Araştırma Makalesi
Adıyaman Üniversitesi
Mühendislik Bilimleri Dergisi
18 (2022) 471-480

TAGUCHI METHOD FOR OPTIMIZING TOOL WEAR RATE AND OVERCUT IN ELECTRO DISCHARGE MACHINING

Ali KALYON*

Department of Mechanical Engineering, Faculty of Engineering, Yalova University, TR-77100 Yalova, Turkey,
Geliş Tarihi/Received Date: 25.02.2022 Kabul Tarihi/Accepted Date: 22.12.2022 DOI: 10.54365/adyumbd.1079127

ABSTRACT

In this study, machinability of Caldie cold work tool steel on EDM machine was experimentally investigated by using Cu-Cr-Zr electrode for tool wear rate (TWR) and overcut. In the experiment tests, discharge current, pulse duration and duty cycle were used as processing parameters. Machinability levels were determined for the lowest TWR and overcut. The effect of level parameters on TWR and overcut were calculated with the help of ANOVA. Experimental results are interpreted with using three-dimensional graphics. While the optimum machining test condition for electrode wear rate was $A_1B_1C_1$, the optimum machining level for overcut was determined as $A_1B_1C_2$. As a result of ANOVA analysis, it was calculated that discharge current was the most powerful parameter on TWR and overcut.

Anahtar Kelimeler: *EDM, Copper, Overcut, Tool wear rate, Optimization*

ELEKTRO EROZYON İLE İŞLEMEDE TAKIM AŞINMA ORANININ VE YANAL AÇIKLIĞIN TAGUCHI YÖNTEMİ İLE OPTİMİZASYONU

ÖZET

Bu çalışmada, Caldie soğuk iş takım çeliğinin EEİ tezgahında işlenebilirliği, takım aşınma oranı ve yanal açıklık için Cu-Cr-Zr elektrot kullanılarak deneysel olarak incelenmiştir. Deneysel çalışmada işleme parametreleri olarak boşalım akımı, vurum süresi ve çevrim süresi kullanılmıştır. En düşük takım aşınma oranı ve yanal açıklık için işlenebilirlik seviyeleri belirlenmiştir. Seviye parametrelerinin takım aşınma oranı ve yanal açıklık üzerindeki etkisi ANOVA yardımıyla hesaplanmıştır. Deneysel sonuçlar üç boyutlu grafikler kullanılarak yorumlanmıştır. Elektrot aşınma oranı için optimum işleme deney koşulu $A_1B_1C_1$ iken, yanal açıklık için optimum işleme koşulu $A_1B_1C_2$ olarak belirlenmiştir. ANOVA analizi sonucunda elektrot aşınma oranı ve yanal açıklık üzerinde en güçlü parametrenin boşalım akımı olduğu hesaplanmıştır.

Keywords: *EEİ, Bakır, Yanal açıklık, Takım aşınma oranı, Optimizasyon*

1. Giriş

In the manufacturing industry for forming the machine parts there are many manufacturing techniques available. Electrical, thermal, mechanical, chemical, many types of energy and processing methods are the most important factors in the classification of manufacturing. Optimization of processing parameters in manufacturing techniques used to shape metal and alloy types varies. It is a known fact that this wide range of usage in machining parameters also changes the structural integrity of the machined surfaces. In addition, research on the machinability of newly developed materials in each passing period of time also reveals new manufacturing techniques to achieve the desired optimum machining parameters. Therefore, different surface structures are formed in machine parts processed by both existing and newly developed manufacturing techniques.

* [1]e-posta: alikalyon@gmail.com ORCID ID: https://orcid.org/0000-0003-3300-1336 (Sorumlu Yazar)

Today, among these manufacturing methods, one of the most remarkable and commercially produced tool is the electro discharge machining (EDM). EDM tools were designed and produced three different types. These are sinker erosion, wire erosion and fast hole drilling electro erosion machines. Processing precision and performance of these tools, which were produced commercially after the 1960s, have been improved with technological developments [1–3]. The surfaces formed in the EDM method are in a crater structure. In other words, there is a surface structure that is formed by the overlapping of craters melted and evaporated on the workpiece surface by thousands of sparks discharged from the bottom surface of the tool during machining, which cannot be achieved with other manufacturing techniques [4,5]. For this reason, the crater dimensions and therefore the surface roughness exhibit a completely different structure. In addition, since the process is carried out in a non-conductive liquid environment. Heat affected layers are formed on the surfaces due to the rapid cooling of the dielectric liquid [6,7].

One of the most important process outputs that should be examined in evaluating the machinability criteria after processing with electro erosion is overcut. Many studies have been conducted in the literature to determine the parameters affecting overcut. In these studies, it is seen that the overcut and TWR are optimized. In many studies, prediction models for overcut have been created using mathematical modeling [8–11]. Rouniyar ve Shandilya has studied on overcut on Aluminium 6061 alloy. Box Behnken design approach was employed for experimental design to carry out the experiments. Experimental results showed discharge current as the most important parameters for overcut as compared to other process parameters on account of higher F-value. Confirmatory experiments revealed good correlation between optimum and experimental results [12]. Belgassim and Abusaada investigated the EDM machining characteristics of hardened AISI D3 tool steel. The machining response is the overcut of the process (OC), and the input parameters are pulse current Ip, pulse-on time Ton, pulse-off time Toff, and the gap voltage Vg. The experimental results have provided the optimal combination of input parameters that gives the minimal overcut on the machined surface [13]. Chiang and Wang the were investigated variation of the side overcut and the bottom overcut, the electrode dimensions, the spark hole dimensions, and the machine positioning accuracy in the EDM. The experiment results show that the coupling effect between the electrode diameter and spark hole diameter is an important factor for estimating the variation of the side overcut in the EDM process [14]. Dewangan et al examined the surface integrity by using the multi objective optimization technique in their studies. Using the optimization technique, they enhanced surface crack density, white layer thickness and surface roughness [15]. Pradhan increased machinability efficiency with the developed hybrid model. Tool wear and radial overcut have been minimized in EDM of AISI D2 tool steel. Determined the effects of machinability parameters using the response surface method and grey relationship method [8]. Using the response surface method, Muthukumar et al. developed a prediction model for radial overcut in electro discharge machining of Incoloy 800 superalloy. As a result of their studies, they stated that the most effective parameter for radial overcut is the discharge current [16]. Ahmed et al. Optimized tool wear and overcut for Titianium alloy using Taguchi L_9 experiment set. They recommended the electrode to be used in positive polarity to minimize tool wear. They obtained the lowest overcut value with the copper electrode in negative polarity [10].

The most important factor in achieving the precision of electro discharge machining is low electrode wear. The wear on the electrode directly affects the dimensions of the profile to be machined. In this study, an optimization technique study was carried out for TWR and overcut during the machining of Caldie cold work tool steel. In the study, three different levels were used for discharge current, pulse duration and duty cycle. Using ANOVA analysis, the effect levels of parameters on TWR and overcut were determined. Experimental results were interpreted with the help of graphics.

2. Materials and Methods

Electro erosion processing experiments were carried out Furkan EDM M25A type machine. The experimental procedure is shown in Figure 1. Cur-Cr-Zr copper alloy with high electrical conductivity was used as the electrode material in the experimental studies. Since Cu-Cr-Zr electrode is alloyed with chrome and zirconium, its hardness is higher than pure copper. Electrodes are commercially available in sizes 15x15mm. The chemical content of Cu-Cr-Zr electrode is given in Table 1.

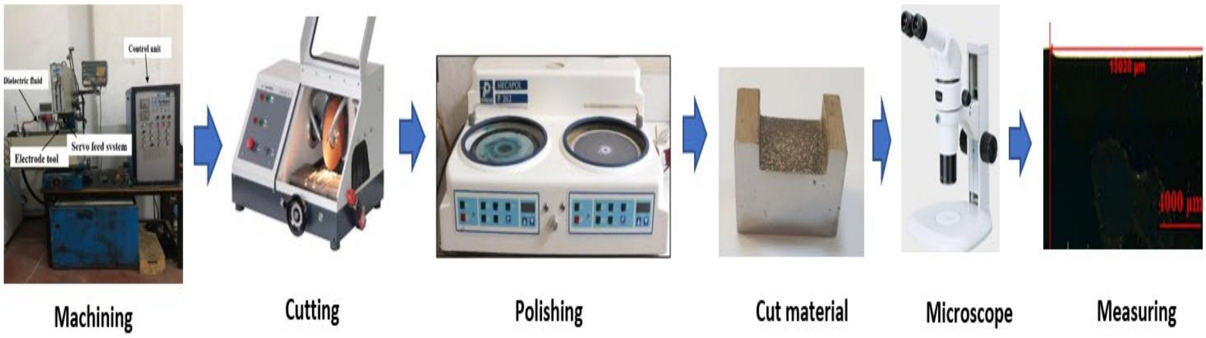

Figure 1. Experimental procedure

Table 1. The chemical content of Cu-Cr-Zr electrode.

Element	Cr	Zr	Others	Cu
weight(%)	1	0,1	0,2	Balance

Caldie cold work tool steel was used as a workpiece in the experimental study. Caldie steel is used in molds where high toughness and compression strength are required. Table 2 shows the chemical content of Caldie cold work tool steel. Discharge current, pulse duration and duty cycle are used as processing parameters. Gas oil was used as dielectric medium fluid and lateral spraying with 0,4 pressure. Processing depth was kept constant at 1 mm in experimental studies. Electrodes were prepared separately for each experimental condition. The machining surfaces of the electrodes have been polished with using sandpaper. Equation 1 shows the calculation of TWR. In this equation Ti is the initial weight of the electrode and Tf is the final weight, q is the density and t is the processing time.

Table 2. Chemical content of Caldie cold work tool steel.

Element	C	Si	Mn	Cr	Mo	V	Fe
weight(%)	0,7	0,2	0,5	5,0	2,3	0,5	Balance

$$TWR(mm^3/min) = \frac{(T_i - T_f)}{\rho x t} \qquad (1)$$

Experimental study was carried out using Taguchi L9 experiment set. Table 3 shows the experimental parameters and levels. Three different parameters (3-6-9 A) for the discharge current, three different parameters (200-400-800 µs) for the pulse duration and three different duty cycles levels (0.4-1.6-3.2) were used. Pulse off was used constant as 200 µs. The "smaller is better" technique was used to evaluate the experimental results obtained in Taguchi optimization method. Because electro erosion machining requires a low TWR for good dimensional accuracy. The low TWR will provide lower overcut values after machining. Equation 2 is used for the "smaller is better" in Taguchi method. In Equation 2 yi is the performance response, i is the observation value and n is the number of tests in an experiments [17,20].

$$S/N = -10log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (2)$$

Table 3. Experiment set and parameters.

Factor	Unit	Level 1	Level 2	Level 3
Discharge current	A	3	6	9
Pulse duration	µs	200	400	800
Duty cycle	-	0,4	1,6	3,2

3. Results and Discussion

Machining parameters and their levels are greatly affecting the machinability of EDM. For this purpose, determining the machinability parameters for the material and tool is an important issue in EDM. In this study, the machinability of Caldie cold work tool steel with Cu-Cr-Zr electrode was investigated. In the experimental set, discharge current, pulse duration and duty cycle were used. As a result of the experimental study, the TWR and overcut were examined. The experimental results are shown in Table 4. When the test results are examined, the highest TWR was calculated as 1,226 mm^3/min at the experimental condition of 9 A, 800 µs pulse duration and 1,6 duty cycle. The highest overcut value was measured as 0,75 mm under the same test condition. It is seen that the lowest TWR and overcut values are 0,225 mm^3 /min and 0,21 mm at 3 A, 200 µs pulse duration and 0,4 duty cycle conditions, respectively.

Table 4. Experimental results.

Sq.	Ip (A)	Ton (µsn)	Duty cycle	TWR mm^3/min	Overcut mm
1	3	200	0,4	0,225	0,21
2	3	400	1,6	0,291	0,25
3	3	800	3,2	0,355	0,30
4	6	200	1,6	0,676	0,34
5	6	400	3,2	0,716	0,42
6	6	800	0,4	0,788	0,45
7	9	200	3,2	0,930	0,61
8	9	400	0,4	1,025	0,68
9	9	800	1,6	1,226	0,75

3.1 Analysis of Tool Wear Rate

Figure 2 shows the S / N ratios of the processing parameters obtained after the Taguchi optimization study for the TWR. When Figure 2 is examined, it is seen that the most effective factors in TWR after processing Caldie cold work tool steel with Cu-Cr-Zr electrode are respectively discharge current, pulse duration and duty cycle.

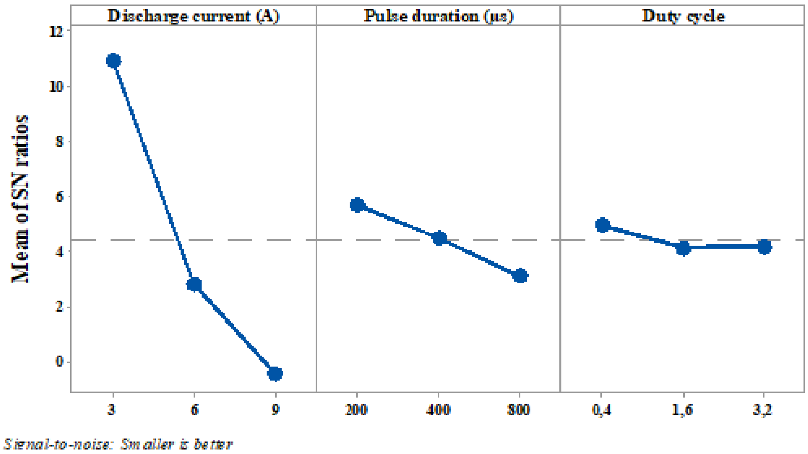

Figure 2. Main effects plot for S/N ratios

The impact of processing parameters and levels on TWR, the S / N ratios demostrated in Figure 2 were indexed in Table 5. These values given in Table 5 show the effect of each level of factors on TWR. The most influential factor and levels are in bold. As a consequence, the Taguchi optimization study, it is seen that the most powerful factors and levels for TWR are discharge current (1), pulse duration (1), duty cycle (1).

Table 5. S/N ratios for TWR.

Level	**Discharge current (A)**	**Pulse duration (µs)**	**Duty cycle**
1	**10,8913**	**5,6626**	**4,9371**
2	2,7908	4,4698	4,1178
3	-0,4513	3,0984	4,1758
Delta	11,3426	2,5642	0,8193
Rank	1	2	3

Figure 3 shows the effects of discharge current, pulse duration and duty cycle on TWR. When Figure 3.a is examined, it is seen that the increase in the discharge current and the pulse duration increases the TWR. In the graph, it is seen that the discharge current has a higher effect on the TWR compared to the pulse duration. In applications, the sparks that occur between the workpiece and the electrode pair cause a decrease in size not only in the workpiece but also in the electrode. This accelerates the wear rate of the electrode [17]. Figure 3.b shows the pulse duration and duty cycle on TWR. It is seen that there are unstable wear rates in tool wear according to duty cycle and pulse duration. It is seen that the TWR is affected more by the discharge current and the pulse duration. Figure 3.c shows that the TWR on the set increases depending on the discharge current, and the amount of wear does not change depending on the duty cycle. It can be seen that the discharge current is the first-degree effective parameter on TWR. Using low discharge current levels of EDM applications will reduce the TWR, but this will also lead to increased processing times.

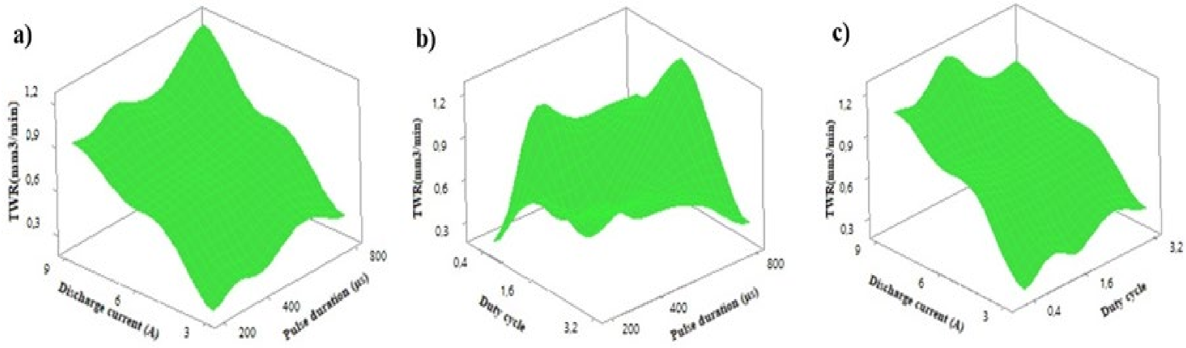

Figure 3. Effect of parameters on TWR

TWR increased significantly in all pulse durations for increasing current values in experiments with both types of materials. This is because, with the increase of discharge energy in the processing zone, more discharge energy is transmitted to the electrode material. In the experiments, it was observed that the TWR increased with the increase of the discharge current. In all experiments, since most of the discharge energy applied in long pulse durations cannot be transmitted to the electrode body as heat, the TWR of the electrode set, which melts and evaporates more material in proportion to the discharge time, increased. As can be seen from these results, the increases in the large values of the discharge current caused large increases in the TWR.

An increase in the value of TWR with an increase in pulse duration is a result that has also been obtained in previous studies. The tendency of the TWR value to decrease after the pulse duration of 50 µs has been interpreted by some researchers as the carbon released by the decay of the dielectric liquid and the melting of the workpiece during long pulse durations, adhering to the surface of the electrode and increasing its wear resistance [18,21]. Another known reason is that most of the discharge energy given during long pulse duration is also transmitted as heat transfer to the electrode body and can melt and evaporate more materials in proportion to the duration of the plasma channel formed [6,11].

ANOVA study has been conducted to better understand the graphics shown in Figure 2 and to express them statistically. ANOVA analysis of TWR is shown in Table 6. When Table 6 is examined, the discharge current is the most powerful parameter on the TWR with 93,658%. Pulse duration and duty cycle are parameters that affect TWR at 5,157% and 0,724, respectively.

Table 6. ANOVA analysis results for TWR.

Source	Adj SS	Adj MS	F Value	PCR
Ip (A)	0,89462	0,447310	203,87	93,658
Ton (µs)	0,04926	0,024634	11,23	5,157
Duty cycle	0,00691	0,003459	1,58	0,724
Error	0,00438	0,002194		0,459
Total	0,95519			100

3.2 Analysis of Overcut

Figure 4 shows the S / N ratios of the processing parameters obtained after the Taguchi optimization study for overcut. When Figure 4 is examined, it is seen that the most effective factors for overcut after processing Caldie cold work tool steel with Cu-Cr-Zr electrode are respectively discharge current, pulse duration and duty cycle.

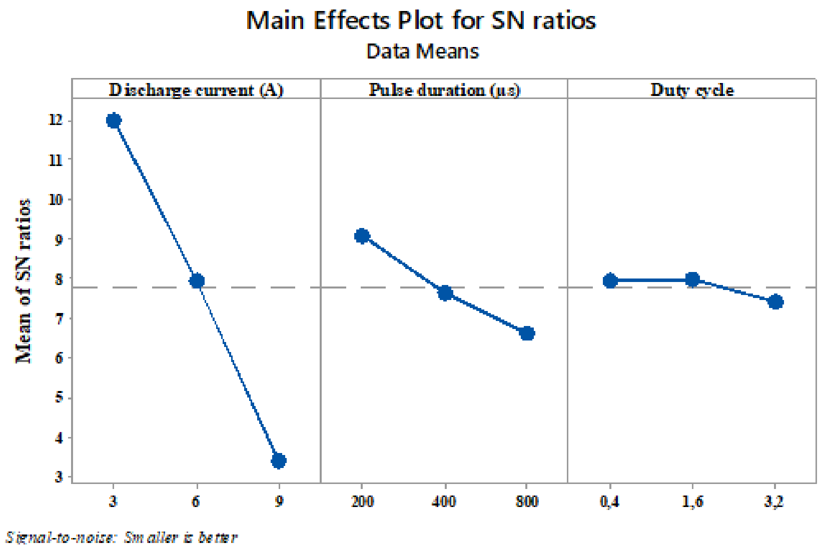

Figure 4. Main effects plot for S/N ratios

S / N ratios shown in Figure 3 are tabulated in Table 7 in order to better understand the effects of processing parameters and levels on overcut. These values given in Table 7 show the effect of each level of factors on overcut. The most influential factor and levels are in bold. As a consequence of the Taguchi optimization study, it is seen that the most poweful factors and levels for overcut are discharge current (1), pulse duration (1) and duty cycle (2).

Table 7. S/N ratios for overcut.

Level	Discharge current (A)	Pulse duration (µs)	Duty cycle
1	**12,018**	**9,073**	7,947
2	7,947	7,642	**7,970**
3	3,381	6,631	7,429
Delta	8,637	2,442	0,541
Rank	1	2	3

Figure 5.a shows the pulse duration and the effect of duty cycle on overcut graphically. When the graph is examined, it is seen that the overcut value increases after the pulse duration 400 µs. The pulse duration is the elapsed time between the start of the spark discharge and the end of the spark. In other words, the long pulse duration means that the same discharge energy flows to the workpiece for a longer time. This means that spark strikes to the processed lateral surfaces per unit time at the same current value in a longer time and more material is removed from the surface of the workpiece. This situation causes the overcut value to increase with the increase of the pulse time. Figure 5.b shows that with the increase in duty cycle, the overcut value also increases. Figure 5.c shows the change in overcut value depending on duty cycle and discharge current. When the gaps are examined, it is seen that the overcut value does not change depending on the duty cycle. This indicates that the duty cycle parameter has a low effect on the overcut value.

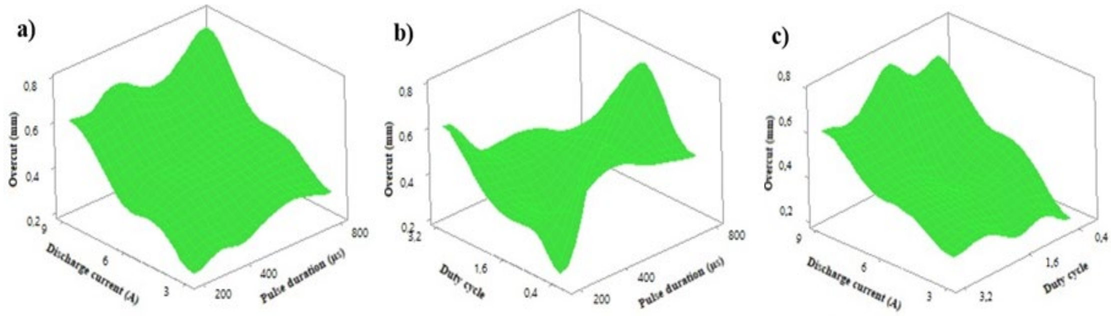

Figure 5. Effect of parameters on overcut

Figure 5 shows the effects of discharge current, pulse duration and duty cycle on overcut. In Figure 5.a, it is seen that the overcut value increases with the increase of the discharge current. When the discharge current is increased, the tool creates a spark from the same locations along the processing line with more discharge energy in the same time period and thus increases the machining area by enabling more material to be processed. The increased processing area also causes the channel width to increase. Figure 6.a shows the microscope image of the processed material with a 15x15 mm copper electrode with a 3 A discharge current, 800 µs pulse duration and 3,2 duty cycle. Figure 6.b shows the microscope image of the material processed at 9 A discharge current, 800 µs pulse duration and 1,6 duty cycle. After processing Figure 6.a, the channel width was measured as 15030 µm. In Figure 6.b, the channel width after processing was measured as 15750 µm. High levels of discharge current and pulse duration appear to increase the width of the working channel.

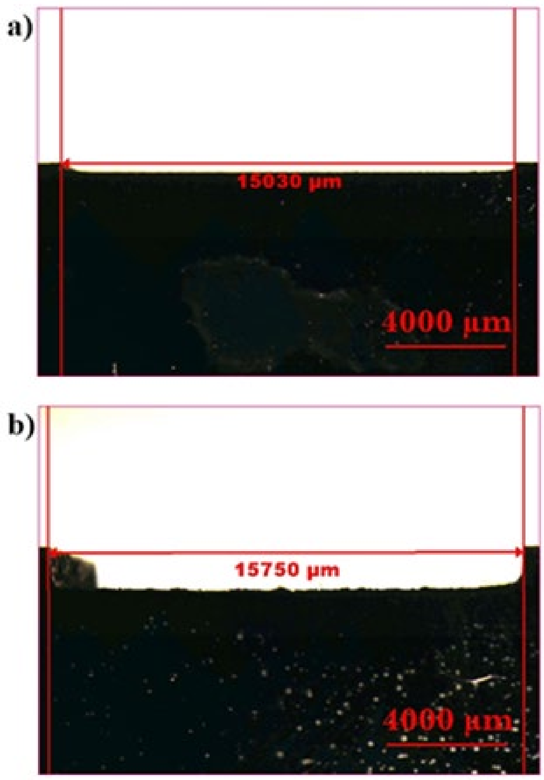

Figure 6. Microscope of image of machined parts

Table 7 shows the values obtained as a result of the ANOVA study for overcut. When Table 7 is examined, the discharge current is the most effective parameter on overcut with 93,25%. Pulse duration and duty cycle are the parameters that affect overcut with 6,42%, 0,01% respectively.

Table 8. ANOVA analysis results for overcut.

Source	Adj SS	Adj MS	F Value	PCR
Ip (A)	0,281089	0,140544	294,16	93,25
Ton (µs)	0,019356	0,009678	20,26	6,42
Duty cycle	0,000022	0,000011	0,02	0,01
Error	0,000956	0,000478		0,32
Total	0,301422			100,00

4. Conclusions

TWR and overcut is one of the most important issues affecting the performance of machining with electro erosion. For this purpose, in this study, the effects of discharge current, pulse duration and duty cycle on EDM machining were investigated. Optimization study were applied on the experimental outputs after machining. Optimum machining levels were determined for machining parameters. With the ANOVA analysis, the effect levels of the parameters on the processing output were determined. As a result of the experimental study, it has been determined that the discharge current is the most effective parameter on TWR and overcut. Increasing discharge current increases TWR and overcut. In the optimization process, $A_1B_1C_1$ experiment set was calculated for the lowest TWR. Optimized experimental condition for the lowest overcut value was determined as $A_1B_1C_2$. As a result of ANOVA analysis, the effect of discharge current was 93,658% for TWR and 93,25% for overcut respectively. Duty cycle value has been calculated to have a low effect on TWR and overcut. It has been determined that the discharge current and pulse duration values to be used at low levels for better dimensional accuracy.

References

[1] Sahu B. K., Datta S. and Mahapatra S. S. On Electro-Discharge Machining of Inconel 718 Super Alloys: An Experimental Investigation. Materials Today: Proceedings 2018; 5: 4861–9.

[2] Jafarian F. Electro discharge machining of Inconel 718 alloy and process optimization. Materials and Manufacturing Processes 2020; 35: 95–103.

[3] Rahul, Datta S., Bhusan B. B. Experimental Studies on Electro-Discharge Machining of Inconel 825 Super Alloy Using Cryogenically Treated Tool/Workpiece. Journal of the International Measurement Confederation 2019; 145: 611–30.

[4] Mahdieh M. S. The Surface Integrity of Ultra-Fine Grain Steel, Electrical Discharge Machined Using Iso-Pulse and Resistance–Capacitance-Type Generator. Proceedings of the Institution of Mechanical Engineers, Part L 2020; 234: 564–73.

[5] Mascaraque-Ramírez C. and Franco P. Comparison Between Different Methods for Experimental Analysis of Surface Integrity in Die-Sinking Electro-Discharge Machining Processes. Proceedings of the Institution of Mechanical Engineers, Part B 2020; 234: 479–88.

[6] Niamat M, Sarfraz S, Shehab E, Ismail S. O. and Khalid Q. S.. Experimental Characterization of Electrical Discharge Machining of Aluminum 6061 T6 Alloy Using Different Dielectrics. Arabian Journal for Science and Engineering, 44, pp. 8043–52.

[7] Tiwary A. P., Pradhan B. B. and Bhattacharyya B. Influence of Various Metal Powder Mixed Dielectric on Micro-EDM Characteristics of Ti-6Al-4V. Materials and Manufacturing Processes 2019; 34: 1103–19.
[8] Pradhan D. M. K. Multi-Objective Optimization of MRR, TWR and Radial Overcut of EDMed AISI D2 Tool Steel Using Response Surface Methodology, Grey Relational Analysis And Entropy. Journal for Manufacturing Science and Production 2012; 12: 51–63.
[9] Dave H. K., Mathai V. J., Mayanak M. K., Raval H. K. and Desai K. P. Study on Effect of Process Parameters on Overcut and Tool Wear Rate During Micro-Electro-Discharge Slotting Process. International Journal of Advanced Manufacturing Technology 2016; 85: 2049–60.
[10] Ahmed N., Ishfaq K., Rafaqat M., Pervaiz S., Anwar S. and Salah B. EDM of Ti-6Al-4V: Electrode and Polarity Selection for Minimum Tool Wear Rate and Overcut. Materials and Manufacturing Processes 2019; 34: 769–78.
[11] Pradhan M. K. Estimating the Effect of Process Parameters on MRR, TWR and Radial Overcut of EDMed AISI D2 Tool Steel by RSM and GRA Coupled with PCA. International Journal of Advanced Manufacturing Technology 2013; 68: 591–605.
[12] Rouniyar A. K., Shandilya, P. Semi-empirical modeling and optimization of process parameters on overcut during MFAPM-EDM of Al6061 alloy. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering 2021; 235: 1784-1796.
[13] Belgassim, O., Abusaada, A. Investigation of the influence of EDM parameters on the overcut for AISI D3 tool steel. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 2012; 226: 365-370.
[14] Chiang, H. N., Wang, J. J. An analysis of overcut variation and coupling effects of dimensional variable in EDM process. The International Journal of Advanced Manufacturing Technology 2011; 55: 935-943.
[15] Dewangan S., Biswas C. K. and Gangopadhyay S. Optimization of the Surface Integrity Characteristics of EDM Process Using PCA based Grey Relation Investigation. Procedia Materials Science 2014; 6: 1091–6.
[16] Muthukumar V., Rajesh N., Venkatasamy R., Sureshbabu A. and Senthilkumar N. Mathematical Modeling for Radial Overcut on Electrical Discharge Machining of Incoloy 800 by Response Surface Methodology. Procedia Materials Science 2014; 6: 1674–82.
[17] Lin Y. C., Wang A. C., Wang D. A. and Chen C. C. Machining Performance and Optimizing Machining Parameters of Al2O3–TiC Ceramics Using EDM Based on the Taguchi Method. Materials and Manufacturing Processes 2009; 24: 667–74.
[18] Lin M. Y., Tsao C. C., Huang H. H., Wu C. Y. and Hsu C. Y. Use of the Grey-Taguchi Method to Optimise the Micro-Electrical Discharge Machining (Micro-EDM) of Ti-6Al-4V Alloy. International Journal of Computer Integrated Manufacturing 2015; 28: 569–76.
[19] Kalyon A. Elektro Erozyon ile İşlemede Yüzey Pürüzlülüğünün ve İş Parçası İşleme Hızının Taguchi Tekniği ile Optimizasyonu Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi 2019; 21: 595–605.
[20] Mohri N., Suzuki M., Furuya M., Saito N., and Kobayashi A. Electrode Wear Process in Electrical Discharge Machinings. CIRP Annals 1995; 44: 165–8.
[21] Chen S. L., Yan B. H. and Huang F. Y. Influence of Kerosene and Distilled Water as Dielectrics on the Electric Discharge Machining Characteristics of Ti-6A1-4V. Journal of Materials Processing Technology 1999; 87: 107–11.