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Study on Multi-objects Optimization in EDM with Nickel Coated Electrode using Taguchi-AHP-Topsis

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PAPER INFO	ABSTRACT
	To improve productivity and quality of machining process using EDM, a lot of electrodes such as coated and alloy electrodes has been applied. Study on multi-objects optimization in EDM with coated electrode will increase number of application of this field into practice. In this study, material removal rate (MRR) and surface roughness (SR) in EDM using nickel coated aluminium electrode were optimized simultaneously using Taguchi-AHP-Topsis methods. Technological parameters including Peak Current (I), Gap Voltage (U) and pulse on time (Ton) were investigated. Titanium alloy (Ti-6Al-4V) was selected as workpiece in experimental process. The results show that combination among Taguchi-AHP-Topsis methods is suitable to solve multi-objects optimization in EDM. The optimized technological parameters are I = 30 A, Ton = 500 µs, U = 50 V and optimized quality criterias are MRR = 0.17 mm^3/min and SR = 8.76 µm.

1. INTRODUCTION

Nowadays, technological parameters in EDM are often selected using the experience of workers or using guide books of equipments in companies and factories. Therefore, efficiency of machine is not high. Study on optimizing technological parameters in EDM using experimental model is a suitable solution to improve the above process [1]. A lot of solutions has been proposed to solve optimized problem in EDM [2, 3]. Not only Taguchi method is used independently but also it is combined with other methods to increase efficiency to solve the optimized problems [4, 5]. Accuracy of the optimized results and multi-objects optimization can be easily solved using Taguchi method and other optimimal methods [6]. A lot of methods which are used to optimize multi-objects and quality criteria presented in EDM field. Researches have been performed to improve productivity, reduce electrode wear and increase machined surface quality. Combination of Taguchi, ANN and RSM is to determine accurate values of MRR and SR in EDM for Ti50Ni40Co10 [7, 8]. Studied results showed

that Taguchi - ANN has higher accuracy and less error compare to others. In a research conducted by Rajamanickam et al. [9], four quality criteria in EDM for Ti - 6Al-4V were optimized simultaneously combining RSM with Fuzzy and Topsis methods, and set of optimized parameters were accurately determined. However, comparing with Taguchi method, number of experiment is large and investigated degree of each parameter is small. Taguchi - Triangular Fuzzy - Topsis were combined to optimize simultaneously 5 quality criteria in EDM, and experimental results show that this combination is efficient for multi-objects optimization [10]. MRR is larger and TWR is smaller, this is result which obtains from multi-objects problem in EDM for Silicon Nitride - Titanium Nitride by Taguchi - Topsis và Taguchi - Grey Relationship Grade (GRA). These are suitable solutions for multi-objects problem in this field [11]. Taguchi - GRA were also combined to optimize simultaneously 3 quality criteria including MRR, EWR and OC in EDM for Cp Titanium [12]. Ananyzied results showed that set of optimized parameters which are calculated is different from set of them in ANOVA of

S/N of GRA. In another research [13], authors optimized set of technological parameters in multi-objects problem of EDM using Taguchi - Topsis. The results showed that Topsis is a strong method to solve multi-objects problem in EDM and also other technological fields. MRR and SR are quality criteria which was optimized simultaneously in EDM using double solution such as Taguchi - Topsis and Taguchi - GRA [14]. Results were analyzed and compared among these combinations, and it shows that efficiency of Topsis is larger. ANOVA in multi-objects problem was performed in EDM. MRR and TWR are quality criteria. In addition, surface quality also analyzied [15]. Using Taguchi - Topsis methods with ANOVA, machining efficiency in EDM was improved significantly. It is about 10% [16]. Taguchi - Topsis was used to solve multi-objects problem in EDM using nanotube copper electrode [17]. Combination of ANOVA and Taguchi - Topsis was also performed to solve multi-objects problem in μ - EDM drilling for 304 stainless steel. The research showed that efficiency is better. It is about 37%. This is a good solution for manufacturing in fact. Topsis method was used to optimize simultaneously seven quality criteria in EDM for AISI 304 steel[18]. ANOVA was also used to analyze optimized criteria C*, and it showed a parameter which affected significantly to C*. ANOVA technology for S/N of optimized criteria (γ) using Taguchi - GRA determined set of optimized parameters in WEDM [19]. MRR and SR were considered as optimal criteria. Combination among Taguchi - AHP - Topsis was used in multi-objects problem of the non-traditional machining technology [20]. This combination showed that selection for number of weight of quality criteria is simple, error appearing in this method is smaller, and technician is not necessary to have knowledge well to do. AHP - Topsis and AHP - GRA have been introduced and they can be applied in a lot of fields. Quality of surface layer at optimized condition was presented by some researches. White layer on machined surface in WEDM was analynized and investigated deeply using factors such as chemical composition, alloy state, mechanical properties and elastic modulus E [21]. However, it is necessary to study continuously and consider deeply for determining suitability of white layer coresponding to work requiment of molds and dies in fact. There are a lot of optimal algorithms which have studied to solve multi-objetcs optimization in EDM such as GRA, ANN, PSO, Topsis, etc. [22]. However, optimal results from these methods are different at the same experimental condition and it is difficult to select set of optimal parameters and results. Therefore, optimization for increasing machining productivity and surface quality in EDM is necessary to study.

Currently, researchers who are in country or abroad are interested to this field. Number of international publication of optimal field in EDM increases significantly every year. A lot of optimal methods has been used to solve single or multi-objects optimization. Normally, Taguchi method is often applied for single objetcs optimization and Topsis is applied for multi-objects optimization. Therefore, multi-objects optimization in EDM with Nickel coated Al electrode was performed in this study. Taguchi - AHP - Topsis were used. MRR and SR are quality criteria and they were investigated in this work.

2. EXPERIMENTAL SETUP

The experiments have been conducted on the Die-sinking EDM model CM323C of CHMER EDM, Ching Hung machinery & Electric Industrial. Co. LTD. Workpiece material is Titanium alloy (Ti-6Al-4V) with dimension of 25×35×5 mm. Nickel is coated on Al electrode and thickness of coating layer is 50 micro. EDAX report of Nickel coating and it was invident that presence of Nickel material in coating, Figure 1. Based on previous researches, technological parameters including Current (I), Voltage (U) and pulse on time (T_{on}) were selected to investigate, levels of the technological paramters are shown in Table 1. Fixed parameters in this work includes dielectric pressure with 0.5 kg/cm^2, machining time with 10 min, servo sensitivity with 9 and anti-arc sensitivity with 5.

Quality criteria in EDM include MRR and SR. The mass of the workpiece was measured before and after machining using AJ 203 electronic balance (Shinko Denshi Co. LTD - Japan). The surface roughness was measured by a surface tester (Model: SV - 2100,
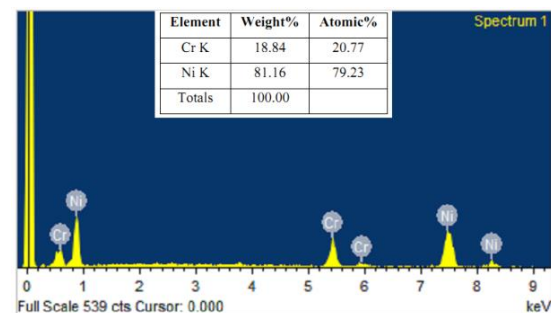

Element	Weight%	Atomic%
Cr K	18.84	20.77
Ni K	81.16	79.23
Totals	100.00	

Figure 1. EDX Report of nickel coating tool electrode

TABLE 1. Input process parameters and levels

Parameters	Symbol	Levels				Unit
		1	2	3	4	
Peak Current	I	10	20	30	40	A
Gap Voltage	U	40	45	50	55	V
Pulse-ON Time	T_{on}	100	500	1000	1500	μS

Mitutoyo, Japan) with the cut off length 0.8mm. The results of quality indicators are shown in Figure 2 and Table 2.

3. OPTIMIZED DESIGN METHOD

Taguchi is a popular method used for optimization process in EDM. Comparing with tradition mahining methods, number of experiment is the smallest, and expermental matrix is simple. Therefore, time and cost of experiment process reduce significantly. Number of the input technological parameters and their levers are investigated, as shown in Table 1. This table shows that L16 of Taguchi method is suitable with this study. The expermental matrix is described as Table 2. Howerver, Taguchi method is difficult to solve multi-objetcs

Figure 2. Machined Surface after EDM using Nickel Coated Electrode

TABLE 2. Experimental results of L16

Expt. No.	Current (I)	Gap Voltage (U)	Pulse-ON Time (T_{on})	MRR (mm³/min)	Ra (μm)
1	1	1	1	0.033	6.918
2	1	2	2	0.040	7.267
3	1	3	3	0.026	7.341
4	1	4	4	0.020	7.721
5	2	1	2	0.046	7.941
6	2	2	1	0.066	8.112
7	2	3	4	0.066	8.421
8	2	4	3	0.066	8.731
9	3	1	3	0.079	8.918
10	3	2	4	0.086	9.267
11	3	3	1	0.099	9.341
12	3	4	2	0.113	9.721
13	4	1	4	0.093	9.941
14	4	2	3	0.113	10.11
15	4	3	2	0.139	10.42
16	4	4	1	0.139	10.58

problem and it is disadvantage of this method. Currently, combination between Taguchi and other methods such as Topsis, GRA, Deng's, etc. have been introduced and it can improve disadvantage of Taguchi method. Selection of weight of quality criteria in multi-objects problem is the most important, because value of quality weight affects to accuracy of optimal problem. This is complex and it is difficult to determine the suitable weight of quality criteria. A lot of solution has been presented and r- number of test in an experiment (repeating times).
y_i- values of experiment.
The higher - the better:
$(S/N)_{HB} = -10\log(MSD_{HB})$

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

where, MSD_{HB} - the average square deviation.
AHP is a simple method. This method can determine accurately weight value. Combination amongs Taguchi - AHP- Topsis is a good solution to solve multi-objects problem in technical fields and EDM. Multi-criteria decision using Taguchi - AHP - Topsis is performed as Figure 3.
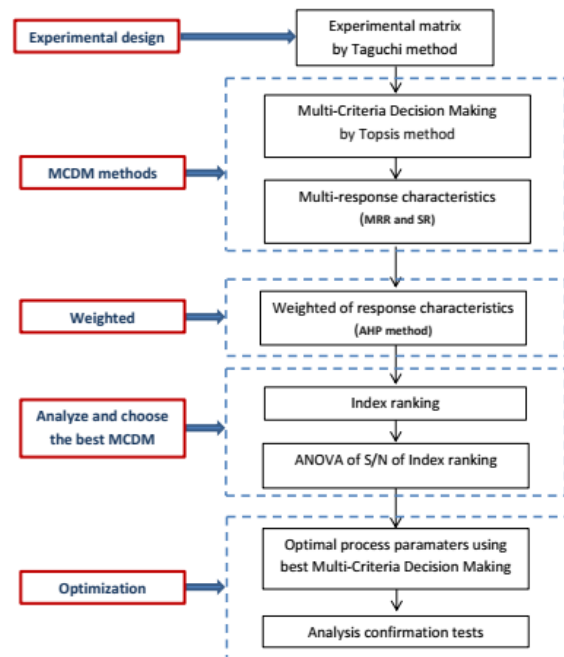Analyzing ratio S/N:
The lower - the better:
$(S/N)_{LB} = -10\log(MSD_{LB})$

$$MSD_{LB} = \frac{1}{r}\sum_{i=1}^{r} y_i^2 \tag{1}$$

where,
MSD_{LB} - the average square deviation.

Figure 3. Steps of multi-criteria decision

4. RESULT AND DISCUSSION

4. 1. Determining the Best Experiment

Step 1: Arranging selected criteria in matrix.

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

Step 2: Normalization matrix.

Step 3: Determine values y_{11} and y_{12}. Determine value of weight of criteria using AHP. Based on number of quality criteria and priority degree of each quality criteria, elements of compared matrix is formed, as shown in Table 3. Matrix of compared pair is shown in Table 4. Normalization matrix of concatenated comparisons and calculation of priority weights and value of weight, the quality criteria is shown in Table 5. Weight of criteria is determined as follows: $W_{MRR} = 0.333$ and $W_{SR} = 0.667$.

Step 4: Determine the best solution and the worst solution: The higher MRR is the better, The smaller SR

TABLE 3. Standartzation data

No.	I (A)	U (V)	T_{on} (µs)	Conversion Vector	
				X_{MRRi1}	X_{SRi2}
1	1	1	1	0.097	0.195
2	1	2	2	0.118	0.205
3	1	3	3	0.077	0.207
4	1	4	4	0.059	0.218
5	2	1	2	0.136	0.224
6	2	2	1	0.194	0.229
7	2	3	4	0.194	0.237
8	2	4	3	0.194	0.246
9	3	1	3	0.233	0.251
10	3	2	4	0.253	0.261
11	3	3	1	0.292	0.263
12	3	4	2	0.333	0.274
13	4	1	4	0.274	0.280
14	4	2	3	0.333	0.285
15	4	3	2	0.410	0.294
16	4	4	1	0.410	0.298

TABLE 4. Matrix of compared pair

Quality Criteria	MRR	SR
MRR	1	0.5
SR	2	1

TABLE 5. Normalization matrix of concatenated comparisons and calculation of priority weights

Quality criteria	MRR	SR	Total	Weight (W)
MRR	0.333	0.333	0.667	0.333
SR	0.667	0.667	1.333	0.667
SUM	1.000	1.000		

TABLE 6. Best and worst solution

	MRR	SR
A+	0.0196	0.1989
A-	0.0196	0.1989

is better, so the smallest value is the best and the largest value is the worst. The values are shown in Table 6.

Step 5: Determine values S_i^+ and S_i^-, as shown in Table 7.

Step 6: Determine value C_i^*, as shown in Table 7.

Step 7: Arrange value C^* and order is decribled in Table 7. The result shows that C^* of the second experiment is the highest. Therefore, it can see that values

TABLE 7. The conversion values are calculated from step 3 to step 7

No.	y_{i1}	y_{i2}	S_i^+	S_i^-	C_i^*	Ranking
1	0.0324	0.1301	0.0925	0.1080	0.538	10
2	**0.0786**	**0.1366**	**0.0667**	**0.1063**	**0.614**	**1**
3	0.0255	0.1380	0.1034	0.1157	0.528	11
4	0.0196	0.1451	0.1018	0.0894	0.468	14
5	0.0451	0.1493	0.0885	0.0915	0.508	13
6	0.0647	0.1525	0.0845	0.1175	0.582	5
7	0.0647	0.1583	0.0687	0.0903	0.568	7
8	0.0647	0.1641	0.0753	0.0974	0.564	8
9	0.0775	0.1676	0.0666	0.1020	0.605	2
10	0.0844	0.1742	0.0786	0.0817	0.510	12
11	0.0971	0.1756	0.0653	0.0832	0.560	9
12	0.1109	0.1827	0.0628	0.0849	0.575	6
13	0.0912	0.1869	0.0779	0.0669	0.462	15
14	0.1109	0.1901	0.0575	0.0483	0.456	16
15	0.1364	0.1959	0.0670	0.0971	0.591	3
16	0.1364	0.1989	0.0686	0.0965	0.585	4

of SR and MRR are the best at I =10 A, T_{on} = 500 μs and U = 45 V.

4. 2. Analynize Multi-objetcs Optimization using Taguchi–Topsis

Figure 4 and Table 8 show set of optimized technology parameters and optimized results of the quality criteria in multi-objects problem in EDM for Niken coated Aluminium electrode using Taguchi-Topsis. The optimized parameters are I = 30 A, T_{on} = 500 μs, U = 50 V. Value of the quality criteria at optimal machining condition can be calculated by Equation (3), and results are shown in Table 8. The highest deviation between calculation and experiment is 13.33%. This shows that the proposed method is suitable.

$$(MRR, SR)_{OPT} = I_3 + T_{on2} + U_3 - 2.T \tag{3}$$

4. 3. Optimal Surface Quality

Machined surface quality using EDM affects to work ability of products and cost of next finishing machining. In this study, authors investigated surface quality at optimal conditions, as follows: I =10 A, T_{on} = 500 μs and U = 45 V. The experimental results show that machined surface appears craters under random distribution and thier shape is spherical concave, as shown in Figure 5. There are a lot of particle adhesion appearing on machined surface and their size is different because electrode and workpiece materials are melted and evaporated and cooled rapidly

TABLE 8. Experimental results

Qualify indicator	Optimal paramter	Optimal value		Deviation (%)
		Caculation	Experiment	
MRR (mm^3/min)	I = 30 A, T_{on} = 500 μs, U = 50 V	0.15	0.17	13.33%
SR (μs)		9.81	8.76	10.71%

Figure 4. The influence of technological parameters on S/N of C_i

by the dielectric fluid and they adhere to the machined surface, Figure 6. Besides, this created micro-cracks on machined surface and SR increases, Figure 7.

Figure 8 shows that surface layer includes white layer, heat affected zone and background layer. White layer is formed by melting and evaporation of electrode and workpiece materials which were not pushed out by dielectric fluid and they adhere to the machined surface [14]. Therefore, micro-structure and chemical
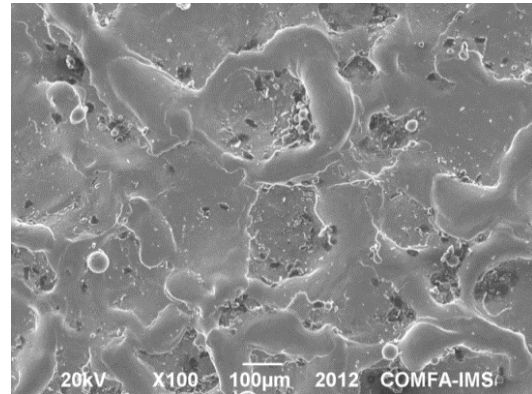

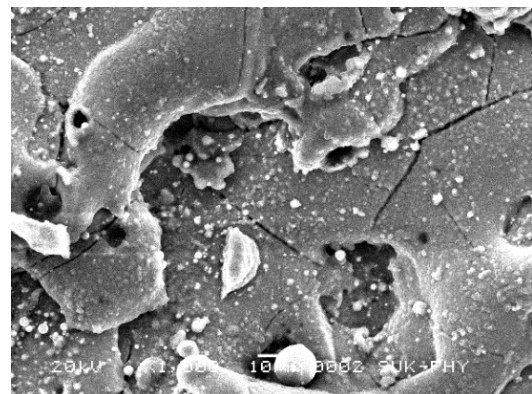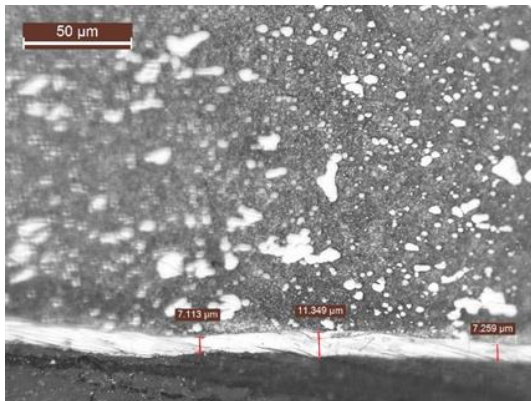**Figure 5.** Topography of machined surface

Figure 6. Adhesive particles of machined surface

Figure 7. Micro- craks of machined surface

Figure 8. Machined surface layers

composition of the white layer are different from background layer [23]. Middle layer (heat affected zone) is formed by heat energy of sparks impacting metal layer under the white layer, it creates phase transition of metal layer. And hardness of this layer is often harder than background layer [23]. Experimental results show that machined surface layer using EDM is changed comparing background layer, and it is different from machined surface using traditional methods such as milling, lathe or grinding etc.

5. CONCLUSION

This study used Taguchi - AHP - Topsis to solve multi-criteria decision in EDM for Niken coated Aluminium electrode for Ti-6Al-4V. Experimental matrix was designed using Taguchi, therefore, cost of experiment is reduced significantly. AHP was applied to determine the suitable value of weight of quality criteria. Calculation using Topsis method is simple, and number of step is small. Set of technological paremeters is I = 30 A, T_{on} = 500 µs, U = 50 V, and MRR_{OPT} = 0.17 mm^3/min, Ra_{OPT} = 8.76 µm. Surface quality at optimized condition was analyzed, combination among methos is simple and clear. It can say that the proposed method in this study is suitable with this field.

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Persian Abstract

چکیده

برای بهبود بهره وری و کیفیت فرآیند ماشینکاری با استفاده از EDM، تعداد زیادی الکترود مانند الکترودهای روکش دار و آلیاژی استفاده شده است. مطالعه بر روی بهینه سازی چند شیء در EDM با الکترود روکش دار ، کاربرد این زمینه را در عمل افزایش می دهد. در این مطالعه ، میزان حذف مواد (MRR) و زبری سطح (SR) در EDM با استفاده از الکترود آلومینیوم با روکش نیکل به طور همزمان با استفاده از روشهای تاگوچی – AHP - Topsis بهینه شده است. پارامترهای تکنولوژیکی شامل پیک جریان (I)، ولتاژ شکاف (U) و نبض در زمان (تن) مورد بررسی قرار گرفت. آلیاژ تیتانیوم (Ti-6Al-4V) به عنوان قطعه کار در فرایند آزمایشی انتخاب شد. نتایج نشان می دهد که ترکیب روش های تاگوچی – AHP - Topsis برای حل بهینه سازی چند شیء در EDM مناسب است. پارامترهای تکنولوژیکی بهینه I = 30 A ، تن = ۵۰۰ µs ، U = 50 V و معیارهای کیفیت بهینه MRR = 0.17 mm3 در دقیقه و SR = 8.76 میکرومتر است.