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RESEARCH ARTICLE

OPTIMIZATION of MACHINING PARAMETERS for BORON ALLOY STEEL by PLUNGE ELECTRO EROSION by TAGUCHI TECHNIQUE

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ABSTRACT

In this study, the machinability of Boron Alloy Steel by electrical discharge machining (EDM) method was investigated. Taguchi L27 vertical knee test set was used in the experimental study. Discharge current, pulse on time, and pulse of time were selected as processing parameters. As a result of the experiments, average surface roughness, material removal rate, electrode wear rate values were investigated. The Taguchi method was used to decide on the optimal machining parameters. The effect of control factors on experimental results was calculated using analysis of variance. In the results of the experimental studies, the discharge current was found to be the most effective parameter on the electrode wear rate (EWR), average surface roughness (Ra) and material removal rate (MRR), It has been shown that increasing the discharge current (I) value will have a negative effect on Ra. The factors affecting the average surface roughness after calculation are 86.51% discharge current, 6.17% pulse on time and 0.2% pulse off time. It was concluded that the effects of the impact time and the impact waiting time on the average surface roughness were insignificant. For MRR, the discharge current is 75.56%, the pulse on time is 9.54%, and the pulse off time is 2.03%. For EWR, the discharge current is 52.87%, toff with 6.25%, and ton with 3.25%

Keywords: *Electrical discharge machining, boron alloy steel, material removal rate, surface roughness, Taguchi analysis*

1. INTRODUCTION

Electro erosion machining (EDM) is one of the most widely used non-traditional manufacturing processes for materials that are difficult to cut (carbides, ceramics, hardened steels), EDM is a thermo-electric process in which material is removed from the workpiece by the erosion effect of a series of electrical discharges known as sparks between the tool and the workpiece immersed in a dielectric fluid. Electro-erosion machining is primarily used in pressure casting dies, forging dies, cold forming dies, pressing dies, cutting and crushing dies, powder compression dies, and mould making [1].

Unlike traditional machining methods, the basic machining principle in these methods is shaping with heat energy produced by electrical sparks that occur in a dielectric fluid without contact between the tool and the workpiece [2].

Recently, research on perforation in difficult-to-machine materials has been influential. Due to their excellent mechanical properties, efficient processing will make them widely used. EDM is an unconventional machining process used for efficient and economical machining difficult-to-machine conductive materials [3]. The most crucial advantage of EDM machining is that there is no cutting force because the tool-workpiece pair does not come into physical contact with each other [4]. Also in addition, low production, and material costs, choosing the appropriate electrode material has an important role in reducing processing costs with EDM [5].

EDM is a metal material forming technique with a complex thermal energy discharge technique in which melting, and solidification events co-occur. Discharge current, pulse on time, pulse off time, dielectric fluid pressure, electrode type, and material properties determine the shape of the pits formed on the machined surfaces. Overlapping craters directly determine the surface structure and machining efficiency [6, 7].

Optimization methods have been created to establish the effective values of the parameters employed by the manufacturing sector during product processing [8]. Factorial designs are used to evaluate all level combinations of each test parameter when there are several test parameters. In other words, a factorial test design combines at least two or more parameters examined and levels in an experiment with at least two or more of these parameters. When a fully factorial experimental design is paired with statistical methodologies, it makes the analysis process much easier for researchers. Complete factorial trials were analyzed using variance (ANOVA) and regression analysis. ANOVA revealed which test parameters were statistically significant [9]. The purpose of regression analysis is to see if there is a precise mathematical relationship between the cause (independent input variable) and the consequence (independent output variable) [10]. Without modifying the order of procedures, these methods can be used to calculate the influence of a factor on the experiment and identify sources of variance [11, 12]. Taguchi test design is a proven strategy for boosting process performance with few tests and a low cost. The number of tests significantly decreases because of Taguchi's vertical index, which saves time and money. Taguchi's technique has the advantage of being able to forecast the outcome. The Taguchi technique yields a solution with the fewest possible experiments and promotes the development of high-quality processes and products. Production circumstances or uncontrolled factors have the most negligible impact on the process or product. By minimizing the total loss generated by the product due to the loss function, the Taguchi approach establishes a new concept of quality cost [13, 14]. Many surface roughness experiments use the Taguchi experimental design extensively. Experimental design is a powerful statistical tool for identifying unknown aspects of threshold parameters and assessing and modelling interactions between variables during the experiment [15].

In a study using the Taguchi method, Lin and colleagues, combining their research with an analysis of variance, argued that I and tone values increased MRR but negatively affected Ra [16]. Raghuraman et al. In their research, optimization techniques to determine the processing parameters for optimum Ra and MRR [17]. In another study using optimization techniques, it was stated that the dwell time and discharge current had a significant effect on the processing parameters [18]. For Lee and Li, the EWR increases with increasing discharge current, but the discharge current negatively affects the

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roughness of the surface [19]. Urtekin et al. the machining performance outputs (the machining current, the machining rate, the average surface roughness, and surface topography) were found for the varying process parameters pulse time, pulse-off time, dielectric flushing pressure, and wire speed [20].

This research processed boron alloy steel with high wear resistance and hardness with the EDM method. Since boron atoms alloyed to these steels make the material very hard, they are difficult to shape by machining techniques. The datasheet for statistical analysis was prepared using Taguchi L27. Three separate parameters were used as variables in the experiments: discharge current, pulse time, and pulse waiting time. Workpiece material removal rate (MRR), electrode wear rate (EWR), and average surface roughness (Ra) were studied as a function of machining parameters. To find optimal parameters, the results were examined experimentally and statistically using ANOVA and regression analysis.

2. EXPERIMENTAL METHOD

2.1. Material Selection (Workpiece/Electrode)

The experimental study used 30x20x10 mm boron alloy steel as the workpiece material. The elements in boron added steel are given by weight in the tables below, and their physical properties are indicated. In Table 1, the element distribution according to the workpiece material weight ratio. In Table 2 and 3, the physical properties of the electrode and the workpiece are given. As the electrode, copper electrodes in prismatic form (20x10 mm and 99.99% purity) were used.

Table 1. Element distribution according to weight ratio of Workpiece Material (Çemaş Döküm A.Ş.),

C	Si	Mn	Ni	P	S	Cr	Mo	V	Nb	Ti	B
0,1	0,3	1,2	0,01-0,03	0,05-0,01	<0,001	0,18	0,01	0.002	0.04	0,1	0,0001

Table 2. Electrode and workpiece physical properties.

Specifactions	Value
Tensile Strenght (MPa)	290,28
Elongation at Break (%)	14,31
Hardness (HB)	99,64
Electrical Conductive (MS/m)	57,61

Table 3. Work Piece Material.

Hardness (HRc)	Yield Strenght (MPa)	Tensile Strenght (MPa)	Thermal (W/m-k)
42,7	1350	172-1450	11.3–53.3

2.2. Electric Discharge process

Experimental studies were carried out at room temperature using FURKAN brand, 50 A "K1 Z-NC" type industrial electro-erosion workbench. Using a universal lathe, the machined surface was cleaned of electrode material after each experiment was completed.

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2.3. Surface Roughness Measurements

Mitutoyo SJ 210 surface roughness measuring device was used to determine the average surface roughness. Thanks to this device, the measurement of channels up to 0.5 mm are easily achieved. The average surface roughness values of the machined surface were measured in triplicate at room temperature. Surface roughness values are calculated by measuring them at three separate sites on the machined surfaces and calculating their average roughness (Ra) values.

2.4. EDM Experiment Parameters

Experiments full factorial design method was applied according to the Taguchi vertical array. The experimental design was designed as L_{27}. The parameters used were determined as pulse on time, pulse of time and discharge current (Amper), The parameters and levels used in the experiments are shown in Table 2.

Table 4. Control factors and levels used in experiments.

Experımental Parameter	Value
Dıscharge Peak Current (AMPRES) (A)	6 12 24
Pulse On Time (μs)	50 100 200
Pulse Off Time (μs)	6 24 48
Stay On Materıal (SN)	5
Electrode Polarıty	-

3. RESULTS and DISCUSSION

The highest Ra value was measured as 0.49, t_{on}=200 μs, current=24A, and the lowest Ra value was measured as 0.01 t_{on}= 50 μs, I=6A. The lowest MRR value was 6 A, at 50 μs ton values of approximately 0.01 g/min, and the highest MRR was calculated as approximately 0.49 g/min at 24 A and 200 μs percussion times. The lowest EWR was calculated as approximately 0.000326 g/min at 12 A and 200 μs ton time, and the highest EWR was approximately 2.58 g/min at 6 A and 50 μs ton time. The Ra, MRR and EWR values obtained from the experimental work performed by electro-erosion machining are shown in Figure 1.

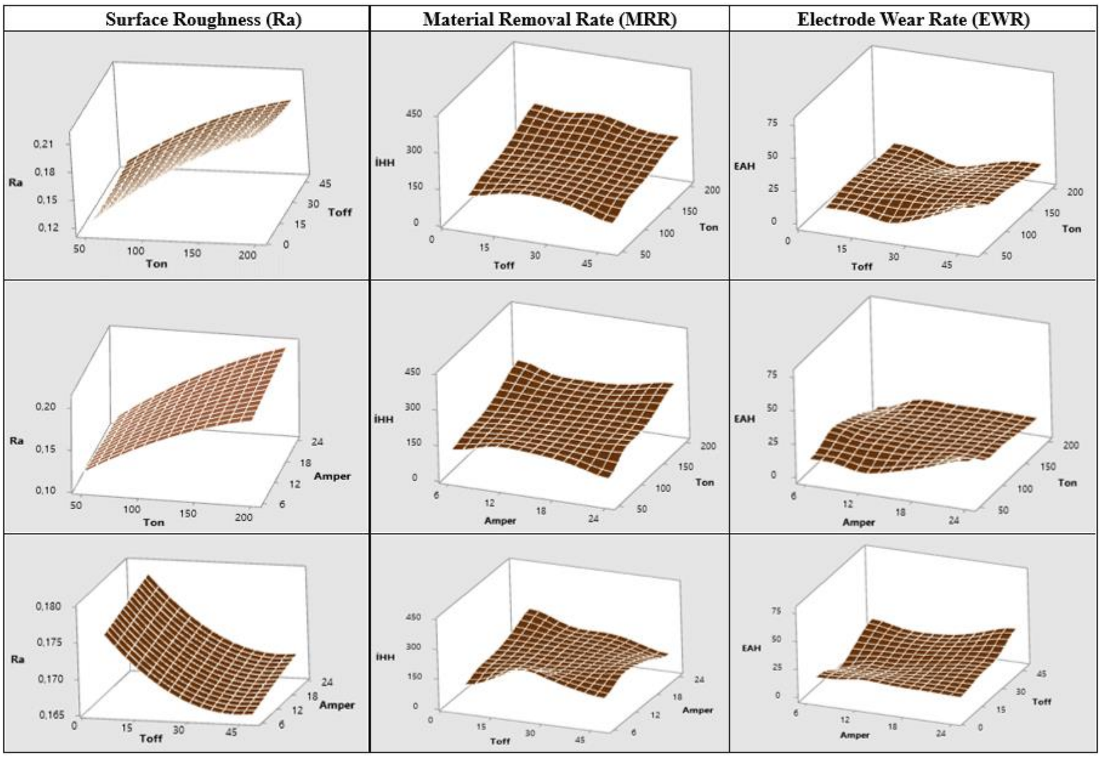

Figure 2. Graphical display of Ra, MRR and EWR values according to amper, t_{on} and t_{off}.

In experimental studies, spark density (energy density) and discharge power are higher when I and ton are high. This caused Figure 1. Graphical display of Ra, IHH and EAH values according to Amper, t_{on} and t_{off} .The surface of the workpiece becomes rougher by removing the amount of material that would cause the formation of a more deep and broader crater on the workpiece surface. As a result of the experimental study, it has been observed that the impact of waiting time has little effect on the surface roughness value of the workpiece. In the graph for the workpiece machining speed in Figure 1, it is seen that the discharge current and the pulse time (t_{on}) increase with the increase and decrease with the increase in the pulse of time (t_{off}), Looking at the graph for EAH in Figure 1, it is observed that as the discharge current increases, the electrode wear rate increases with the discharge current, and the electrode wear rate increases and then decreases with the increase of the pulse duration.

3.1. Signal Noise(S/N) Ratio Analysis

The Taguchi Method allows the user to control variables that are affected by uncontrollable factors that aren't taken into account in standard experimental design. Taguchi measures the performance qualities of the control factor against the level of these factors by converting the goal function's value into a signal-to-noise ratio (S/N), The needed signal ratio of the undesired random noise value is the Signal/Noise ratio, which reflects the quality qualities of the experimental results [21].

There are some methods for using Taguchi to evaluate experimental results. One of these methods, "the smallest is better", was the first choice for surface roughness in this research. This is because the

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surface roughness is expected to be at low levels during the electro-erosion process. Equation 2 below is derived from the "smallest best" logic used in the Taguchi method. In order to complete the production process in a short time, it is hoped to obtain a higher UTL value, so the "biggest best" method is adopted in the UTL optimization. Equations 1 and 2 calculations are shown [22].

$$The\ smallest\ best: \left(\frac{S}{N}\right) = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i{}^2\right) \quad (1)$$

$$The\ biggest\ best: \left(\frac{S}{N}\right) = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i{}^2}\right) \quad (2)$$

The effect of the parameters (T_{on}, T_{off} and Ampere) on the surface roughness is given in Tables 5, 6 and 7 to show the control factors and their levels better. The S/N response table created by the Taguchi method was used to determine the optimal level of control factors. These values, given in the table below, show the effect of each level of factors on the change in mean surface roughness, IIH, and EAH. The maximum S/N values in this table represent the ideal level of the control coefficient and are shown in bold. As a result of the Taguchi method, it is understood that the most influential factors and levels found for average surface roughness, MRR, and EWR are discharge current (1), pulse on time (2), and pulse off time (3), Looking at the table, the parameters that have the most significant effect on the surface roughness are determined as Amper, ton, and toff, in the order in which they affect.

Table 5. Surface Roughness S/N ratio table (db),

Levels	**t_{on}**	**t_{off}**	**Amper**
Level 1	**-26,30**	**-25,64**	**-21,25**
Level 2	-28,63	-19,93	-24,49
Level 3	-19,50	-28,85	-28,68
Delta	9,13	8,92	7,43

Table 6. S/N ratio table for IHH (db),

Levels	**t_{on}**	**t_{off}**	**Amper**
Level 1	**35,23**	**35,56**	**38,56**
Level 2	36,95	38,25	36,46
Level 3	38,67	37,03	35,82
Delta	3,44	2,69	2,74

Table 7. Table of S/N ratios for EAH (db),

Levels	**t_{on}**	**t_{off}**	**Amper**
Level 1	**-26,30**	**-25,64**	**-21,25**
Level 2	-28,63	-19,93	-24,49
Level 3	-19,50	-28,85	-28,68
Delta	9,13	8,92	7,43

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When the main effects graph (Figure 2) for the average surface roughness is examined, the parameters affecting the surface roughness value are determined as Level 1 (50 µs) for the ton, and Current (6A) according to the smallest best case.

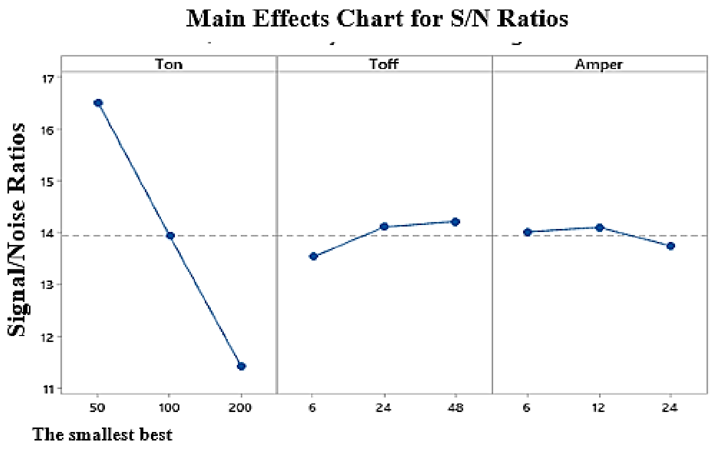

Figure 3. S/N effect plot for surface roughness by ampere, ton and toff.

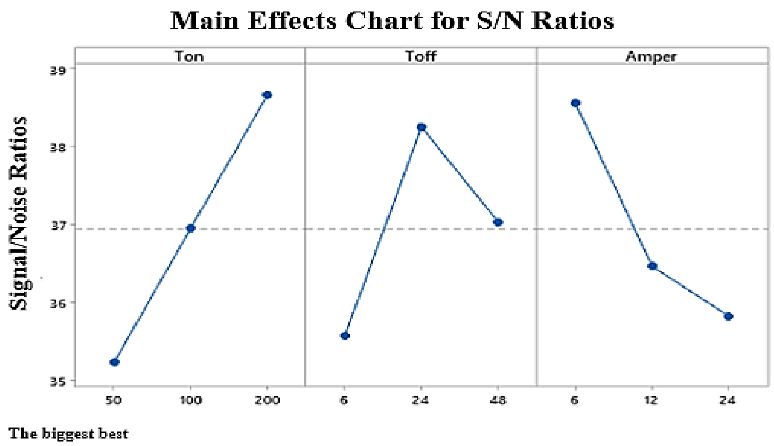

Figure 4. S/N effect graph for IHH according to ampere, ton and toff.

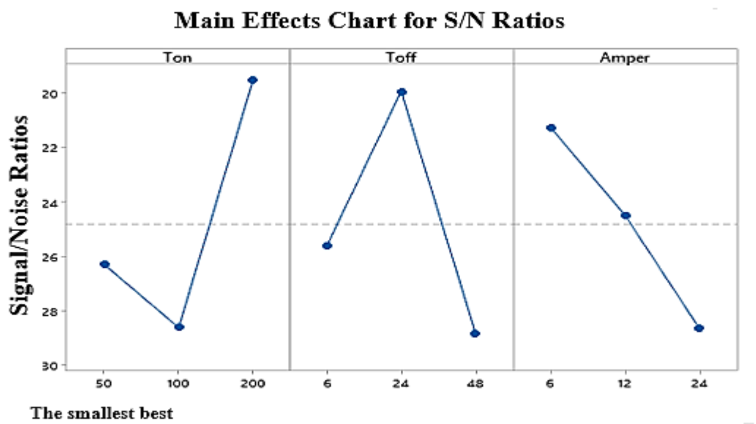

Figure 5. S/N effect plot for EAH according to amps, tones and toffs

3.2. Anova

Statistical analysis of variance (ANOVA) is used to interpret the experimental data and determine the effect ratio of the parameters. ANOVA is a statistical tool used to reveal the average performance difference between applied test sample groups. With the analysis of variance, it is possible to determine which factors are influential in which processes and how. ANOVA aims to determine how the factors examined affect the selected output value to measure the quality and type of variation caused by different levels [23]. The results of the ANOVA analysis performed to determine the effect of processing parameters on Ra, EWR and MRR are presented in Tables 8, 9 and 10. The table shows that the most influential factor for Average Surface Roughness, MRR and EWR is discharge current. The significance level, degrees of freedom (DF), the sum of squares (SS), root mean square (RS), F-number, contribution ratio, and P-value for each variable in the result are displayed here. In the analysis of the variance table, when $P<0.05$, the effects of the parameters on Ra, MRR, and EWR are statistically plausible. As we can see from the tables below, the effect of each of the parameters on Ra, EWR and MRR is seen.

Table 8. Anova Analysis Results for Workpiece Machining Speed.

Control Factor	DF	SS	RS	F	% Contribution
t_{on}	2	38667	19333	7,42	9,54
t_{off}	2	8240	4120	1,58	2,03
Amper	2	306258	153129	58,73	75,56
Error	20	52143	2607	-	-
Total	26	405306	-	-	-
R-sq:87,14% R-sq(adj):83,28					

Table 9. Anova Analysis Results for EAH Processing Speed.

Control Factor	DF	SS	RS	F	% Contribution
t_{on}	2	326,8	163,4	0,86	3,25

t_{off}	2	628,3	314,2	1,66	6,25
Amper	2	5312,5	2656,3	14,05	52,87
Error	20	3780,1	189,0	-	-
Total	26	10047,8	-	-	-
R-sq:62,38% R-sq(adj):51,09%					

Table 10. Anova Analysis Results for Surface Roughness.

Control Factor	DF	SS	RS	F	% Contribution
t_{on}	2	0,032872	0,016436	8,44	6,17
t_{off}	2	0,001063	0,000532	0,27	0,2
Amper	2	0,461926	0,230963	118,63	86,51
Error	20	0,038937	0,001947	-	-
Total	26	0,534797	-	-	-
R-sq: 92,72% R-sq(adj):90,54%					

The effect ratios of the parameters on the variables Ra, EAH and IHH were calculated. In Table 8, the effective ratio of the discharge current on Ra was 86.51%. It was observed that the effective rate of the impact time on the surface roughness was 6.17%. Table 6 shows the effect coefficients of the parameters on the MRR. The effective discharge flow rate on the MRR was high and was found to be 75.56%. The impact rates of the impact time and the impact waiting time material were 9.54% and 2.03%, respectively. The impact waiting time has little effect on the MRR. The effect ratio of the discharge current was found to be 52.87%, with an expected value on the EWR. The impact rates of the impact time and the impact waiting time on the material were 3.25% and 6.25%, respectively, and it was seen that they had little effect on the EWR.

3.3. Regression analysis

Regression analysis is used in experimental research to find the relationship between controls and experimental factors. In this study, I, ton, and toff were chosen as modifiers. Ra, MRR, and EWR are the result of the experimental process. A linear regression model was set up to find the Ra, MRR, and EWR values. Equations 3,4, and 5 show the linear regression models generated for Ra's rendering performance outputs, MRR, and EWR.

$$\mathrm{MRR} = -82{,}7 + 0{,}606ton - 0{,}689toff + 14{,}21I \quad (3)$$

$$EWR = -10{,}95 - 0{,}0502ton + 0{,}190toff + 1{,}860I \quad (4)$$

$$Ra = -0{,}1414 + 0{,}000556ton - 0{,}000322toff + 0{,}01747I \quad (5)$$

4. CONCLUSION

The results of the research, in which the machinability of the boron alloy steel material by using copper electrodes on the EDM machine and statistical analyses were carried out, are presented below.

• It was observed that the increase in discharge current and impact time affected the surface roughness negatively.

• High discharge current has increased the machining speed of the part.

• It was revealed that the parameter that most affected the results on Ra, MRR, and EWR was discharge flow.

• ton and toff turned out to have little effect on Ra, MRR, and EWR.

• The optimum machining parameters for the average surface roughness were measured at ton=200 μs I=24A, and the lowest Ra was 0.01 ton= 50 μs I=6A.

• The best machining parameters for the MRR were 50 μs tons at the lowest 6A current and the highest MRR at 24A current and 200 μs tons.

• According to the analysis of variance's outputs, the discharge current's percentage effect on the surface roughness is 86.51%. The effective discharge flow rate for MRR was determined as 75.14%, and the effective rate on EWR was determined as 52.87%.

• According to the results of the Anova analysis, the hit waiting time is the parameter that has a minor effect on the machining.

Accurate experiments results show that Taguchi's optimization studies can successfully apply to EDM.

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