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Process Parameter Optimization in EDM using Ni Coated Electrode for MRR and Ra Using Taguchi Method and TOPSIS for Titanium Alloy

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Abstract

Currently, using coated electrodes in EDM is a new technology, and the effectiveness of this technical solution in improving the EDM machining process has been proven by recently published results. However, research to determine the optimal set of process parameters in EDM with coated electrodes is very necessary, because it will contribute to improving the efficiency of using this technology in practice. In this article, the optimal process parameters in EDM with Nickel Coated Electrode for Ti-6Al-4V have been determined. The Topsis method is used to solve the multi-objective problem in this study. The problem experimental work was performed using Taguchi based L16 orthogonal to solve multi-objective optimization. The current (I), voltage (U) and pulse on time (Ton) were used as input response variables for investigation process while material removal rate (MRR) and surface roughness (SR) were selected as performance measures. The experimental results show that the optimal process parameters of the multi-objective decision problem in EDM with Nickel Coated Electrode include U = 40 V, I = 40 A, Ton = 1000 µs, resulting in an MRR of 0.028 mg/ min and an SR of 7.56 µm. The combination between TOPSIS and Taguchi method has contributed to reducing the time and cost of experimental research.

Keywords*:* EDM; TOPSIS; 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 µ 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 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 process 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 process 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 (Ra) in EDM by Taguchi - TOPSIS has higher efficiency than it using Taguchi - GRA [24]. Few research results have shown that PSI method is a multi-objective decision solution with higher efficiency than that of TOPSIS, GRA, etc. It was found that TOPSIS method, GRA and GRA Fuzzi can be suitable for thin film coated electrode EDM process.

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 SR. Process parameters including U, I, Ton 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. The section 2 is dealt with experimental methodology and section 3 is discussed with interpretation of results. Section 4 is discussed with the derived conslusion 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 Ti-6Al-4V. Size of work-piece of 15x15x5 mm. Nickel coated Aluminum electrode was selected for investigation in the study. The shape of electrode is cylindrical with 10 mm in diameter and 35 mm in length, as shown in Figure 1. Figure 2 shows EDAX of nickel coating and it was evident that presence of nickel material in coating. The dielectric solution used in the present study was HD-1 oil.

Measuring tools to determine quality indicators: 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 200grams, with an accuracy of 0.001grams. Ra of machined workpiece surface was measured by contact type surface roughness tester (Taylor Hobson machine) with the cut off length of 0.8mm. 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.

Figure 1. Thin film nickel coated electrode

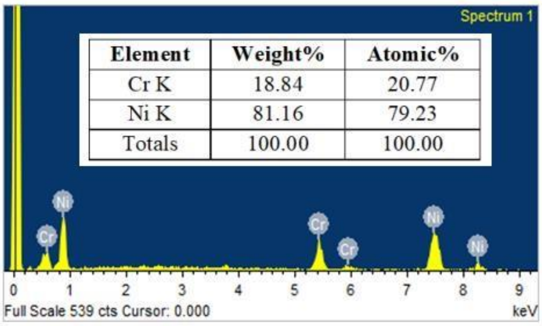

Figure 2. EDAX Report of nickel coating tool electrode

2.2. Build the experimental matrix by Taguchi method

The choice of the experimental design matrix in Taguchi depends on the number of process parameters and its levels examined. In this study, three process parameters (U, I and Ton) and the levels of each parameter have been selected, as shown in Table 1. And the degrees of freedom of the experimental matrix are 9. Thus, Taguchi's experimental design table is L16. The experimental matrix and results are shown as Table 2.

Table 1. 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	Ton	µs	100	500	1000	1500	3
Total							9

Table 2. Experimental results

Expt. No.	**Current (A)**	**Gap Voltage (V)**	**Pulse on time (µs)**	**MRR (mm^3/min)**	**SR (µm)**
1	10	40	100	0.033	6.918
2	10	45	500	0.040	7.267
3	10	50	1000	0.026	7.341
4	10	55	1500	0.020	7.721

5	20	40	500	0.046	7.941
6	20	45	100	0.066	8.112
7	20	50	1500	0.066	8.421
8	20	55	1000	0.066	8.731
9	30	40	1000	0.079	8.918
10	30	45	1500	0.086	9.267
11	30	50	100	0.099	9.341
12	30	55	500	0.113	9.721
13	40	40	1500	0.093	9.941
14	40	45	1000	0.113	10.112
15	40	50	500	0.139	10.421
16	40	55	100	0.139	10.583

2.3. Multi-Objective Decision with Taguchi-Topsis

Evaluating the multi-objective results determined by Taguchi can be complex due to the interdependence of MRR and SR in the EDM process. To address this complexity, we have harnessed the Taguchi-Topsis methodology. This combined approach enables the simultaneous assessment of MRR and SR and thus paves the way for informed decision-making in EDM using nickel-coated electrodes.

The steps involved in integrating the Taguchi and Topsis methods are outlined in Figure 3. This process offers a balanced and pragmatic approach to multi-objective optimization, making it a valuable tool in our research.

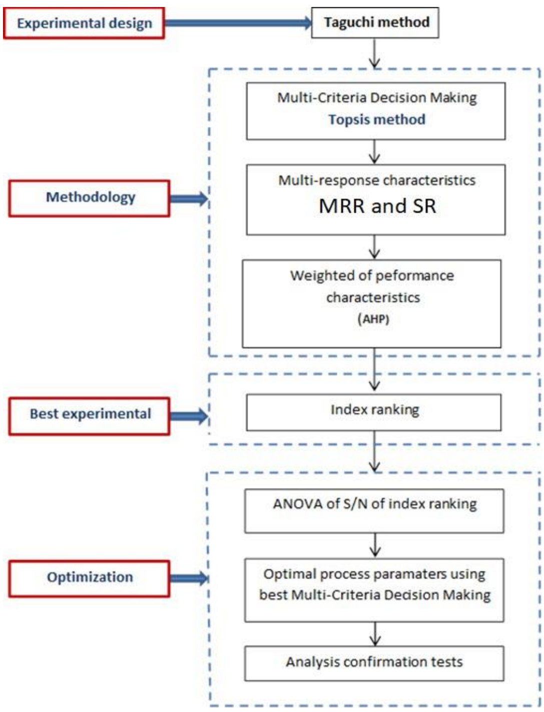

Figure 3. Steps by Taguchi – Topsis.

2.5 Topsis Method

Topsis, a widely-recognized technique in multi-objective optimization, provides a robust framework for realistic decision-making. It assists in selecting the most ideal indicator from a set of favorable ones and the most adverse indicator from a group of unfavorable ones.

The Topsis method unfolds through a series of steps:

Step 1: Arrange the chosen indicators in matrix form as equation (1).

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

Where:

x_{11} , x_{12} , ..., x_{1n} - Represents the criteria selected in the optimization problem.

x_{11} , x_{21} , ..., x_{m1} - Denotes the values of indicator 1 at different levels.

n – Signifies the number of selected criteria.

m – Represents the number of values for a given indicator.

Step 2: Standardize the matrix values as equation (2).

$$x'_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (2)$$

Step 3: Assign appropriate weights to the standardized indicators as equation (3).

$$Y=w_j.x'_{ij} \quad (3)$$

Where:

w_j - Weight of the indicators.

Y – Standardized matrix of weighted indicators.

Step 4: Identify the best and worst solutions, represented as the best criteria and worst indicators, respectively.

The best solution:

$$A^+ = \{(\max_i y_{ij} | \hat{I}J), (\min_i y_{ij} | j\hat{I}J' | i=1,2,...,m)\}$$

(Best indicator)

$$A^+ = \{y^+_1, y^+_2, ..., y^+_j, ..., y^+_n\} \quad (4)$$

The worst solution:

$$A^- = \{(\min_i y_{ij} | \in J), (\max_i y_{ij} | j \in J' | i=1,2,...,m)\}$$

(Worst indicator)

$$A^- = \{y^-_1, y^-_2, ..., y^-_j, ..., y^-_n\} \quad (5)$$

Where:

y^+_j and y^-_j - Represent the best and worst value of x_j , respectively.

J and J′ - Encompasses good and bad indicators, respectively.

Step 5: Compute the nearest and farthest distances for each indicator.

Nearest distance (S^+_i):

$$S^+_i = \sqrt{\sum_{j=1}^{n} (y_{ij} - y^+_j)^2} \quad (6)$$

Farthest distance (S^-_i):

$$S^-_i = \sqrt{\sum_{j=1}^{n} (y_{ij} - y^-_j)^2} \quad (7)$$

for i = 1, 2, …, m

Step 6: Calculate the Topsis numerical values for each alternative.

$$C^*_i = \frac{S^-_i}{S^+_i + S^-_i}, \text{ for } i = 1,2,...,m; \text{with } 0 \leq C^*_i \leq 1 \quad (8)$$

Step 7: Sort the computed Topsis values (C^*_i).

By adhering to this structured methodology, we aim to gain a comprehensive understanding of the performance improvements achieved through the utilization of nickel-coated electrodes in EDM, and the complex interplay between MRR and SR.

In the following sections, we will delve into the results and insights derived from our experimentation, culminating in a holistic comprehension of the effects and benefits of this novel approach in EDM utilizing nickel-coated electrodes.

2.4. Analyzing and optimizing results

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:

The higher the better:

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

Where: $MSD_{HB} = \frac{1}{r}\sum_{i=1}^{r}\left(\frac{1}{y_i^2}\right)$

MSD_{HB} - average square deviation

r- number of the tests in an experiment (*repeating times*).

y_i- experimental values.

3. RESULTS AND DISCUSSION

3.1. Determining the Optimal Experiment Using Topsis Method in EDM Using Nickel Coated Alumium

Step 1: Criteria Matrix

The criteria matrix, X, defined by equation (1), is as follows:

$$X=\begin{bmatrix} MRR_1 & SR_1 \\ MRR_2 & SR_2 \\ . & . \\ . & . \\ . & . \\ MRR_{16} & SR_{16} \end{bmatrix}$$

Step 2: Normalizing the Criteria Matrix

The normalized data, as computed using equation (2) and presented in Table 3, ensures that all criteria are on a common scale.

Table 3. Normalized data

Exp. No	I (A)	U (V)	T_{on} (µs)	Vector normalization	
				X_{MRR}	X_{SR}
1	10	40	100	0.0972	0.1950
2	10	45	500	0.1178	0.2048
3	10	50	1000	0.0766	0.2069
4	10	55	1500	0.0589	0.2176
5	20	45	100	0.1355	0.2238
6	20	40	500	0.1944	0.2286
7	20	55	1000	0.1944	0.2373
8	20	50	1500	0.1944	0.2461
9	30	50	100	0.2327	0.2513
10	30	55	500	0.2534	0.2612
11	30	40	1000	0.2917	0.2633
12	30	45	1500	0.3329	0.2740
13	40	55	100	0.2740	0.2802
14	40	50	500	0.3329	0.2850
15	40	45	1000	0.4095	0.2937
16	40	40	100	0.4095	0.2983

Step 3: Weight Assignment Using AHP Method

In this study, the AHP method determined the weights as W_{MRR} = 0.333 and W_{SR} = 0.667. The assignment of weights to the quality criteria is calculated as shown in Table 4.

Table 4. Calculation results in Topsis and S/N ratio values

Exp. No	y'_{MRR}	y'_{SR}	y^+_{MRR}	y^+_{SR}	y^-_{MRR}	y^-_{SR}	S_i^+	S_i^-	C_i^*	Ranking	S / N ratio
1	0.032	0.130	-0.104	0.000	0.013	-0.069	0.1040	0.0701	0.403	12	-7.8939
2	0.039	0.137	-0.097	0.007	0.020	-0.062	0.0973	0.0653	0.402	13	-7.9155
3	0.026	0.138	-0.111	0.008	0.006	-0.061	0.1111	0.0612	0.355	15	-8.9954
4	0.020	0.145	-0.117	0.015	0.000	-0.054	0.1177	0.0538	0.314	16	-10.0614
5	0.045	0.149	-0.091	0.019	0.026	-0.050	0.0932	0.0558	0.375	14	-8.5194
6	0.065	0.152	-0.072	0.022	0.045	-0.046	0.0751	0.0648	0.463	9	-6.6884
7	0.065	0.158	-0.072	0.028	0.045	-0.041	0.0770	0.0607	0.441	10	-7.1112
8	0.065	0.164	-0.072	0.034	0.045	-0.035	0.0793	0.0570	0.418	11	-7.5765
9	0.078	0.168	-0.059	0.038	0.058	-0.031	0.0698	0.0658	0.485	8	-6.2852
10	0.084	0.174	-0.052	0.044	0.065	-0.025	0.0682	0.0693	0.504	6	-5.9514
11	0.097	0.176	-0.039	0.046	0.078	-0.023	0.0601	0.0809	0.574	5	-4.8218
12	0.111	0.183	-0.026	0.053	0.091	-0.016	0.0585	0.0927	0.613	3	-4.2508
13	0.091	0.187	-0.045	0.057	0.072	-0.012	0.0726	0.0726	0.500	7	-6.0206
14	0.111	0.190	-0.026	0.060	0.091	-0.009	0.0652	0.0917	0.584	4	-4.6717
15	0.136	0.196	0.000	0.066	0.117	-0.003	0.0658	0.1168	0.639	1	-3.8900

16	0.136	0.199	0.000	0.069	0.117	0.000	0.0689	0.1167	0.629	2	-4.0270

Step 4: Identifying the Best and Worst Solutions*

The best solution (A+) and worst solution (A-) are determined according to formulas (4) and (5) and result in A^+ = {MRR = 0.1364; SR = 0.130} and A^- = {MRR = 0.0196; SR = 0.199}.

Step 5: Calculation of S_i^+ and S_i^-

S_i^+ and S_i^- are calculated based on equations (6) and (7) and presented in Table 4.

Step 6: Computing C* Values

The C* values are determined using equation (8) and are summarized in Table 4.

Step 7: Ranking

The ranking results from Table 4 and Figure 4 reveal that the 15th experiment is the best. The optimal process parameters are U = 45 V, I = 40 A, Ton = 1000 µs, MRR = 0.139 mg/min, and SR = 10.421 µm.

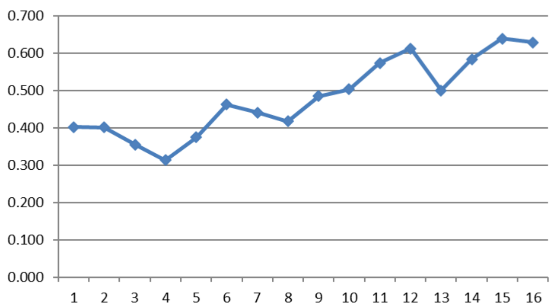

Figure 4. Results ranking of C*

3.2. Determining Optimal Results Through S/N Analysis

S/N ratio is determined according to formula (9), and the results are shown in Table 2. Figure 5 illustrates the optimal process parameters determined by Topsis, which are U = 40 V, I = 40 A, and Ton = 1000 µs. These parameters yield the optimal results (Eq. 10) presented in Table 5. A comparison between the results of MRR and SR calculations with the experimental results indicates good accuracy. However, upon comparing the optimal quality criteria obtained through S/N analysis with the ranking of C*, it is evident that the C* ranking holds more significance. Thus, the study concludes that the optimal process parameters and quality indicators are determined based on the C* ranking.

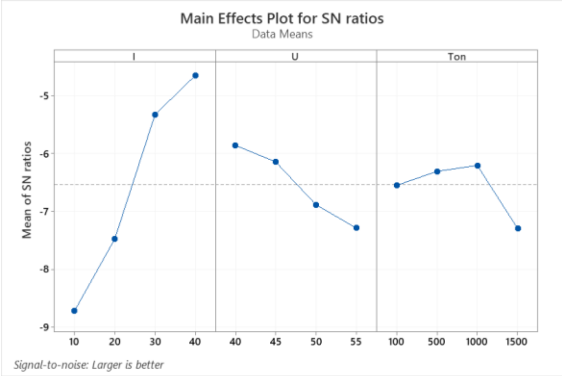

Figure 5. Analysis of S/N of C* in Topsis

$$(MRR, SR)_{opt} = U_4 + I_1 + T_{on3} - 3.\,T \qquad (10)$$

Table 5: Comparison Between the Two Methods

Quality indicators	Ranking	S/N ratio	Improvement (%)
MRR (mg/min)	0.139	0.135	-2.88
SR (µm)	10.421	7.56	-27.45

4. Conclusions

Solving the multi-objective optimization problem in EDM with Ni coated electrode for Ti-6AL-4V by Taguchi- TOPSIS has been done, and I, U and Ton were used as input parameters. From the experimental results, the following conclusions were drawn:

- The optimal set of process parameters was found as U=40 V, Ton=1000 µs, I = 40 A. The optimal indicator values were found as MRR= 0.135 mg/min and SR=7.56 µs.
- It has proved that TOPSIS is an effective method to solve multi-objective optimization in the field of EDM with Ni coated electrode in particular and other machining technologies.

• The S/N analysis will produce better optimal results, and this contributes to improving the machining efficiency of EDM with Ni-coated electrodes.

Reference

[1]. Vijay, K.M., Man, S.A., “Micro-EDM multiple parameter optimization for Cp titanium”. Int J AdvManufTechnol, 89, (2017), 897–904.

[2]. Phan, N.H. et al. (2021). Material Removal Rate in Electric Discharge Machining with Aluminum Tool Electrode for Ti-6Al-4V Titanium Alloy. Advances in Engineering Research and Application. ICERA 2020. https://doi.org/10.1007/978-3-030-64719-3_58

[3]. Chausov, M., Pylypenko, A., Berezin, V., Volyanska, K., Maruschak, P., Hutsaylyuk, V., Markashova, L., Nedoseka, S., &Menou, A., “Influence of dynamic non-equilibrium processes on strength and plasticity of materials of transportation systems”. Transport, 33(1), (2018), 231-241.

[4] Phan, N.H. et al. (2021). Tool Wear Rate Analysis of Uncoated and AlCrNi Coated Aluminum Electrode in EDM for Ti-6Al-4 V Titanium Alloy. Advances in Engineering Research and Application. ICERA 2020. https://doi.org/10.1007/978-3-030-64719-3_91

[5]. Durairaj, M., Sudharsun, D., Swamynathan, N., “Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade”,Procedia Engineering, 64,(2013), 868-877.

[6] Pragadish, N., & Kumar, M. P., “Optimization of dry EDM process parameters using grey relational analysis”, Arabian Journal for Science and Engineering, 41(11), (2016) 4383-4390.

[7] Ilani, M.A., Khoshnevisan, M. 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, 3263–3277 (2021). https://doi.org/10.1007/s00170-021-06626-1

[8]. Taherkhani, A., Ilani, M.A., Ebrahimi, F. 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, 1783–1799 (2021). https://doi.org/10.1007/s00170-021-07573-7

[9]. Ilani, M.A., Khoshnevisan, M. Powder mixed-electrical discharge machining (EDM) with the electrode is made by fused deposition modeling (FDM) at Ti-6Al-4V machining procedure. Multiscale and Multidiscip. Model. Exp. and Des. 3, 173–186 (2020). https://doi.org/10.1007/s41939-020-00070-6

[10]. Ilani, M.A., Khoshnevisan, M. 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, 1763–1782 (2021). https://doi.org/10.1007/s00170-021-07569-3

[11]. N. H. Phan, P. V. Dong, T. Muthuramalingam, 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”, International Journal of Engineering, Transactions A: Basics Vol. 34, No. 04, (2021) 928-934

[12]. Phan, N.H., Van Dong, P., Dung, H.T. et al. “Multi-object optimization of EDM by Taguchi-DEAR method using AlCrNi coated electrode”Int J AdvManufTechnol

(2021). https://doi.org/10.1007/s00170-021-07032-3

[13]. G Sakthivel, D Saravanakumar, T Muthuramalingam "Application of failure mode and effects analysis in manufacturing industry- an integrated approach with FAHP - FUZZY TOPSIS and FAHP -FUZZY VIKOR ," International Journal of Productivity and Quality Management, 24(3), 398-423, 2018.

[14] Prosun Mandal &Subhas Chandra Mondal, Surface characteristics of mild steel using EDM with Cu-MWCNT composite electrode

[15].R. Jothimurugan, K.S. Amirthagadeswaran and Joel Daniel, 2012. Performance of Silver Coated Nickel Tool with Kerosene-servotherm Dielectric in EDM of Monel 400TM. Journal of Applied Sciences, 12: 999-1005. DOI: 10.3923/jas.2012.999.1005

[16]. Yu Liu, Wenjian Wang,Wenchao Zhang, Fujian Ma, Dapeng Yang, Zhihua Sha, Shengfang Zhang, Experimental Study on ElectrodeWear of Diamond-Nickel Coated Electrode in EDM Small Hole Machining, Advances in Materials Science and Engineering, Vol 2019, ID 7181237, 10 pages. https://doi.org/10.1155/2019/7181237

[17]. D. L. Panchal, S. K. Biradar, V. Y. Gosavi, Analysis of EDM Process Parameters by Using Coated Electrodes, International Journal of Engineering Trends and Technology (IJETT) – Volume-41 Number-4 - November 2016

[18]. Asif Rashid, Azat Bilal, Chong Liu, M. P. Jahan, Didier Talamona, Asma Perveen, Effect of Conductive Coatings on Micro-Electro-Discharge Machinability of Aluminum Nitride Ceramic Using On-Machine-Fabricated Microelectrodes, Materials, 2019, 12, 3316; doi:10.3390/ma12203316

[19]. Ablyaz, T.R., Shlykov, E.S. & Kremlev, S.S. Nickel-coated electrodes for electrical discharge machining of 38X2H2MA steel. Russ. Engin. Res. 37, 910–911 (2017). https://doi.org/10.3103/S1068798X17100033

[20]. E. Uhlmann, M. Langmack, R. Garn, D. Oberschmidt, J. Fecher, S. M. Rosiwal, R. F. Singer, Using Diamond Coated Tool-electrodes for Drilling Micro Holes with EDM, Proceedings of the euspen International Conference – Como - May 2011.

[21]. Dastagiri, M., Srinivasa, R.P., Valli, P.M., "TOPSIS, GRA Methods for Parametric Optimization on Wire Electrical Discharge Machining (WEDM) Process",Design and Research Conference (AIMTDR–2016) College of Engineering, (2016).

[22].Prabhu, S., Vinayagam, B.K., "Multiresponse optimization of EDM process with nanofluids using TOPSIS method and Genetic Algorithm",Archive of Mechanical Engineering, 63(1), (2016) 45–71.

[23].Durairaj, M., Sudharsun, D. &Swamynathan, N., "Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade"Procedia Engineering, 64, (2013) 868 – 877.

[24]. Nayak, I., Rana, J. &Parida, A, "Performance optimization in electro-discharge machining using a suitable multiresponse optimization technique"Decision Science Letters, 6, (2017) 283–294.