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*Research Article*

# *Investigation of Drilling Performance of Hardened 32CRMOV12-10 Tool Steel on Electro-Discharge Machine*

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## ABSTRACT

In this study, EDM process was applied to DIN 32CrMoV12-10 (1.7765) high-quality cold work tool steel with a hardness of 50 HRC with different processing parameters. The experimental design of the study was prepared using Taguchi L27 orthogonal array. Processing parameters were used three different electrode materials (copper, graphite, tuncop), three different currents (10, 20, 30 Amps), three different pulse durations (200, 400, 600 µs), constant cutting depth (1 mm) and constant time off (50 µs). Following the experiments, the hole diameters formed by the electrode materials on the material surface were measured. The results obtained were examined experimentally and statistically. The smallest hole diameter was measured as 12.2085 mm in the experiments carried out with the copper electrode, and the largest hole diameter was measured as 12.5284 mm with the tuncop electrode. When the study was examined statistically (Signal-to-noise ratio), it was determined that the most suitable processing parameters to create the ideal hole diameter were 10 Amps current and 200 µs pulse duration in copper electrode material. When the analysis of variance (ANOVA) results were examined, it was determined that the most effective machining parameter for the hole diameter was the Amps value of 47.85%.

**Keywords:** *Electro discharge machining, Hole diameter, Taguchi method.*

# *Sertleştirilmiş 32CRMOV12-10 Takım Çeliğinin Elektro-Erozyon Tezgahında Delme Performansının İncelenmesi*

## ÖZET

Bu çalışmada, sertliği 50 HRC olan DIN 32CrMoV12-10 (1.7765) yüksek kaliteli soğuk iş takım çeliğine farklı işleme parametreleriyle EDM işlemi uygulanmıştır. Çalışmanın deneysel tasarımı Taguchi L$^{27}$ ortogonal dizi kullanılıp hazırlanmıştır. Deneylerde işleme parametreleri olarak üç farklı elektrot malzeme (bakır, grafit, tuncop), üç farklı akım (10, 20, 30 A), üç farklı vurum süresi (200, 400, 600 µs), sabit talaş derinliği (1 mm) ve sabit bekleme süresi (50 µs) kullanılmıştır. Yapılan deneylerin ardından elektrot malzemelerin malzeme yüzeyinde oluşturduğu delik çapları ölçülmüştür. Elde edilen sonuçlar deneysel ve istatistiksel olarak incelenmiştir. Çalışma sonucunda tüm elektrot malzemeleriyle yapılan deneylerde en küçük delik çapının 200 µs ve 10 amper akımda, en büyük delik çapının ise tüm elektrot malzemelerinde 600 µs ve 30 amper akımda oluşmuştur. En küçük delik çapının bakır elektrot ile gerçekleştirilen deneylerde 12.2085 mm olarak, en büyük delik çapının ise tuncop elektrot ile 12.5284 mm olarak ölçülmüştür. Çalışma istatiksel (Sinyal-gürültü oranı) olarak incelendiğinde ideal delik çapını oluşturmak için en uygun işleme parametrelerinin bakır elektrot malzemede, 10 A amper akım ve 200 µs vurum süresi olduğu belirlenmiştir. Varyans analizi (ANOVA) sonuçları incelendiğinde ise delik çapı için en etkili işleme parametresinin %47.85 oranında amper değerinin olduğu tespit edilmiştir.

**Anahtar Kelimeler:** *Delik çapı, Elektro erozyon işleme, Taguchi metot.*

## I. INTRODUCTION

Electro discharge machining (EDM) is a non-traditional manufacturing process and has proven to be an effective alternative compared to conventional manufacturing processes. In this electro-thermal process, chip is removed from the material by controlled arcs produced between the tool electrode immersed in dielectric liquid and the workpiece. The high temperature of the discharge current melts and vaporizes the workpiece material and creates overlapping craters on the machined surfaces (Clijsters et al., 2010). During this period, no mechanical cutting force is applied to the workpiece material. All metals that have(the ability to conduct electricity can be subjected to this process (Chen et al., 1999). Since there is no mechanical contact between the two electrodes, the process is able to shape any conductive component, regardless of its hardness, into accurate and complex shapes.

In the early 1980s, local Turkish companies produced EDM machines to meet the needs of the domestic market and Electro-erosion became a production method that can process complex shapes and hard materials to precise dimensions. Machining properties are independent of the hardness, toughness and strength values of the material. On the other hand, processing efficiency depends on the melting temperature and thermal conductivity of the material (Yilmaz et al., 2015) (Yilmaz, 2013) (Her and Weng, 2001). In research aiming to meet the low machining time, high quality and low-cost expectations of the production sector, special importance is given to improving relative wear, workpiece processing speed, average surface roughness and electrode wear rate (Yilmaz et al., 2015). The development of Electro EDM Machining started in 1943 using controlled discharge conditions to achieve precision machining, and since then, EDM technology has developed rapidly and has been used in mold making, micro machining, prototyping, etc. It has become indispensable in manufacturing applications (Dutta et al., 2015). However, understanding arc discharges even at a steady state remains a challenge. The electrical discharge phenomenon in EDM occurs in a very narrow space filled with liquid in a very short time period and involves evaporation and melting of the electrodes and material, thus making both observation and the theoretical analysis extremely difficult (Kunieda et al., 2005).

EDM technology provides significant improvements in terms of time and cost in metals that are very difficult to process in current processes (Yilmaz, 2013). Any conductive material can be processed by electrodischarge. Tooling electrodes that act as templates are required for machining. The negative of the electrode form becomes processed on the material surface. The most important limitation of EDM is that it removes chips very slowly compared to other machines. The second limitation of the bench is the preparation and consumption of electrodes. Electro-discharge machines require other machines to prepare the electrodes (Özgedik, 2014). Additionally, in order to expand the application scope of the EDM method, rotating electrodes with a diameter of 30-50 mm are used in the drilling process (Springborn, 1967). In the surface finishing process, there are different studies such as metal powder mixed with dielectric liquid (Mohri, 1988), surface variability with composite electrode (Mohri et al., 1993), linear machining (Saito et al., 1986).

In this study, the etching process of DIN 32CrMoV12-10 (1.7765) tool steel, which has a hardness of 50 HRC, will be carried out on the EDM machine using different processing parameters. The test results will be examined both experimentally and statistically to determine the ideal processing parameters. The result of this study will guide researchers for subsequent EDM studies to be carried out with the same material at different processing parameters.

## II. MATERIAL AND METHOD

In this section, the materials, devices, systems used in the experiments and the methods used to evaluate the data obtained are explained.

### *A. Material and Electrode*

Experiments carried out at room temperature were carried out using a King ZNC–K-3200 brand model plunge erosion bench. DIN 32CrMoV12-10 (1.7765) steel (Figure 1) with dimensions of Ø15X10 mm, which is difficult to machine, was used as the workpiece. Heat treatment was applied to a hardness of 50 HRC by vacuum hardening method. This material, which is resistant to high temperatures, has recently been widely used in the defense industry engineering field. Electrolytic copper, graphite and tuncop materials of Ø12X100 mm size with density of 8.90 g/cm$^3$, 1.80 g/cm$^3$, 15.20 g/cm$^3$ were used as electrodes, respectively.

Table 1. Chemical composition of DIN 32CrMoV12-10 (1.7765) steel used in experiments.

| **Carbon %** | **Silicon %** | **Manganese %** | **Chromium %** | **Molybdenum %** | **Vanadium %** |
|---|---|---|---|---|---|
| 0.32 | 0.35 | 0.60 | 3.00 | 1.00 | 0.30 |

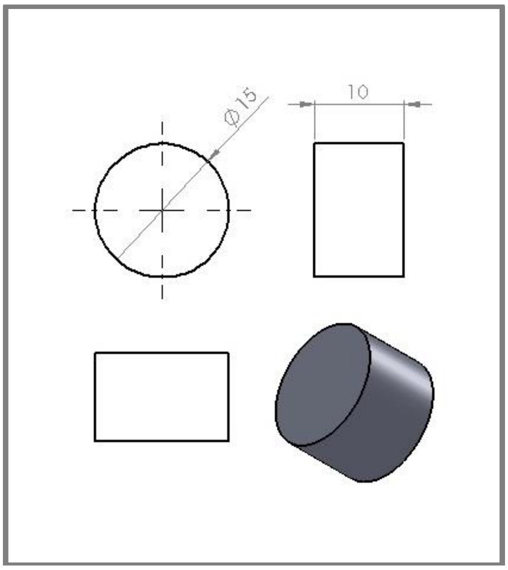
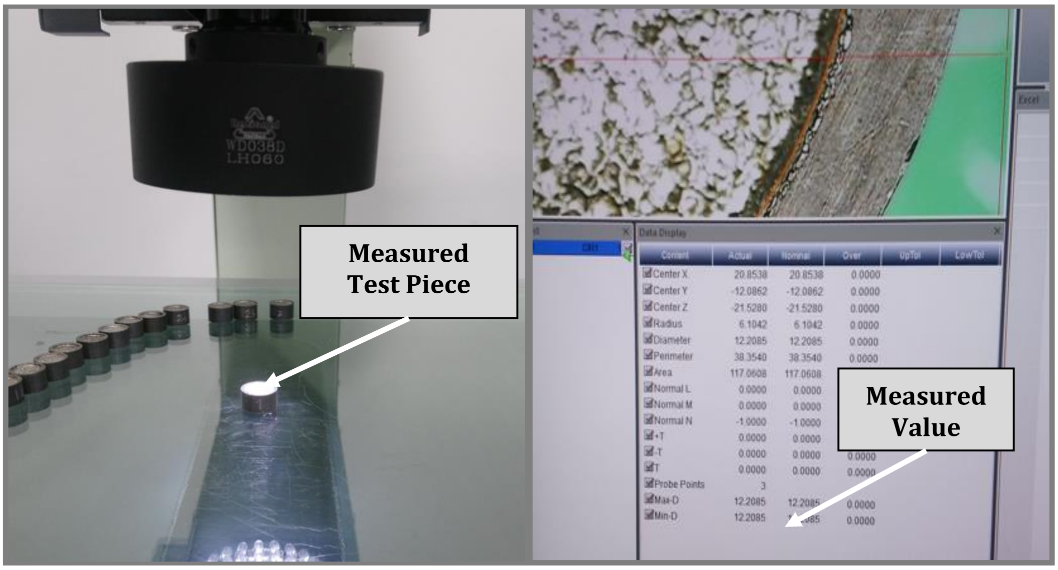


Figure 1. Technical drawing of the workpiece used in experimental studies.

### B. *Hole Diameter Measurements*

The hole diameters resulting from the abrasions on the material surface of the three different electrodes used in the experiments were determined with the arithmetic average by making 3 different measurements with the Rational VMS-4030G brand video measuring device with a measurement accuracy of 1/10.000.



| Content | Actual | Nominal | Over | UpTol | LowTol |
|---|---|---|---|---|---|
| ☑ Center X | 20.8538 | 20.8538 | 0.0000 | | |
| ☑ Center Y | -12.0862 | -12.0862 | 0.0000 | | |
| ☑ Center Z | -21.5280 | -21.5280 | 0.0000 | | |
| ☑ Radius | 6.1042 | 6.1042 | 0.0000 | | |
| ☑ Diameter | 12.2085 | 12.2085 | 0.0000 | | |
| ☑ Perimeter | 38.3540 | 38.3540 | 0.0000 | | |
| ☑ Area | 117.0608 | 117.0608 | | | |
| ☑ Normal L | 0.0000 | 0.0000 | | | |
| ☑ Normal M | 0.0000 | 0.0000 | | | |
| ☑ Normal N | -1.0000 | -1.0000 | | | |
| ☑ +T | 0.0000 | 0.0000 | | | |
| ☑ -T | 0.0000 | 0.0000 | 0.0000 | | |
| ☑ T | 0.0000 | 0.0000 | 0.0000 | | |
| ☑ Probe Points | 3 | | | | |
| ☑ Max-D | 12.2085 | 12.2085 | 0.0000 | | |
| ☑ Min-D | 12.2085 | [illegible] | 0.0000 | | |

Figure 2. Image of RATIONAL brand VMS-4030G device during hole diameter measurement.

### C. *Experimental Parameters*

Experiments performed by Taguchi the orthogonal array design is designed according to L$_{27}$ (3^3) and full factorial design method. The parameters to be used after the preliminary experiments were carried out were defined as three different pulse durations, current intensity and constant waiting time (Figure 3). The control factors and levels used in the experiments performed are shown in Table 2.

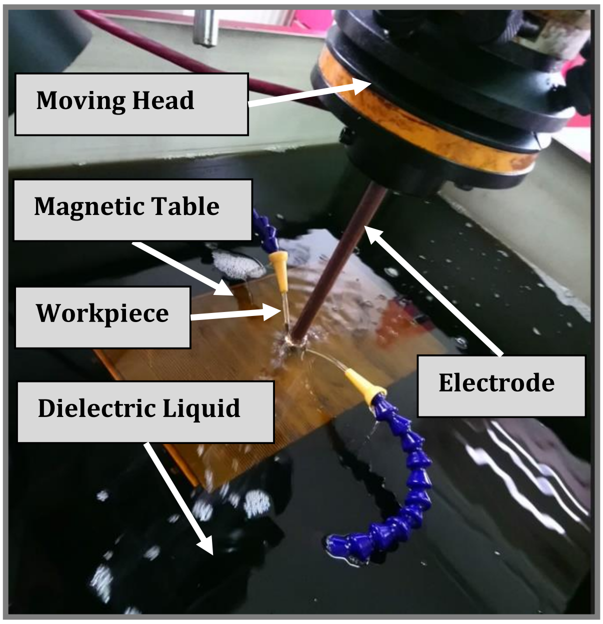


Figure 3. Image of preliminary experiments conducted to determine experimental parameters.

Table 2. Control factors and levels.

| Factors | Values | Symbol | Levels |
|---|---|---|---|
| Electrode | Copper, Graphite, Tuncop | A | 3 |
| Pulse Duration (Tone), (µs) | 200, 400, 600 | B | 3 |
| Current (Amps), (A) | 10, 20, 30 | C | 3 |
| Waiting Time (Toff ), (µs) | 50 | D | 1 |

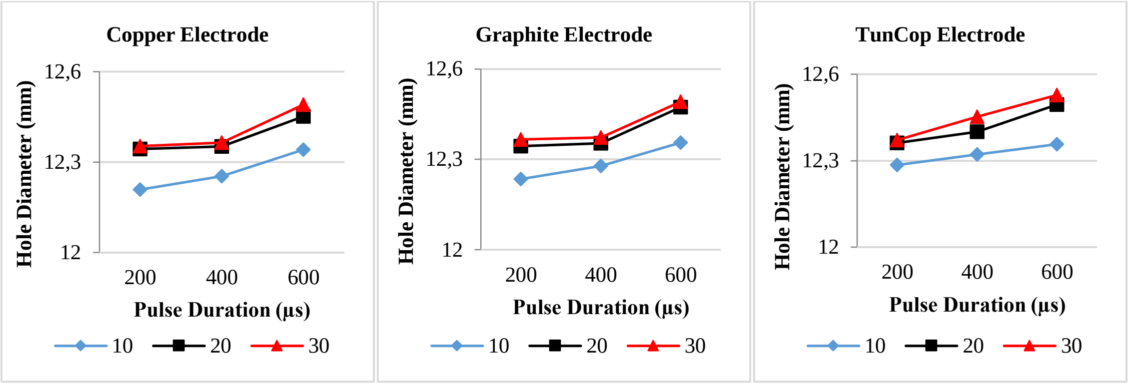
## III. **ANALYSIS AND EVALUATION OF EXPERIMENTAL RESULTS**

The average hole diameter values obtained as a result of experimental studies carried out with the electro discharge machining method are shown in Table 3.

Table 3. Average hole diameter values in the experimental study.

| Experiment No. | Amps (A) | Time on (µs) | Hole Diameter Ø(mm) | | |
|---|---|---|---|---|---|
| | | | Electrode | | |
| | | | Copper | Graphite | TunCop |
| 1 | 10 | 200 | 12.2085 | 12.2346 | 12.2855 |
| 2 | | 400 | 12.2528 | 12.2785 | 12.3222 |
| 3 | | 600 | 12.3416 | 12.3559 | 12.3569 |
| 4 | 20 | 200 | 12.3429 | 12.3441 | 12.3613 |
| 5 | | 400 | 12.3521 | 12.3532 | 12.4011 |
| 6 | | 600 | 12.4518 | 12.4733 | 12.4950 |
| 7 | 30 | 200 | 12.3524 | 12.3662 | 12.3715 |
| 8 | | 400 | 12.3648 | 12.3721 | 12.4526 |
| 9 | | 600 | 12.4905 | 12.4917 | 12.5284 |

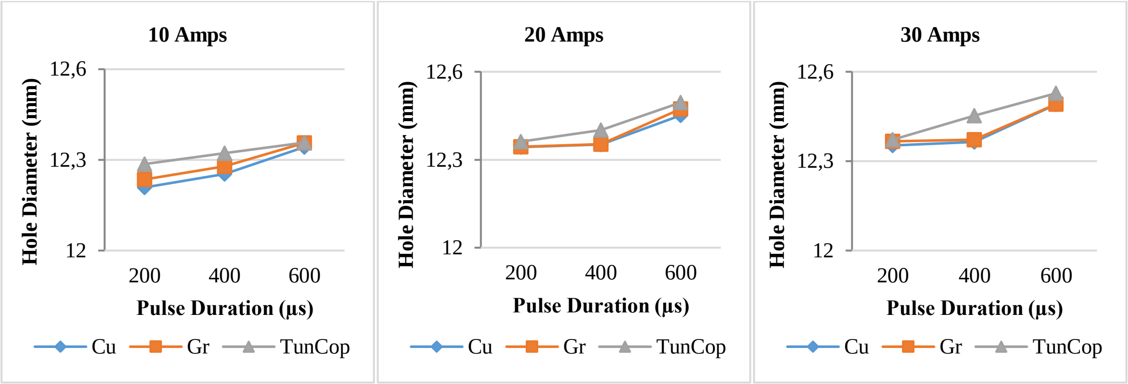
Copper, graphite and tuncop electrode materials, as seen in Table 3, the lowest hole diameter average values were 12.2085 mm, 12.2346 mm and 12.2855 mm, respectively, at 200 µs pulse duration and 10 Amps current. It was determined that the average values of the largest hole diameter at 600 µs pulse duration and 30 Amps current processing parameters were 12.4905 mm, 12.4917 mm and 12.5284 mm, respectively. The changes in the average hole diameters of copper, graphite and tuncop electrode materials specified in Table 3 depending on the pulse durations are shown in Figure 4. The hole diameter changes on the material surface at 10, 20 and 30 Amps for copper, graphite and tuncop electrode materials depending on the pulse durations are shown in Figure 5. The hole diameter changes of copper, graphite and tuncop electrode materials at and 10, 20 and 30 Amps depending on the pulse duration are shown graphically in Figure 6.



(a) (b) (c)

Figure 4. Average hole diameter values compared to pulse times of copper (a), graphite (b) and tuncop (c) electrode.

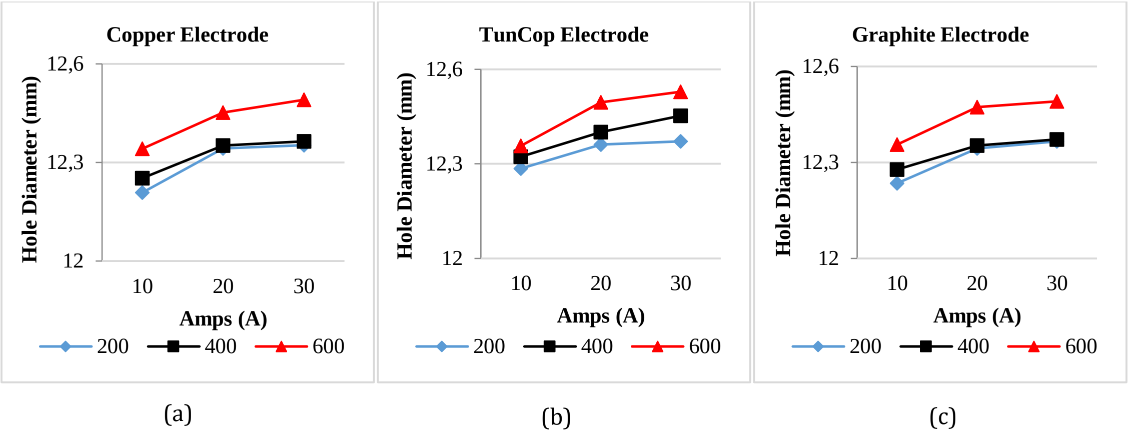
When the graph in Figure 4 is examined, it is observed that the hole diameter value increases with the increase of pulse duration for copper, graphite and tuncop electrode materials at 10, 20 and 30 Amps current. The hole diameter was larger than the electrode diameter, and as the timeout decreased and the amperage increased, the electrode came into contact with the side walls of the hole depending on the pulse duration, causing a larger diameter to occur (Nas et al., 2021). Therefore, to obtain a specific hole diameter, the pulse duration must be taken into account (Singh et al., 2004).



(a) (b) (c)

Figure 5. Hole diameter changes on the material surface of the electrodes depending on pulse duration at 10 (a), 20 (b) and 30 (c) Amps current.

When the graph in Figure 5 is examined, it shows that the hole diameter values increase with the increase of pulse duration at 10, 20 and 30 Amps current (Singh et al., 2004). Increasing pulse duration created larger arcs in the machining range, simultaneously causing more evaporation and material removal from the workpiece (Yilmaz, 2013).



(a) (b) (c)

Figure 6. Hole diameter changes of copper (a), graphite (b), tuncop (c) electrode materials depending on pulse duration at 10, 20 and 30 Amps current.

When the graph shown in Figure 6 is examined, it is seen that as the amperage increases for copper, graphite and tuncop electrodes, the hole diameter increases depending on the pulse duration. As the current value increases, the electrode produces sparks with more erosion energy along the hole path. This causes more material to be abraded, resulting in an increase in hole diameter (Yilmaz, 2013).

### *A. Taguchi Method*

Taguchi method, one of the most widely used analysis methods, was used to statistically analyze the results obtained. This method was developed by Japanese scientist Dr. It was developed by Genichi Taguchi. In the Taguchi method, the results are converted to Signal/Noise ratio, which is a statistical performance measure. The actual values obtained affect the result as the signal factor, and the factors that affect the result, which are not included in the experimental design, affect the result as the noise factor [16]. In calculating S/N ratios; nominal (written value) is best, smallest is best and largest is best methods are used. For the hole diameter to be closest to the electrode diameter, the "smallest is the best" objective function shown in Equation (1) was used (Nas and Akıncıoğlu, 2019).

$$\text{Most Small -Most Good}: \frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

### *B. Signal to Noise Ratio*

The results obtained were analyzed with the Minitab 19 statistical program and the resulting Signal/Noise ratios are shown graphically in Figure 7.

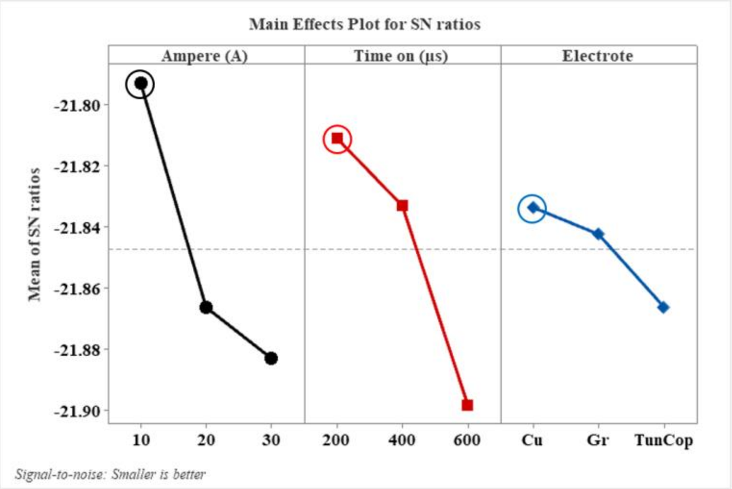


Figure 7. Signal/Noise ratio analysis graph.

The highest vertical point in the graphs is interpreted as the most effective parameter. When Figure 7 is examined, the ideal processing parameter was determined as 10 Amps, 200 µs pulse duration and copper electrode in order to ensure that the hole diameter is closest to the electrode diameter.

### *C. Variance Analysis*

ANOVA statistical method was used to determine the effect rates of processing parameters. The purpose of ANOVA is to reveal how much input factors affect output values (Özlü, 2021). ANOVA results obtained from the experimental study are shown in Table 4.

Table 4. ANOVA statistical results.

| Source | D.F. | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Amps (A) | 2 | 0.083623 | **47.85%** | 0.083623 | 0.041812 | 147.67 | 0.000 |
| Time on (µs) | 2 | 0.075122 | 42.99% | 0.075122 | 0.037561 | 132.65 | 0.000 |
| Electrote | 2 | 0.010353 | 5.92% | 0.010353 | 0.005176 | 18.28 | 0.000 |
| error | 20 | 0.005663 | 3.24% | 0.005663 | 0.000283 | | |
| Total | 26 | 0.174761 | 100.00% | | | | |
| | | **R- sq** | | | 96.76% | | |

When ANOVA results were examined, the most effective parameter was determined to be Amps with 47.85%. When the study was examined, it was determined that increasing the amount of amperage negatively affected the hole diameter. This situation causes large deformation on the material surface with the increase in amperage during the machining process (Pekşen and Kalyon, 2021).

### *D. Regression Analysis*

Regression analysis is used to examine the dependence of a variable on one or more quantitative variables. The mathematical model obtained by analyzing the results obtained from the experimental study allows for predicting the results of studies that will be carried out with the same material and different parameters. This prevents loss of time, energy, labor and materials (Özlü, 2021).

Table 5. Mathematical models of the results obtained by regression analysis.

| **Electrote** | | | |
|---|---|---|---|
| Cu | Diameter (mm) | = | 12.0984 |
| Gr | Diameter (mm) | = | 12.1109 + 0.006409 Amps (A) + 0.000311 Time on (µs) |
| TunCop | Diameter (mm) | = | 12.1447 |

## IV. RESULTS

In this study, the drilling performance of hardened DIN 32CrMoV12-10 (1.7765) tool steel with copper, graphite and tuncop electrodes was examined experimentally on an electro-erosion bench. After the experiments, the effect of variable parameters on the measured hole diameter results was statistically investigated. The results obtained are presented below in items.

- It was determined that the lowest hole diameter obtained with the copper electrode was 12.2085 mm at 200 µs pulse duration and 10 Amps value, and the highest hole diameter was 12.4905 mm at 600 µs pulse duration and 30 Amps value.
- It was observed that the lowest hole diameter obtained with the graphite electrode was 12.2346 mm at 200 µs pulse duration and 10 Amps value, and the highest hole diameter was 12.4917 mm at 600 µs pulse duration and 30 Amps value.
- The lowest hole diameter obtained with the Tuncop electrode was found to be 12.2855 mm with a pulse duration of 200 µs and a value of 10 Amps, and the highest hole diameter was found to be 12.5284 mm with a pulse duration of 600 µs and a value of 30 Amps.
- It has been determined that the hole diameter increases as the pulse duration increases for copper, graphite and tuncop electrode materials.

- In the experiments, it was determined that the minimum hole diameter for all electrode materials was 10 Amps and 200 μs pulse duration, and the maximum hole diameter was 30 Amps and 600 μs pulse duration.
- Among the electrode materials, the smallest hole diameter in experiments using copper electrodes is 12.2085 mm, and in experiments using tuncop electrodes, the maximum hole diameter value is 12.5284 mm.
- When the signal-to-noise ratio was examined statistically, it was determined that the most suitable processing parameters to obtain the optimum hole diameter value were copper for the electrode material, 10 Amps for the current value and 200 μs for the pulse duration.
- When ANOVA analyses were examined, it was determined that the most effective processing parameter was the amperage value with 47.85%.

## V. DISCUSSION

In the study, optimum conditions were determined for the processing of hardened DIN 32CrMoV12-10 (1.7765) tool steel on the EDM machine, experiments were carried out with different processing parameters (electrode, waiting time, pulse time and amperage) and the electrode forms formed on the machined surface were ensured to be formed at the most ideal values. Since the increase in the pulse duration will cause the effect of the discharge current to last longer, the amount of chip removed by creating much faster melting has directly affected the hole diameter and increased in the measurements. Compared to other studies in the literature, the re-cast layer, micro cracks, micro pits, spherules, craters and surface damage caused by high thermal energy, which are considered disadvantages of the raw hardness material on the machining surface, increase depending on the hitting time (Salman and Kayacan, 2006). It has been confirmed that as the hardness increases, the resistance of the material against abrasion increases in direct proportion, resulting in a decrease in the amount of craters formed on the material surfaces, resulting in better quality surfaces and healthier measurement results in the operations performed.

## VI. CONCLUSION

By calculating the electrode forms that will form on the material with the estimated results, time and cost loss will be minimized, and material with advanced surface quality will be produced in a short time compared to different processing methods.

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