

Multi-criteria decision making in electrical discharge machining with nickel coated aluminium electrode for titanium alloy using preferential selection index

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Abstract. In the present scenario, great effort is expended to improve the machining process by adopting multi-criteria decision making in electrical discharge machining (EDM). In this research article, an attempt was made to optimize the process parameters of EDM with Nickel Coated Aluminium Electrode for machining Titanium Alloy using Preference Selection Index (PSI). The experimental work were performed using Taguchi based L16 orthogonal to solve multi-objective optimization problem. The current (I), voltage (U) and pulse on time (T_{on}) were used as input response variables for investigation process while material removal rate (MRR) and tool wear rate (TWR) were selected as performance measures. The experimental results show that set of optimized parameters of the multi-objective optimization problem in EDM with nickel coated aluminium electrode could improve the machining with better surface measures with less deviation from the prediction. The combination between PSI and Taguchi method reduced and saved significantly the experimental time and cost and increased accuracy for optimization process.

Keywords: EDM / PSI / Taguchi

1 Introduction

Electrical discharge machining (EDM) is widely used among all non-traditional machining method for the machining of moulds [1,2]. It is highly effective with complex shapes made from materials that are difficult to achieve using traditional machining methods [3,4]. The machining productivity and surface quality are main limitations of such process [5]. The large number of process parameters with wide range makes high difficult to optimize process parameters in EDM [6]. Hence the optimization for improving machining productivity and machined surface quality in EDM is still attracting the attention of many researches and experts [7–10]. Using coated electrode in EDM is a new research direction, its results are very feasible in practice and industrial manufacturing [11,12]. The results of studies in this direction are few. The optimization algorithms can enhance the performance measures in manufacturing processes [13].

The invention of newer electrode materials with improved mechanical and chemical properties can enhance the productivity, quality of machined surface and accuracy machining in EDM. The utilization of coated electrodes in EDM process is still an engaging research area to overcome the limitations of this machining method. The micro-hardness (HV) of the machined surface has been enhanced by 163% compared to the base material layer [14]. As compared to the uncoated electrode, the microscopic cracks formed on the machining surface in EDM using Cu-MWCNT coated electrode could be significantly reduced. Compared to the EDM using uncoated electrode, the use of a 5 micrometer coating with silver on the Cu in EDM electrode surface resulted in a significant increase in MRR of 26.8%, a sharp drop of TWR by 25%, dimensional accuracy and surface quality is significantly improved [15]. Using electrodes with different coating materials, it will give very different machining efficiency in EDM. Compared to the nickel coated electrode, the TWR in EDM using diamond-nickel coated electrode has been significantly enhanced [16]. And the diameter size accuracy in EDM using coated electrode is higher than it with

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uncoated electrode. TiN and TiAlN were used to coat the surface of Cu electrode in EDM [17]. Compared to the uncoated Cu electrode, the machining efficiency of the coated electrode is better, and the TiN coated electrode is better than the TiAlN coated electrode. And EDM using TiN coated electrode is suitable for finishing. Coating material has been found on the machined surface layer, which is capable of improving the surface layer after EDM using coated electrodes [18]. The use of coated electrodes has resulted in a drop in the cost of the electrode, and this will contribute in improving the economics of the EDM machining process [19]. Electrodes coated in EDM are a new technology solution, which requires further research in this area including optimization of technological parameters, the types of coating materials used, coating thickness on electrode surface, etc. [20]. The material is used to coat the surface of the electrode, it alters the properties of mechanical and physical chemistry of the material layer of electrode surface. It can affect the process of spark formation in the discharge gap. It will affect the selection of technology parameters to enhance the machining process in EDM. Hence, it is essential to determine optimal technological factors for each new material coated on the electrode surface for improving machining efficiency in EDM.

Recently, some researches have shown that combining Taguchi with other methods such as GRA (Grey Relational Analysis), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), PSO (Particle Swarm Optimization), etc. can simultaneously optimize multi-objective in EDM [21]. Taguchi – GRA was used to simultaneously optimize the MRR, TWR and overstriation expenditures in μ -EDM [22,23]. However, the study of simultaneous optimization of MRR and surface roughness (R_a) in EDM by Taguchi – TOPSIS has higher efficiency than it using Taguchi – GRA [24].

Among the researches of optimization processes in EDM, some quality characteristics in EDM using Taguchi – TOPSIS also presented in [25]. The quality parameters are optimized including MRR, R_a , dimensional accuracy. The results showed that among the process parameters (such as I , U , T_{on}), U has the strongest influence (42.42%) and T_{on} has lowest influence (11.13%). In multi-objective optimization, TOPSIS is a simple and powerful method [26]. At the same time, this method allows to consider quantitative and qualitative factors, so this solution can be approached in favor of multi-objective decision which is more favorable [27]. The quality parameters in μ -EDM were simultaneously optimized by Topsis [28–30]. The influence of process parameters has been presented. Optimum results of productivity, surface quality and machining accuracy in EDM were determined by the TOPSIS method [31,32]. The value of the weights of the quality criteria taken in the jar is a limitation of PSI, which may not be suitable for many practical cases [33]. However, the mechanism of EDM using coated electrode is very new and its application is very small, so it is extremely difficult to determine its importance in practice [34,35]. Therefore, PSI is the appropriate solution for this study. This paper showed that the optimal results are better than some other methods such as Taguchi, GRA etc. [36]. The above

Table 1. Elements in nickel coating.

Element	Weight%	Atomic%
Cr K	18.84	20.77
Ni K	81.16	79.23
Totals	100.00	100.00

research results have shown that the solutions used in the multi-objective optimization problem in EDM have achieved certain results [37]. However, the value of the weights of the defined criteria is difficult for optimization process. Recently, the PSI method has been introduced for multi-objective optimization in machining methods [38]. This method does not require determining the weight of the criteria, so the optimization problem will be solved much simpler. Few research results have shown that PSI method is a multi-objective decision solution with higher efficiency than that of TOPSIS, GRA, etc. [39,40]. Taguchi-DEAR method can provide simplest methodology [41,42]. However, the accuracy is still to be enhanced. Whereas GRA could need knowledge of selecting proper design of experiments and Grey coefficient [43,44]. It was found that TOPSIS method, GRA and GRA Fuzzi can be suitable for thin film coated electrode EDM process [45,46].

It can be seen that the researches in the EDM field focusing on the application of titanium Nickel coated electrodes are very few and there are many problems that need to be studied, especially determining the optimal process parameters to increase productivity, quality and reduce cost of products in EDM. Based on above literature review, this paper studied on multi-criteria decision making in EDM with Nickel coated Aluminium electrode for Titanium alloy material using PSI to find out optimized quality indicators including MRR and TWR. Process parameters including U , I , T_{on} were selected for optimization process. To reduce experimental time and cost and increase accuracy, Taguchi – PSI methods was used to design experimental and perform multi-objective optimization process. Section 2 is dealt with experimental methodology and Section 3 is discussed with interpretation of results. Section 4 is discussed with the derived conclusion for the experimental results.

2 Experimental methodology

2.1 Experimental setup

The CNC-AG40L Machine (Sodick, Inc. USA) was used to perform the experiment with Titanium alloy (Ti-6Al-4V) material. Such technique can be proposed to manufacture complex shape mould and dies in manufacturing industries using EDM process. The characteristics of the mold steels are indicated in Table 1 with size of work-piece of $15 \times 15 \times 5$ mm. Nickel coated Aluminium electrode was selected for investigation in the study. The coating for electrode can efficiently enhance the surface performance measures in EDM process [47]. The shape of electrode is cylindrical with 10 mm in diameter and 35 mm in length, as shown in



Fig. 1. Thin film nickel coated electrode.

Figure 1. Table 1 and Figure 2 shows EDAX of copper coating and it was evident that presence of copper material in coating. The dielectric solution used in the present study was HD-1 oil [48]. This is the type of oil used quite commonly in the fields of pulse machining today in Vietnam. AJ 203 electronic balance (Shinko Denshi Co. LTD – Japan) was used to measure the weight of the workpiece and electrode before and after machining. The maximum weight that the scale can weigh is 200 g, with an accuracy of 0.001 g. The measurement were taken 3 times of measurements on each test sample and the average value were considered as final values to enhance the measurement accuracy [47].

2.2 Build the experimental matrix by Taguchi method

The choice of the experimental design matrix in Taguchi depends on the number of technological parameters and its levels examined. In this study, three process parameters (U , I and T_{on}) and the levels of each parameter have been selected, as shown in Table 2. And the degrees of freedom of the experimental matrix are 9. Thus, Taguchi's experimental design table is L16 [11]. The experimental matrix and results are shown as Table 3 and Figure 3.

2.3 Multi-objective optimization using PSI

The main steps of the PSI for solving MCDM problems include several steps, as follows:

Step 1: Determine the objective of the problem and select the evaluation criteria to ensure the objective, and select the empirical matrix related to the decision-making problem under consideration.

Step 2: Build the initial decision matrix from the initially selected criteria. If the number of experiments is m and the number of indicators is n , then the decision matrix of $m \times n$ can be represented by equation (1) [40]:

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

Step 3: In multi-objective problems, it is required to make the values of the criteria non-unit. Therefore, these values will be converted to 0 and 1, and this conversion

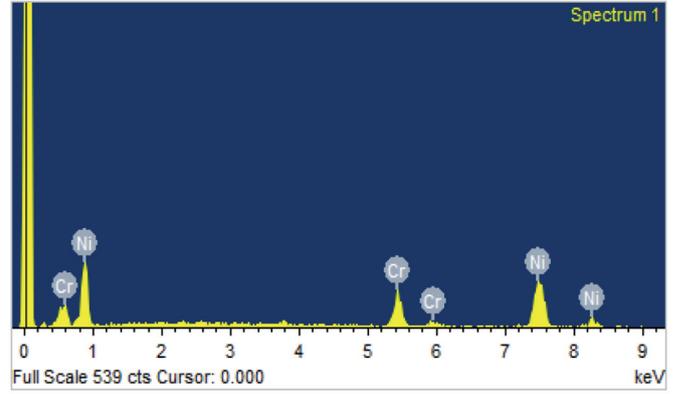


Fig. 2. EDAX Report of nickel coating tool electrode.

process is called normalization. If the indicator is larger, then it is normalized according to the formula (2a) [40]:

$$x'_{ij} = \frac{x_{ij}}{x_{ij}^{\max}}, \quad i = 1, \dots, m. \quad (2a)$$

If the indicator is smaller, it is better, it will be normalized according to the equation (2b):

$$x'_{ij} = \frac{x_{ij}^{\min}}{x_{ij}}, \quad i = 1, \dots, m \quad (2b)$$

where x_{ij} is values of the indicators at row i and column j ($i = 1, 2, 3, \dots, m$ and $j = 1, 2, \dots, n$). Decision matrix is normalized by equation (2a) and (2b) according to objective of problem.

Step 4: Compute the mean value of the normalized data (N): In this step, the average value of the normalized indicators can be calculated by equation (3), as follows [40]:

$$N = \frac{1}{n} \sum_{i=1}^m x'_{ij}. \quad (3)$$

Step 5: Compute the preference variation value (ϕ_j): The optional variable value among indicators is calculated using equation (4) [40]:

$$\phi_j = \sum_{i=1}^m (x'_{ij} - N)^2. \quad (4)$$

Step 6: Determine the deviation in preference value (Ω_j): Determine the deviation of the value of the priority relating to each criterion using equation (5) [40]:

$$\Omega_j = 1 - \phi_j. \quad (5)$$

Step 7: Compute the overall preference value (W_j): In this step, the overall priority value is determined for each criterion using equation (6) [40]:

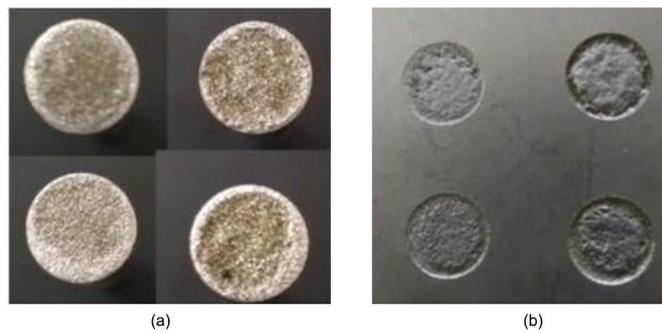
$$W_j = \frac{\Omega_j}{\sum_{j=1}^n \Omega_j}. \quad (6)$$

Table 2. Process parameters in the experiment.

Parameters	Symbol	Unit	Levels				DOF
			1	2	3	4	
Peak current	I	A	10	20	30	40	3
Gap voltage	U	V	40	45	50	55	3
Pulse on time	T_{on}	μs	100	500	1000	1500	3
Total							9

Table 3. Experimental results.

Expt. No.	Current (A)	Gap Voltage(V)	Pulse on time(μs)	MRR(mm^3/min)	TWR(mm^3/min)
1	10	40	100	0.033	0.015
2	10	45	500	0.040	0.019
3	10	50	1000	0.026	0.022
4	10	55	1500	0.020	0.019
5	20	40	500	0.046	0.019
6	20	45	100	0.066	0.022
7	20	50	1500	0.066	0.030
8	20	55	1000	0.066	0.037
9	30	40	1000	0.079	0.030
10	30	45	1500	0.086	0.033
11	30	50	100	0.099	0.048
12	30	55	500	0.113	0.048
13	40	40	1500	0.093	0.037
14	40	45	1000	0.113	0.048
15	40	50	500	0.139	0.067
16	40	55	100	0.139	0.070

**Fig. 3.** Images of electrode and workpiece. (a) Electrode surface; (b) Workpiece surface.

In addition, the sum of the overall priority values of all criteria must satisfy the equation (7) [40]:

$$\sum_{j=1}^n w_j = 1. \quad (7)$$

Step 8: Compute the preference selection index (θ_j): The preference selection index was calculated for each experiment using equation (8) [40]:

$$\theta_j = \sum_{j=1}^n x_{ij} \cdot w_j. \quad (8)$$

Step 9: Select the appropriate alternative for the given application: Based on the priority index value to rank, the ranking must be done according to the descending value of θ_j . The experiment with the largest value θ_j is the greatest, it will be the best solution (optimal solution).

2.4 Analyzing and optimizing

Analyze experimental results: The experiment with the highest value of S/N coefficient will give the optimal result that is least affected by noise. S/N is used to determine the level for optimal output. The S/N coefficients of the outputs are determined as follows [43]:

– *The higher the better:*

$$(S/N)_{HB} = -10 \log(\text{MSD}_{HB}) \quad (9)$$

$$\text{where } \text{MSD}_{HB} = \frac{1}{r} \sum_{i=1}^r \left(\frac{1}{y_i} \right).$$

MSD_{HB} – average square deviation; r – number of the tests in an experiment (*repeating times*); y_i – experimental values; – standard value is the best:

$$(S/N)_{NB} = -10 \log(\text{MSD}_{NB}) \quad (10)$$

$$\text{where } \text{MSD}_{NB} = \frac{1}{r} \sum_{i=1}^r (y_i - y_0)^2$$

MSD_{NB} – average square deviation; y_0 – standard value or target value.

– *The lower the better:*

$$(S/N)_{LB} = -10 \log(\text{MSD}_{LB}) \quad (11)$$

$$\text{where } \text{MSD}_{LB} = \frac{1}{r} \sum_{i=1}^r y_i^2$$

MSD_{LB} – average square deviation; $\sum_{i=1}^r y_i^2$ – sum of the squares of all the results of each experiment.

Optimizing outputs: Optimized value (μ) is estimated by the strong influence parameters and is determined by equation (12), as follows:

$$\mu_{A_2, B_3, C_3} = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_3 - \bar{T}) + (\bar{C}_3 - \bar{T}). \quad (12)$$

where \bar{C}_3 – average value at levels A_2 , B_3 , C_3 .

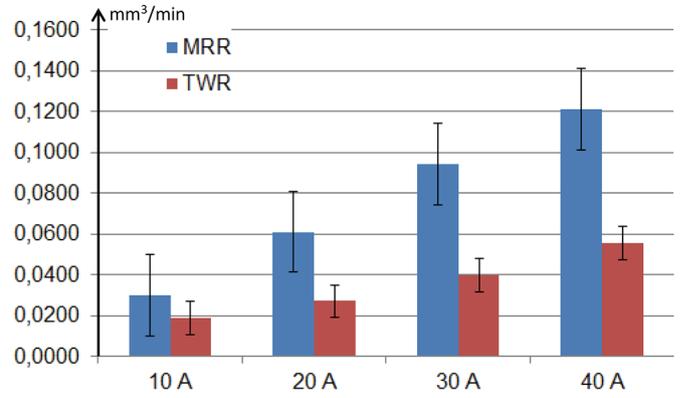


Fig. 4. Effect of I on MRR and TWR in EDM using coated electrode.

3 Results and discussion

3.1 Effect of process parameters on quality criterias

Effect of current (I): MRR and TWR also increase when current (I) increases, as shown in Figure 4. MRR and TWR change significantly when current (I) changes. Comparing with $I = 10$ A, increase of MRR was 306.7% and TWR is 196.0% at $I = 40$ A. This problem comes from the increase of current (I), therefore, energy which was used to machine increases. So, energy of electrical sparks increases significantly. Therefore, electrode and work-piece material which are melt and vaporized also increase. Comparing EDM using Aluminium (Al) electrode, effects of current (I) to quality criteria in EDM using coated electrode is better and MRR in EDM using coated Al electrode is higher and TWR is smaller [48]. This shows that Nickel coated layer affects well to machining efficiency using EDM.

Effect of voltage (U): Effects of voltage (U) to MRR and TWR is the same effects of current (I), as shown in Figure 5. However, change of MRR and TWR by voltage (U) is lower. Comparing with $U = 40$ V, increase of MRR and TWR at $U = 55$ V is 34.6% and 72.4%, respectively. This problem comes from the change of voltage (U), it will affect to energy of sparks and energy which break the insulation of the dielectric solution, and this energy increases when voltage (U) increases. However, increase of voltage (U) affects badly to EDM machining process using coated electrode because increase of MRR is smaller than increase of TWR [48]. So, electrode life will be decreased, machining accuracy is low. Results showed that Nickel is affected significantly.

Effect of pulse on time (T_{on}): Figure 6 shows that T_{on} affects to MRR and TWR in EDM using coated electrode. The results also show that MRR and TWR decrease significantly when T_{on} increases. Comparing with $T_{on} = 10$ μ s, decrease of MRR and TWR in EDM using coated electrode are 21.4% and 23.2% comparing with $T_{on} = 1500$ μ s, respectively. This problem comes from the increase of T_{on} , therefore, particles removing time and

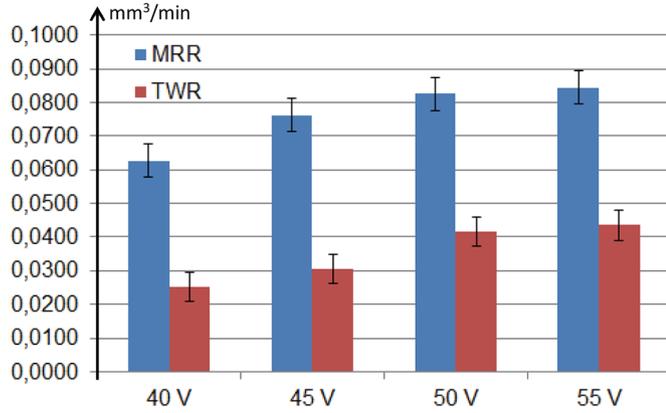


Fig. 5. Effect of U on MRR and TWR in EDM using coated electrode.

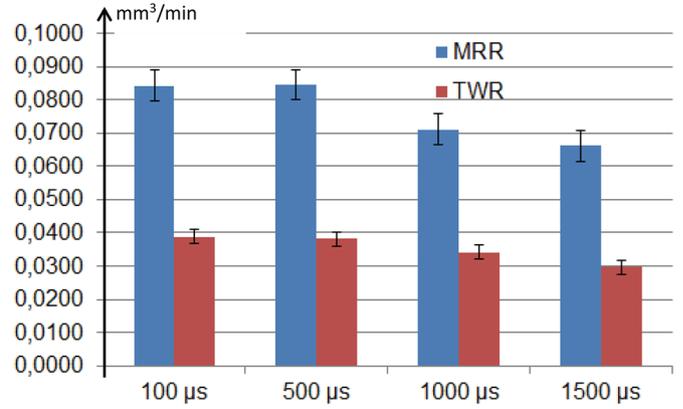


Fig. 6. Effect of T_{on} on MRR and TWR in EDM using coated electrode.

Table 4. Normalization results.

No	I	U	T_{on}	x'_{ij} (MRR)	x'_{ij} (TWR)
1	10	40	100	0.2374	1.0000
2	10	45	500	0.2878	0.7895
3	10	50	1000	0.1871	0.6818
4	10	55	1500	0.1439	0.7895
5	20	40	500	0.3309	0.7895
6	20	45	100	0.4748	0.6818
7	20	50	1500	0.4748	0.5000
8	20	55	1000	0.4748	0.4054
9	30	40	1000	0.5683	0.5000
10	30	45	1500	0.6187	0.4545
11	30	50	100	0.7122	0.3125
12	30	55	500	0.8129	0.3125
13	40	40	1500	0.6691	0.4054
14	40	45	1000	0.8129	0.3125
15	40	50	500	1.0000	0.2239
16	40	55	100	1.0000	0.2143

dielectric solution affected by sparks are reduced. They make instability in machining using EDM, short circuit cycle and the phenomenon of electric arc discharge appear with the larger frequency. Therefore, the energy of the useful sparks is reduced. And this is the main cause which reduces machining productivity, and TWR is also reduced at the same time. Compared with EDM using Al electrode, MRR and TWR were more strongly affected by the change of T_{on} with Nickel coated electrode [48] because the Nickel coated layer is strongly influenced by T_{on} .

3.2 Multi-criteria decision

Calculation process using PSI:

Step 1: With the goal of simultaneously improving productivity and surface quality, two criteria including MRR and TWR will be selected for investigation (MRR

will be increased; TWR will be reduced). The experimental results of the two indicators were surveyed according to Taguchi's L16 matrix, as shown in Table 2.

Step 2: Building the matrix of the investigated criteria, according to equation (1), we have:

$$X = \begin{bmatrix} \text{MRR}_1 & \text{TWR}_1 \\ \text{MRR}_2 & \text{TWR}_2 \\ \vdots & \vdots \\ \text{MRR}_{16} & \text{TWR}_{16} \end{bmatrix}. \quad (13)$$

Step 3: Standardization of the indicators: MRR is normalized according to equation (2a) and TWR is normalized according to equation (2b), the results are shown in Table 4.

Table 5. The values of conversion parameters and priority index.

No	N	ϕ MRR	ϕ TWR	ϕ_j	Ω_j	W _j	θ_j	Ranking	SN of θ_j
1	0.619	-0.381	0.381	0.291	0.709	0.050	0.062	11	-24.1522
2	0.539	-0.251	0.251	0.126	0.874	0.062	0.067	9	-23.4785
3	0.434	-0.247	0.247	0.122	0.878	0.062	0.054	15	-25.3521
4	0.467	-0.323	0.323	0.208	0.792	0.056	0.052	16	-25.6799
5	0.560	-0.229	0.229	0.105	0.895	0.063	0.071	5	-22.9748
6	0.578	-0.103	0.103	0.021	0.979	0.069	0.080	1	-21.9382
7	0.487	-0.013	0.013	0.000	1.000	0.071	0.069	8	-23.2230
8	0.440	0.035	-0.035	0.002	0.998	0.071	0.062	12	-24.1522
9	0.534	0.034	-0.034	0.002	0.998	0.071	0.075	2	-22.4988
10	0.537	0.082	-0.082	0.013	0.987	0.070	0.075	3	-22.4988
11	0.512	0.200	-0.200	0.080	0.920	0.065	0.067	10	-23.4785
12	0.563	0.250	-0.250	0.125	0.875	0.062	0.070	6	-23.0980
13	0.537	0.132	-0.132	0.035	0.965	0.068	0.073	4	-22.7335
14	0.563	0.250	-0.250	0.125	0.875	0.062	0.070	7	-23.0980
15	0.612	0.388	-0.388	0.301	0.699	0.049	0.061	13	-24.2934
16	0.607	0.393	-0.393	0.309	0.691	0.049	0.059	14	-24.5830

Step 4 to step 8: The results are calculated according to the equations (3)–(8). The values of the calculated results are shown in Table 5.

Step 9: Based on index calculation results of PSI, it shows that the 6th experiment will give the largest value, as shown in Figure 7. This will be the experiment that gives the most reasonable results with the set of process parameters. Optimal values are follows: $U = 45$ V, $T_{on} = 100$ μ s, $I = 20$ A.

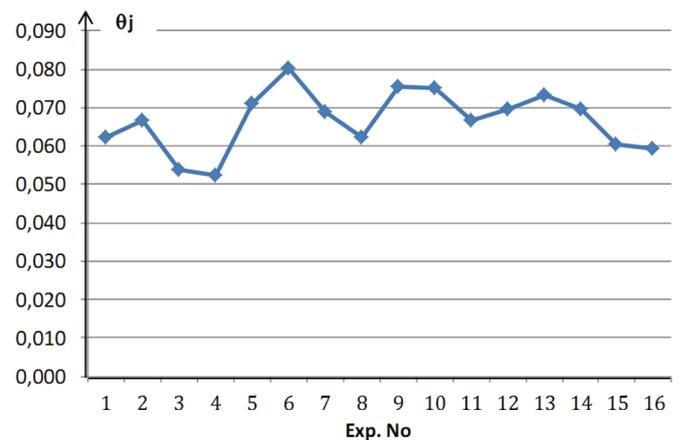
Determining the optimal set of parameters

The results of the S/N analysis of θ_j are shown in Figure 8. The results show a reasonable set of process parameters including $U = 45$ V, $I = 30$ A, $T_{on} = 500$ μ s. The value of the quality criterias at optimal conditions is determined according to (12), and the exact optimal value is determined by equation (14). The accuracy of the calculated results and the experimental results are consistent and the maximum error of the calculated results is 9.01%, as shown in Table 6.

$$(\text{MRR}, \text{TWR})_{\text{OPT}} = I_3 + U_2 + T_{\text{on}2} - 2.T. \quad (14)$$

3.3 Machined surface in EDM with optimization processes

Electrical Discharge Machining (EDM) is a finished machining method in shaped operations of a product. However, machined surface in EDM often appears a lot of defects such as transformation of workpiece surface layer comparing background material layer, micro cracks, particle adhering on surface and empty holes appearing on surface layer. The cause comes from machining

**Fig. 7.** Ranking PSI index.

mechanism of EDM. This method uses heat energy of sparks to melt and vapour workpiece and electrode material. Therefore, machined surface in EDM is often machined lastly using grinding or polishing operation. So, machined surface quality in EDM using coated electrode will affect significantly to cost and time of the last finished machining operation. Analyzing results of machined surface in EDM using Nickel coated electrode is shown in Figures 9–11. Craters, pores and micro cracks are distributed randomly on machined surface, as shown in Figure 9. Micro cracks are formed by high heat of sparks which causes the material of workpiece surface to evaporate and melt, and this material layer is cooled rapidly by dielectric solution. In EDM, pores are formed by air bubbles which exist in dielectric solution, it is intrusive on workpiece surface in machining process. The particles

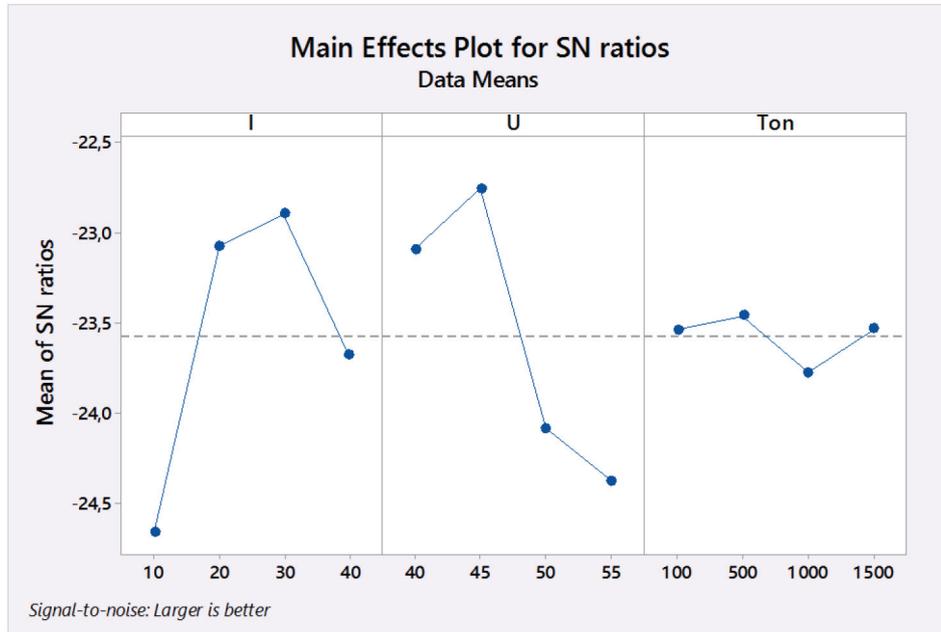


Fig. 8. Chart of main effects for S/N ratios of θ_j .

Table 6. Confirmation of experimental results of PSI method.

Machining characteristics	Optimal parameters	Optimal value	Difference	
		Cal. Value	Exp. Value	(%)
MRR (mm^3/min)	$U = 45 \text{ V}, T_{\text{on}} = 500 \mu\text{s}, I = 30 \text{ A}$	0.088	0.096	9.01%
TWR (mm^3/min)		0.029	0.027	6.9%

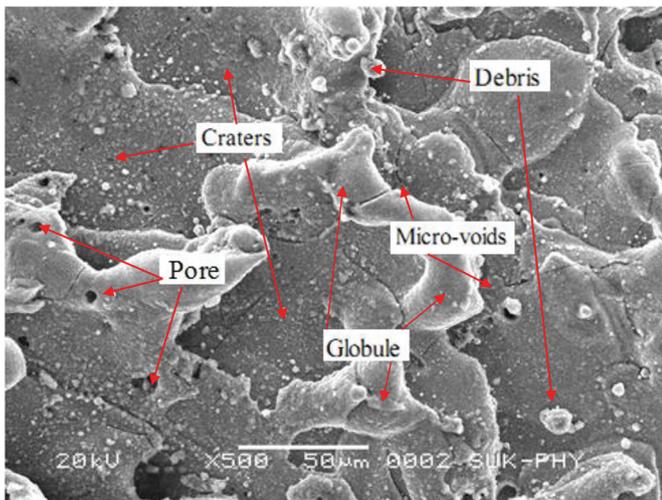


Fig. 9. Topography of machined surface.

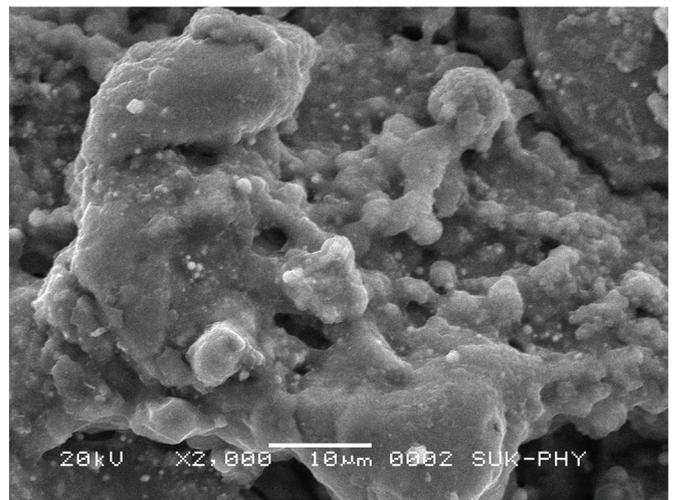


Fig. 10. Defects on the machined surface.

adhere to the machined surface, they include two types which are the fastened adhesion and the weak adhesion particles. The fastened adhesion particles are formed by melting and vapouring of workpiece material and a part of electrode material and they are cooled rapidly by dielectric

solution. They are recasted intermediately on machined surface. The weak adhesion particles (Globules) are formed by melting and vapouring of particles of workpiece and electrode material which are removed out surface of workpiece and electrode but they are pushed out spark

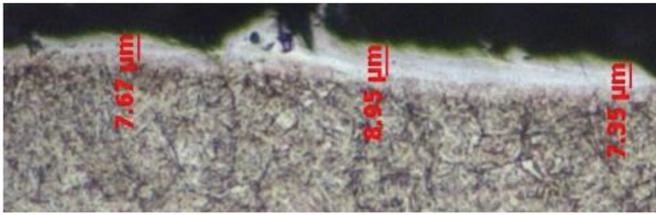


Fig. 11. White layer thickness of machined surface.

gap by dielectric solution. There are a lot of empty holes on machined surface, so its structure is porous, as shown in Figure 10. This affects to work ability of machined surface. A white layer is also formed on machined surface, as shown in Figure 11. It is necessary to remove this layer out the surface of workpiece using finished machining methods. Cut depth of finished machining methods has to be larger than thickness of white layer ($\geq 9 \mu\text{m}$).

4 Conclusions

In present study, an attempt was made to optimize EDM process with Nickel Coated Aluminium Electrode for machining Titanium Alloy using PSI (Preference Selection Index). The current (I), voltage (U) and pulse on time (T_{on}) were used as input variables for investigation process. From the experimental results, the following conclusions were drawn:

- Current (I) is the parameter which affects significantly to MRR and TWR in EDM using coated, U and T_{on} is parameter which affects insignificantly.
- The optimal set of process parameters was found as $U = 45 \text{ V}$, $T_{on} = 500 \mu\text{s}$, $I = 30 \text{ A}$. The optimal indicator values were found as $\text{MRR} = 0.076 \text{ mm}^3/\text{min}$ and $\text{TWR} = 0.016 \text{ mm}^3/\text{min}$ with deviation of 9.09%.
- It has proved that PSI is an effective method to solve multi-objective optimization in the field of EDM in particular and other machining technologies.
- Another research direction which needs attention is the optimal methods which needs to give results with high accuracy and are suitable for production practice.
- The surface quality after EDM using coated electrode is good but amount of material removal during the process is less ($\approx 7.79 \mu\text{m}$).

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