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Research Article

Overcut Optimization in Machining of DIN 1.2767 Tool Steel with Electro Erosion Technique

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ABSTRACT

Electro discharge machining is an energy based method that can cause fast electrode wear and dimensional errors. This study aimed to identify the optimum process parameters for processing 1.2767 steel using copper-based electrodes. The Taguchi optimization approach was used, and 18 pieces of 1.2767 steel were prepared for the experiments. The electrodes used were CuCoNiBe and $CuNi_2SiCr$, and the electrode surfaces were sanded and polished before processing. The results showed that the $CuNi_2SiCr$ electrode produced the lowest overcut value of 0.07 mm, while the CuCoNiBe electrode had the highest observed overcut value of 0.320 mm. The discharge level had the most significant impact on overcut, while the type of electrode had the least. The optimal parameters for the $CuNi_2SiCr$ electrode were 12 A discharge current, 50 µs pulse duration, and 800 µs pulse off time. The processing under ideal conditions resulted in an overcut measurement value of 0.05 mm.

Keywords: *EDM, Overcut, Copper, Taguchi, Optimization*

DIN 1.2767 Takım Çeliğinin Elektro Erozyon Tekniği ile İşlenmesinde Yanal Açıklık Optimizasyonu

ÖZ

Elektro erozyon ile işleme, hızlı elektrot aşınmasına ve boyutsal hatalara neden olabilecek enerji tabanlı bir işleme yöntemidir. Bu çalışma, bakır bazlı elektrotlar kullanarak 1.2767 çeliğini işlemek için optimum işlem parametrelerini belirlemeyi amaçlamıştır. Taguchi optimizasyon tekniği kullanılarak deneyler için 18 adet 1.2767 çeliğinden işparçası hazırlanmıştır. İşleme deneylerinde CuCoNiBe ve $CuNi_2SiCr$ elektrot kullanılmıştır ve elektrot yüzeyleri işlemeden önce zımparalanarak parlatılmıştır. Çalışma sonucunda $CuNi_2SiCr$ elektrot ile en düşük yanal açıklık değeri olan 0.07 mm, CuCoNiBe elektrod ile en yüksek yanal açıklık değeri olan 0.320 mm elde edilmiştir. Boşalım akımı, yanal açıklık üzerinde en önemli etkiye sahipken, elektrot tipi en az etkiye sahip parametre olmuştur. $CuNi_2SiCr$ elektrot için optimum işlem parametreleri 12 A boşalım akımı, 50 µs vurum süresi ve 800 µs bekleme süresi olarak belirlenmiştir. Optimum işleme şartında, yanal açıklık değeri 0.05 mm olarak elde edilmiştir.

Anahtar Kelimeler: *EEİ, Yanal açıklık, Bakır, Taguchi, Optimizasyon*

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I. INTRODUCTION

Complex and highly precise parts are processed using the electrical discharge machining (EDM) technique. Furthermore, it is particularly suggested for precision machining and the processing of hard materials. It is evident from the benefits that the EDM process is among the best manufacturing techniques for molding. The two most crucial output parameters in the processing of industrial molds are surface quality and measurement accuracy. Surface quality affects the service life of molding components and varies significantly based on processing Parameters [1-3]. In order to avoid production-related errors, dimensional integrity is a critical consideration when producing molding products for mass production. Desired dimensional and shape errors in the EDM process are caused by machining parameters. Vibrations that arise during the machining process, particularly in machining methods, have an impact on both measurement accuracy and surface quality [4-5]. For this reason, it is a subject that needs to be studied to determine the effect of machining parameters on the EDM method. It is important to determine the optimum processing parameters in advance to shorten the processing time and ensure the accuracy of the measurement and surface quality [6-7].

The machinability of electro-discharge machining is dependent on numerous factors. The discharge current, pulse length, pulse on time, electrode type, workpiece material, fluid type of the dielectric medium, and application technique are these. Achieving high-performance processing requires careful selection of these parameters. If not, processing costs rise and processed parts develop dimensional errors. Processing time is decreased by selecting high processing parameters. In terms of cost, this arrangement appears advantageous, but in terms of electrode wear and measurement accuracy, it is not. In a study on Ti-6Al-4V machining, Ahmed et al. used four electrode materials with two different polarities: graphite, aluminum, copper, and brass. In an effort to reduce overcutting and tool wear, they looked into overcutting and tool wear rate. They met the requirements of minimum tool wear and minimum overcut (OC) by choosing the best tool with common tool polarity [8]. Patil and Jadhav came to the conclusion that material removal rate (MRR) is most affected by discharge current (Ip), but also significantly influenced by pulse on time (Ton) and Gap voltage (V). Ip and Ton have the biggest effects on tool wear rate (TWR); duty cycle and V have less of an impact. While surface finishes are improved by higher values of Ton, SR increases as Ip and Toff increase. The largest effect on OC is caused by Ip. Ton and the duty cycle both significantly affect OC. Gap voltage has little effect on open circuit voltage [9]. Kumar, Dewangan, and Pandey's study focuses on how the parameters of the EDM process affect the overcut and surface integrity of machined surfaces. They use the RSM approach to optimize performance metrics, with P91 steel serving as the workpiece and copper serving as the electrode tool. The results show that peak current is the most important factor, followed by duty cycle and pulse-on time [10]. In the EDM process, Chiang and Wang looked into variations in the side and bottom overcuts, electrode dimensions, spark hole dimensions, and machine positioning accuracy. The experiment's findings demonstrate that a key element in determining how the side overcut varies during the EDM process is the coupling effect between the electrode and spark hole diameters [11]. The reduction of side overcut through distortion of the electrical field between the tool and workpiece's side was the subject of Moghanizadeh's investigation. The findings show that using an external voltage around the side of the tools reduces side overcut, and that increasing the external voltage causes the value of overcut to decrease [12]. In Ti-6Al-4V EDM, Ishfaq et al. performed experiments with nano-graphene mixed with kerosene dielectric. They discovered that dimensional errors in axial and radial machining orientations are highly influenced by spark voltage and pulse-time ratio. While a large pulse-time ratio minimizes machining errors in both cutting directions [13]. In order to enhance surface integrity aspects following EDM of AISI P20 tool steel, Dewangan et al. suggested the best possible EDM process parameter settings. The impact of different EDM process parameters on different facets of surface integrity was examined, including Ip, pulse-on Ton, tool work time (Tw), and tool lift time (Tup). They came to the conclusion that dimensional accuracy is negatively impacted by greater pulse duration and current [14]. Using a response surface methodology (RSM) experimental design, Das et al. studied the effects of process variables on overcut. The findings demonstrated that overcut was highly influenced by discharge current, with higher current producing more overcut. The gap, pulse on, and pulse off times were additional factors influencing overcut. Increasing the gap led to the lowest overcut, which was also the result of having the highest pulse on and the lowest pulse time [15]. During the EDM of Ti-6Al-4V, a reversal trend was seen between OC and discharge current (i.e., low intensity of discharge current provided poor dimensional accuracy) [16]. According to a different study, the most important factors in determining the OC magnitude are the tool material and pulse on time [17]. Grey relational analysis and analysis of variance were used in another study on Ti-6Al-4V EDM. It was determined that the key input parameter influencing the OC value is spark voltage [18].

Cold work tool steels have gathered significant interest for critical roles in a variety of industrial domains, including blanking and forming dies, gauges, and collets. They are commonly used in a variety of applications, including dies for cutting and shaping, coining, punching, shear blades, fullers, thermosetting resin forming, cold forming, thread rolling, fine blanking, stripper plates, profiling rollers, press tools, brick molds, chisels, and pneumatic tools [19,20]. Cakir and Ceritbinmez conducted a study to investigate the performance enhancement of brass EDM electrodes using cryogenic treatment while machining cold work steel AISI D2.The results show that cryogenic treatment improves material removal rate, tool wear, and surface quality, which can be attributed to increased electrical conductivity and changes in the internal structure of the brass electrode [21]. A study on cryogenically treated mold steel electrodes demonstrates the potential of machine learning algorithms to predict electro-erosion wear during EDM processes. The models showed exceptional accuracy, identifying factors affecting wear patterns and improving productivity and production quality [22]. Ramesh et al conducted an experimental study of powder-mixed electric discharge machining of AISI P20 steel with various powders and tool materials. Experiments are conducted using Taguchi's L_{27} orthogonal array. The results show that the copper tool combined with Al powder achieves the highest material removal rate, while the Al_2O_3 powder combined with tungsten tool produces the least radial overcut [23]. Dewangan et al investigated the optimization of input parameters in EDM of AISI 1020 steel with 0.2% carbon content. Five samples were chosen, each with distinct physical characteristics. The samples' hardness varied after heat treatment, taking into account current, pulse-on-time, and pulse-off-time variables. The study discovered that water and oil-quenched specimens could be machined with less current, indicating that heat treatment had successfully improved the material's properties [24]. Nas investigated the machinability of AISI H13 hot work tool steel that had undergone deep cryogenic treatment with electro-erosion machining. The parameters used in the study included current, pulse time, and three electrodes (copper, graphite, and tuncop). The experimental design was based on the Taguchi L_{27} model, and machinability tests were carried out to evaluate the results. The study discovered that surface roughness, hole diameter, material wear, and crater diameter increased with ampere and impact time [25]. Electro discharge machining is a sort of energy-based machining. A disadvantage of this electrodischarge machining approach is the inability to control the energy used in uncommon production processes. Choosing high processing settings, especially to reduce processing times, results in fast electrode wear and the formation of dimensional errors. An optimization analysis was carried out in this study to identify optimum process parameters in the processing of 1.2767 steel using various copper-based electrodes for this purpose. Graphics are used to interpret the impact of process parameters. Using the Taguchi optimization approach, ideal machining settings were found in order to produce the optimum dimensional values.

II. MATERIAL & METHODS

The Taguchi L_{18} orthogonal experiment set was used for electro-discharge machining experiments. 18 pieces of 1.2767 steel with dimensions of 50 mm x 25 mm x 12 mm were prepared for the experimental studies. The chemical composition of 1.2767 steel is shown in Table 1. As electrodes in the experiment, 16 mm CuCoNiBe, and $CuNi_2SiCr$ were used. A holder connects the electrodes to the bench. Each experimental condition required its own set of electrodes. The chemical composition of the electrodes is shown in Table 2.

__Table 1.__ DIN 1.2767 steel chemical composition (weight percentage)

Element	C	Si	Mn	Cr	Mo	Ni	Fe
Weight (%)	0.45	0.25	0.35	1.35	0.25	4.05	Balance

__Table 2.__ Copper electrode chemical composition (weight percentage)

	Cu	Cr	Si	Be	Co+Ni	Mn	Ni	Pb	Fe	Others
CuCoNiBe	Base	-	-	1	2	-	-	-	-	0.5
$CuNi_2SiCr$	Base	0.35	0.65	-	-	0.10	2.5	0.02	0.15	-

The Furkan M25A sink erosion machine was used for the experiments. The experiments were conducted on the FURKAN M25A sinker electrical discharge machine. The maximum peak current is 25 Amps and the maximum pulse on-time and pulse off-time are 1600 µs. The sinking EDM machine tool consists of the power supply, control unit, tool holder, worktable, servo control system and dielectric fluid delivery system. Three different electrodes, three different discharge currents, pulse on time, and pulse off time were used in the processability experiments. During the processing, a negative pole was chosen for the workpieces and a positive pole for the electrode. The dielectric medium fluid was kerosene. Laterally, dielectric medium fluid was applied to the processing zone. Each workpiece was processed for 1 hour for processing experiments. A stereomicroscope was used to measure the processed areas after they had been processed. Figure 1 represents the schematic diagram of the experimental study.

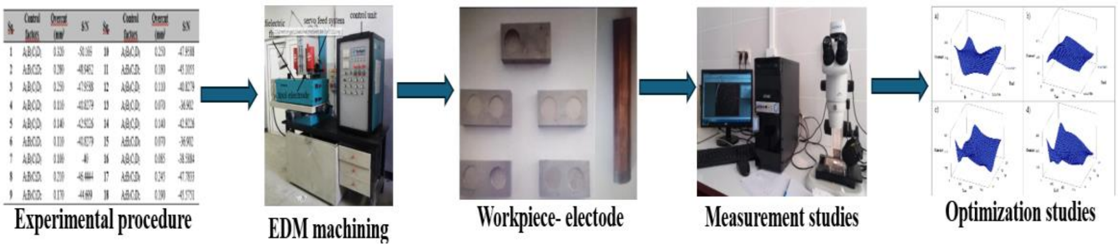

Figure 1. *Schematic diagram of the experimental study*

In industrial settings, traditional experimental design techniques are expensive and time-consuming, which increases experimentation and challenges. The Taguchi method (TM) of fractional factorial design provides a simpler and more effective solution by minimizing the number of experiments needed and enabling independent factor evaluation. By creating equal samples for various levels of factors under each tested condition, the TM maintains equilibrium in the experimental design. Reducing variability around the target value is the TM's primary goal [26,27].

A signal-to-noise (S/N) ratio, which compares the actual value required from the system to a factor not taken into account during design, is used to evaluate the measurement results. A product with a higher S/N ratio is of higher quality, and as signal values rise, noise levels should also fall. The three most popular methods for calculating the S/N ratio are "nominal is best," "smaller is better," and "larger is better." In this study, the maxim "smaller is better" was applied to minimize overcut, as determined by Equation (1), in which n is the number of experiments and yi is the experiment's data [28,29]. The Taguchi experimental design determined for the experimental study is shown in Table 3.

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

__Table 3.__ Erosion Parameters and levels

Inputs	Unit	Level 1	Level 2	Level 3
Electrode		CuCoNiBe	CuNi2SiCr	
Ip	A	6	12	25
Ton	µs	50	200	800
Toff	µs	50	200	800

III. RESULTS AND DISCUSSION

The overcut values obtained from the experimental investigation utilizing CuCoNiBe and $CuNi_2SiCr$ electrodes are displayed in Table 4. Three different discharge current levels 6, 12, and 25 Amperes as discharge current, as pulse on and pulse off times 50, 200, and 800 µs were employed in the experimental investigation. The experimental study resulted in the lowest overcut value of 0.07 mm when the $CuNi_2SiCr$ electrode was used in the circumcantes of $A_2B_2C_1D_2$ and $A_2B_2C_3D_1$ experimental conditions. Under experimental conditions of 6 A, 50 µs, and 50 µs, the CuCoNiBe electrode resulted in the highest measured overcut value of 0.320.

Table 4. *Experimental results and S/N ratios*

Sq.	Control factors	Overcut (mm)	S/N	Sq.	Control factors	Overcut (mm)	S/N
1	$A_1B_1C_1D_1$	0.320	-50.103	**10**	$A_2B_1C_1D_1$	0.250	-47.9588
2	$A_1B_1C_2D_2$	0.280	-48.9432	**11**	$A_2B_1C_2D_2$	0.180	-45.1055
3	$A_1B_1C_3D_3$	0.250	-47.9588	**12**	$A_2B_1C_3D_3$	0.110	-40.8279
4	$A_1B_2C_1D_2$	0.110	-40.8279	**13**	$A_2B_2C_1D_2$	0.070	-36.902
5	$A_1B_2C_2D_3$	0.140	-42.9226	**14**	$A_2B_2C_2D_3$	0.140	-42.9226
6	$A_1B_2C_3D_1$	0.110	-40.8279	**15**	$A_2B_2C_3D_1$	0.070	-36.902
7	$A_1B_3C_1D_3$	0.100	-40	**16**	$A_2B_3C_1D_3$	0.085	-38.5884
8	$A_1B_3C_2D_1$	0.210	-46.4444	**17**	$A_2B_3C_2D_1$	0.245	-47.7833
9	$A_1B_3C_3D_2$	0.170	-44.609	**18**	$A_2B_3C_3D_2$	0.190	-45.5751

The graphs generated from the overcut values measured resulting from electro erosion processing using two different electrodes are shown in Figure 2. The application of the $CuNi_2SiCr$ electrode has a negative, though slight, impact on the overcut value, as Figure 2.a illustrates. It appears that the CuCoNiBe electrode can lead to improved measurement accuracy. It can be observed that the overcut value rises as the discharge current value accomplishes. In particular, high discharge current values had a positive impact on the overcut value, whereas low discharge current values increased the overcut value. The impact of electrode type and pulse duration on overcut can be seen in Figure 2.b. It can be observed that as pulse time increases, the overcut value rises as well [30-31]. Compared to the $CuNi_2SiCr$ electrode, it appears that the CuCoNiBe electrode has a more detrimental effect on overcut.

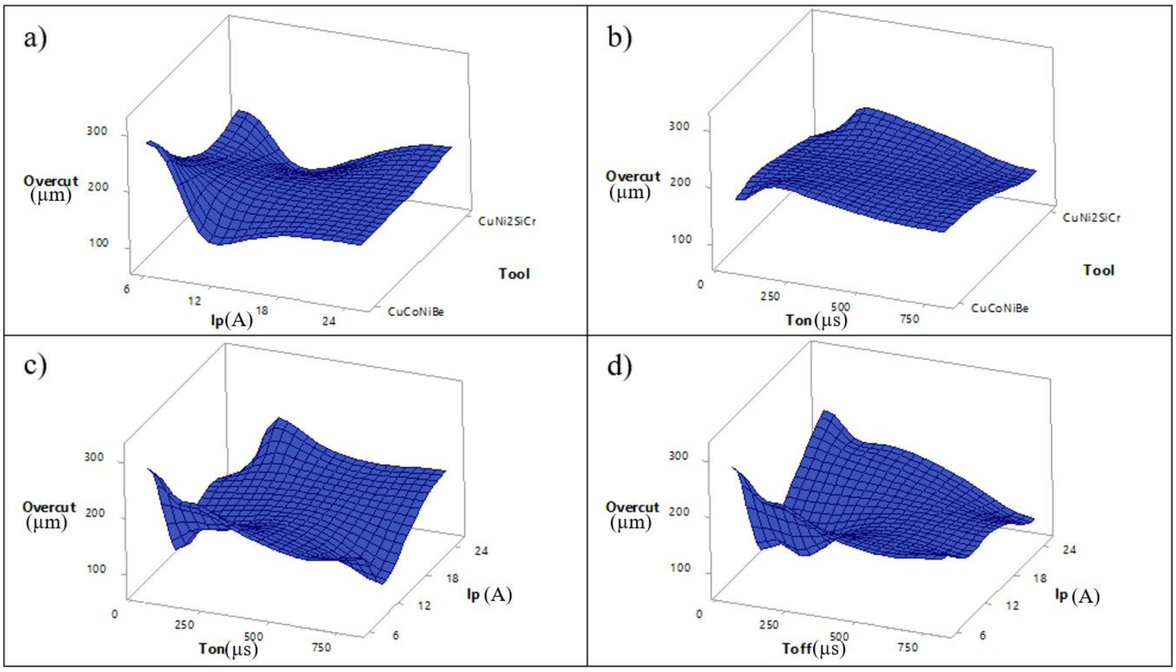

Figure 2. *Effect of erosion parameters on overcut*

Figure 2.c shows that the effect of pulse duration and discharge current on overcut varies according to parameter levels. It seems that increasing the pulse duration has a negative effect on overcut. However, while low discharge and high discharge levels increased the overcut value, better results were obtained at medium discharge current values. Figure 2.d shows that increasing the pulse off time has a positive effect on the overcut value. It is known that increasing the pulse off time results in better cleaning of the processing area and the creation of a better processing environment [32]. It is seen that using high discharge current at high erosion levels reduces the overcut value [33,34]. This shows that cleaning the processing area from particles formed after processing is an important issue for the measurement accuracy of the processing operation.

The S/N ratios of the parameter effect on the overcut are displayed in Figure 3. Examining the graph reveals that overcut is significantly influenced by the discharge level. It is evident that the electrode type has the lowest effect level. Overcut values are observed to rise with the CuCoNiBe electrode and at low current levels. Overcut values are also adversely affected by medium pulse duration and low pulse off times [35,36].

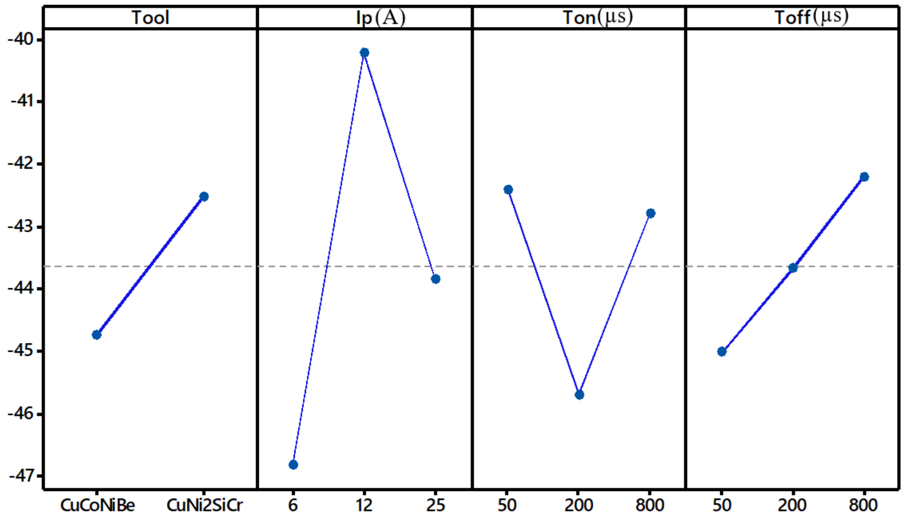

Figure 3. *S/N ratios*

The S/N ratios in Figure 3 can be better understood by examining at the tabulated values in Table 5. The optimal values for the processing Parameters electrode type, discharge current, pulse on time, and pulse off time can be observed by studying Table 5. It was determined that the $CuNi_2SiCr$ electrode, discharge current of 12 A, pulse on time of 50 μs, and pulse off time of 800 μs were the ideal parameter levels for the electrode type.

Table 5. *Optimum machining levels for the overcut*

Level	Tool	Ip	Ton	Toff
1	-44.74	-46.82	-42.40	-45.00
2	-42.51	-40.22	-45.69	-43.66
3		-43.83	-42.78	-42.20
Delta	2.23	6.60	3.29	2.80

The workpiece processed using the $CuNi_2SiCr$ electrode under the $A_2B_2C_1D_2$ experimental condition characterized by a 12 A discharge current, 50 μs pulse on time, and 200 μs pulse off time yielded an overcut value of 0.07 mm, as depicted in Figure 4.a. Through Taguchi optimization, the $A_2B_2C_1D_3$ experimental condition was identified as the optimal set of parameters. The predicted overcut value for this condition, according to Taguchi analysis, was 0.0438 mm. Upon validating this prediction, the overcut measurement under the optimized conditions (using the $CuNi_2SiCr$ electrode with a 12 A discharge current, 50 µs pulse on time, and an extended 800 µs pulse off time) resulted in a measured overcut of 0.05 mm, as shown in Figure 4.b.

This finding highlights the effectiveness of using Taguchi optimization to fine-tune the EDM process parameters for achieving minimal overcut. The reduction in overcut from the initial 0.07 mm to 0.05 mm demonstrates that adjusting the pulse off time plays a critical role in enhancing machining precision. Consequently, by systematically experimenting with different electrodes and processing conditions, it is possible to accurately determine the ideal overcut value for machining DIN 1.2767 steel, thereby improving the overall accuracy and quality of the final product.

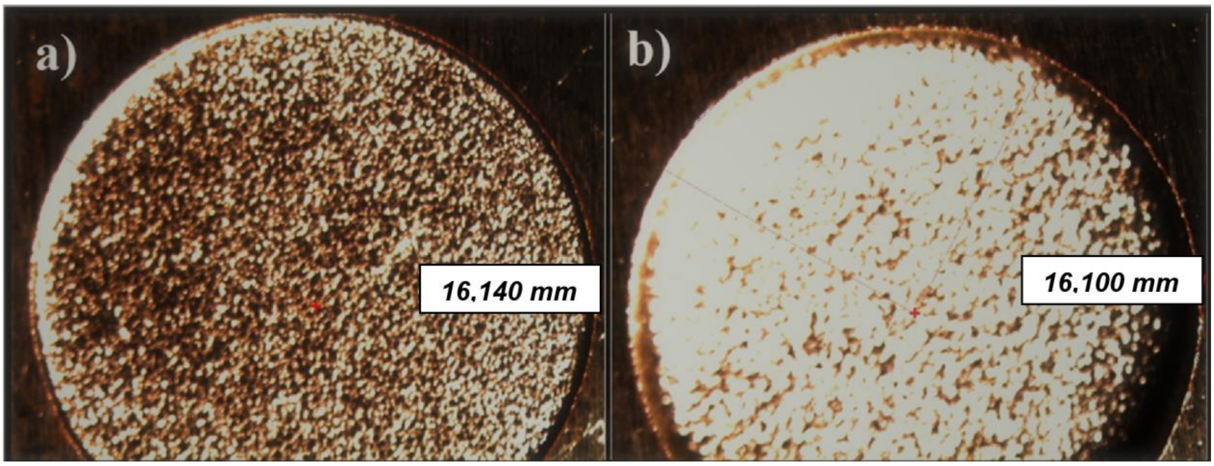

Figure 4. *Overcut measurement results a) $A_2B_2C_1D_2$ b) $A_2B_2C_1D_3$*

IV. CONCLUSION

Taguchi optimization aids in establishing the ideal combination of input parameters such as voltage, current, pulse duration, and electrode material, resulting in improved machining efficiency. By systematically adjusting these parameters using Taguchi methodologies, the process could be adjusted to get the required machining results with little trial and error. CuCoNiBe and $CuNi_2SiCr$ electrodes were used in this work to process DIN 1.2767 steel under various processing conditions. The impacts of the process parameters on the overcut value were examined by measuring the machining area. As the $CuNi_2SiCr$ electrode was employed in the circumcantes of the $A_2B_2C_1D_2$ and $A_2B_2C_3D_1$ experimental settings, the experimental investigation produced the lowest overcut value of 0.07 mm. The CuCoNiBe electrode exhibited the highest observed overcut value of 0.320 mm while investigated at 6 A, 50 µs, and 50 µs. The discharge level has a major impact on overcut. The least impact on overcut is caused by the type of electrode. At low current levels, it is observed that overcut values increase when using the CuCoNiBe electrode. Medium pulse on time and low pulse off times also have a negative impact on overcut values. The optimal parameter levels for the electrode type were found to be the CuNi2SiCr electrode, discharge current of 12 A, pulse on time of 50 µs, and pulse off time of 800 µs. Processing under ideal experimental circumstances led to a measurement of the overcut measurement value of 0.05 mm. By identifying the optimal combination of parameters, Taguchi methods help to achieve precise control over the machining process, reducing overcut and improving dimensional accuracy.

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