41.297
6	140	10000	200	2.377	60.725
7	160	100	600	1.472	100.988
8	160	1000	200	1.307	67.213
9	160	10000	400	2.391	119.632
Tổng trung bình (T)				1.521	69.871

Taguchi method is a widely used method in EDM and Micro-EDM studies because the number of experiments is very small, and the levels of the parameters are selected arbitrarily. Taguchi method was used to design the experiment in this study, and the experimental results are shown in **Table 1**. However, the multi-objective decision results determined by Taguchi are very complex, so combining Taguchi with other multi-objective techniques is the solution being used commonly. In this study, Taguchi-Topsis was used to decide simultaneously Z and OVC in micro-EDM using carbon coated electrode. The TOPSIS methodology gives more practical models because the optimal indicators are allowed to trade off in this method, where good results received for one indicator would imply poor results in other indicators. The number of experiments performed in the Taguchi method is very small, so the optimal results in this study may not belong to the experiments investigated. Therefore, the optimal value needs to be determined by S/N factor analysis.

3. Results and discussion

3. 1. Determine the experiment with the best results by Topsis's method

Step 1. Criteria matrix:

$$X = \begin{bmatrix} Z_1 & OVC_1 \\ Z_2 & OVC_2 \\ \cdots & \cdots \\ \cdots & \cdots \\ \cdots & \cdots \\ Z_9 & OVC_9 \end{bmatrix}.$$

Step 2. Normalize the criteria matrix (**Table 2**).

Table 2
Normalized data

Exp. No	Voltage (V)	Capacitance (pF)	*RPM* (rpm)	Vector normalization	
				X_Z	X_{OVC}
1	120	100	200	0.1329	0.2675
2	120	1000	400	0.2512	0.1351
3	120	10000	600	0.4224	0.2638
4	140	100	400	0.1613	0.3977
5	140	1000	600	0.2852	0.1839
6	140	10000	200	0.4846	0.2704
7	160	100	600	0.3001	0.4497
8	160	1000	200	0.2665	0.2993
9	160	10000	400	0.4874	0.5327

Step 3. Criteria weights: The Analytic Hierarchy Process (AHP) method is used in this study because of its simplicity and good accuracy. The following results $W_Z = 0.667$ and $W_{OVC} = 0.333$. The weight assignment with the quality criteria, and calculation results in **Table 3**.

Step 4. The best solution (A^+) and the worst solution (A^-): the result is as follows $A^+ = \{Z = 0.325; OVC = 0.045\}$ and $A^- = \{Z = 0.089; OVC = 0.117\}$.

Step 5. Calculation S_i^+ and S_i^-: the results are as shown in **Table 3**.

Step 6. Calculation C^*: these results in **Table 3**.

Step 7. Ranking: the ranking results are as shown in **Table 3**.

*The best experiment: analysis of the ranking results in **Table 3** showed that $C_4^* < C_1^* < C_7^* < C_8^* < C_2^* < C_5^* < C_9^* < C_3^* < C_6^*$. This shows that the 6th exp. is the best. The best results of the multi-objective decision problem in this study are as follows $V = 140$ V, $C = 10000$ pF and $RPM = 200$ rpm, and $Z = 2.377$ mm, $OVC = 60.725$ µm.

Table 3
Calculation results in Topsis and S/N ratio values

Exp. No.	y'_Z	y'_{OVC}	y^+_Z	y^+_{OVC}	y^-_Z	y^-_{OVC}	S_i^+	S_i^-	C_i^*	Ranking	*S/N* ratio
1	0.089	0.089	–0.236	0.044	0.000	–0.088	0.2405	0.0883	0.269	8	0.269
2	0.168	0.045	–0.158	0.000	0.079	–0.132	0.1576	0.1541	0.494	5	0.494
3	0.282	0.088	–0.043	0.043	0.193	–0.090	0.0610	0.2128	0.777	2	0.777
4	0.108	0.132	–0.218	0.087	0.019	–0.045	0.2345	0.0487	0.172	9	0.172
5	0.190	0.061	–0.135	0.016	0.102	–0.116	0.1359	0.1543	0.532	4	0.532
6	0.323	0.090	–0.002	0.045	0.235	–0.087	0.0451	0.2503	0.847	1	0.847
7	0.200	0.150	–0.125	0.105	0.111	–0.028	0.1631	0.1149	0.413	7	0.413
8	0.178	0.100	–0.147	0.055	0.089	–0.078	0.1572	0.1182	0.429	6	0.429
9	0.325	0.177	0.000	0.132	0.236	0.000	0.1324	0.2365	0.641	3	0.641

3. 2. Determination of the optimal results by analysis of *S/N*

The *S/N* value is determined by formula (1). **Fig. 1** has shown that the optimal technological parameters performed by Topsis include V = 160 V, C = 10000 pF, RPM = 600 rpm, **Table 4**.

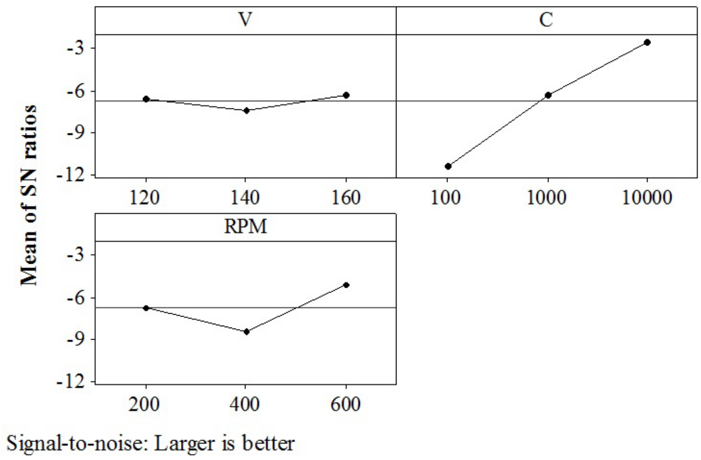

Fig. 1. Analysis of *S/N* of Topsis

Table 4
Multi-objective optimization results

Methods	Process parameters	Quality indicators	Results		Deviation (%)
			Cal.	Exp.	
Topsis	V = 160 V, C = 10000 pF, RPM = 600 rpm	Z (mm)	2.407	2.525	4.90
		OVC (µm)	60.078	61.718	2.75

Compared with the calculated results of Z and OVC, the experimental results of Z and OVC have good accuracy:

$$(Z, OVC)_{opt} = V_3 + C_3 + RPM_3 - 3 \cdot T. \quad (1)$$

3. 3. Machined surface quality at optimum conditions

The dimensions of the machining hole after the micro-EDM using coated electrode at optimal conditions are shown in **Fig. 2**. The surface of the machined hole consists of adherent particles, **Fig. 3**. The cause may be that the chip particles have not been pushed out of the discharge gap between the electrode and the workpiece by the dielectric solution [14]. **Fig. 4** shows that the shape and size of the adhesion particles are very variable, and they are distributed arbitrarily on the surface of the workpiece. This may be due to the random occurrence of sparks during the machining process, and the energy of each spark is not the same. Pores and cracks appear on the surface of the workpiece micro-EDM using coated in a significant amount, **Fig. 5**. These phenomena will significantly affect the roughness and working characteristics of the machined surface layer.

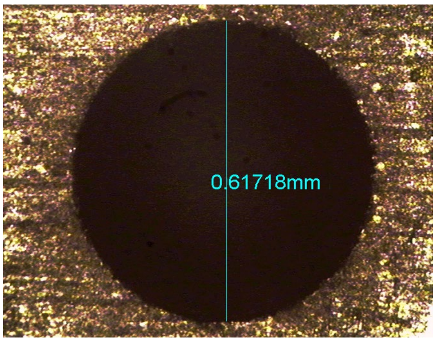

Fig. 2. Dimensions of the machining hole

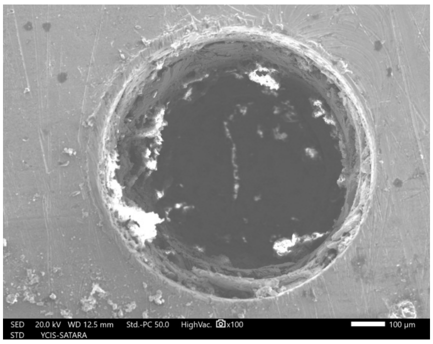

Fig. 3. SEM ×100 of machining hole

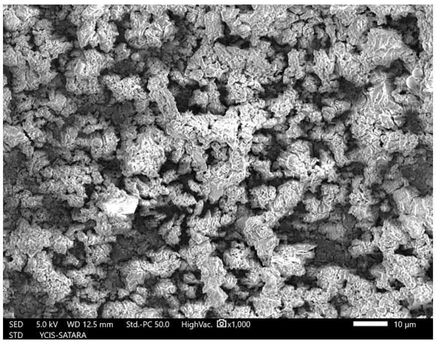

Fig. 4. Topography of machined surface

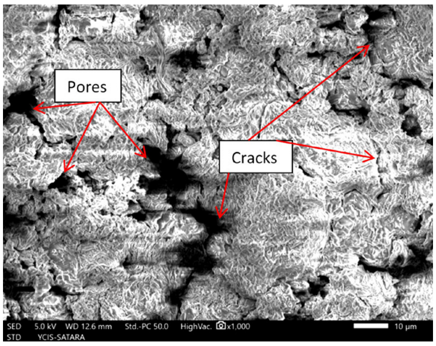

Fig. 5. Cracks on machined surface

4. Conclusions

The quality indicators in the micro-EDM using carbon coated WC electrode include *Z* and *OVC*, they were decided simultaneously by Taguchi-Topsis.

The results of the study came to the following conclusions:

– Taguchi-Topsis were utilized to optimize the levels of process parameters and it was observed that Taguchi-Topsis is a very simple technique and easy to implement on any system;

– compared with the good result calculated by the rating, the optimal result by *S*/*N* is better;

– the optimal technology parameters include $V = 160$ V, $C = 10000$ pF, $RPM = 600$ rpm and $Z_{opt} = 2.525$ mm, $OVC_{opt} = 61.718$ µm;

– surface quality at optimum condition includes some defects such as microcracks, adherent particles and many subtle voids;

– further studies are needed to clarify the effectiveness of using carbon coated electrodes in micro-EDM processing.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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The study was performed without financial support.

Data availability

Manuscript has no associated data.

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