Optimization of machining parameters in Electric Discharge Machining of Magnesium and Aluminium by Taguchi Technique

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Abstract. Aluminium, Magnesium and its alloys are preferred whenever weight reduction is needed without compromising its strength. Both alloys have been used in numerous fields like aerospace, defence field, automobile wheeling parts and also, they have been used in Medical field because of their biodegradability. In this study, Statistical investigation on surface roughness in Electric discharge machining of aluminium and Magnesium using Taguchi optimization Technique has been reported. Electric discharge machining was carried out under the condition of Current (5, 10, 15 A), Voltage (50, 55, 60 V), Pulse On time (10, 20, 30 µs) and constant flushing pressure of 0.50 Kg/sq.cm. Twenty-seven Experiments are carried out based on L27 orthogonal array. After machining the surface roughness (Ra,Rq,Rz) of the machined surface is measured using SURFTESTSJ-210. Optimizations of the results were done by Taguchi technique and the optimal parameters for the machining operation of aluminium and magnesium are determined. It is found that for Ra, Rq and Rz the most influencing factor is Current followed by the pulse on time, pressure and voltage.

1. Introduction
Aluminium and its alloys have been used in various applications because of their properties light weight, corrosion resistance. Strength to weight ratio is comparable high when compared to any other alloys. They also have very good machining properties which make to applicable for the various applications [1]. Magnesium is the lightest and low density material which is used in constructional applications. The weight of the Magnesium compound is 35% lower than that of Al and shows predominant vibration characteristics. Mg is a preferable material for alloy especially with the Aluminium increasing both corrosion resistance and hardness. Mainly because of this property the Mg-alloys have been used in the aircraft applications especially in aircraft fuselages [2]. Electrical discharge machining (EDM) process is used for machining the Al and Mg alloys. Because an Al and Mg alloy requires high accuracy for machining, this can be achieved by the EDM process [3].

Nine EDM experiments of three levels with four parameters were conducted on the AZ31 magnesium alloy to detect its optimal machining parameters by using Taguchi method. Parameters considered are Pulse on time, pulse off time, peak current and voltage. It is found that out of these parameters Pulse on time is the most influencing factor. Optimum result is obtained when the peak current is 47A, voltage is 80 and Pulse on time is 16µs. The cracks and craters formation were formed on the machined
surface even though the use of EDM which has very good machining properties. Thereby in this process Powder mixed EDM is used to avoid the craters and cracks formation during the process [4]. In biodegradable Magnesium using EDM, because they have a various uses in medical field especially in the bone replacement. Magnesium alloys are degraded inside the human body leaving without any trace and they have the high biocompatibility and very good structural stability. An attempt made to analyze the micro and macro surface properties using the EDX and SEM analysis. Thereby the continuous corrosion of the magnesium leads to decrease its Viability and observed that toxicity of machined magnesium occurs which can be avoided by using of optimized process parameters [5].

In recent days, normal and cryogenic cooled EDM process was carried out with different machining parameters such as discharge current, pulse on time and gap voltage. The response parameters are material removal rate, electrode wear rate, surface roughness and also they taken the micro, macro surface using the SEM and EDX analysis. The results obtained were the electrode wear rates are reduced by 18% when cooled by the cryogenics. And also the use of the liquid nitrogen gives a better EDMed surface region avoiding the cracks and craters that formed during the machining process [6]. Both C- EDM and PM- EDM process were carried out in nine experiments with same setting parameters. The optimized surface roughness obtained from PD-EDM is reduced to 44% from the C- EDM. Also the Powder Mixed – EDM is proven to reduce the surface roughness from the machining process. In order to reduce the corrosion of the machined magnesium alloy by the use of the PD-EDM process [7].

The machining parameters of Mg alloy and Al alloys were optimized using various single and multiple parameters optimization techniques. The parameters considered are pulse on time, pulse off time, and peak current. Analysis based on the ANOVA found out that the pulse off time is least affecting factor and the pulse on time and the peak current are the most affecting factor [8, 9, 10].

In EDM process in Mg alloys, accuracy of the holes were examined by giving the various inputs and calculate the outputs. From the result it is came to know that the surface roughness and the taper majorly depends on the pulse on time and servo speed of the input given to the EDM during the process [11].

In our present work, optimize the machining parameters in aluminium and magnesium during EDM process.

2. Materials and Methods
Magnesium is a combination of silvery white, light- weight metal. Unlike other alloys it doesn’t require oxygen free environment to store them because they are naturally protected by their thin layer of oxide.
Aluminium alloys have very good physical properties like high hardness, low density, high specific strength, good casting ability and also having very good machining capability.

2.1. Experimental setup
The selected material is cut into require dimension based on the working process shown in fig 1. Then the material is machined through the selected machine. Experiments were conducted using an EDM machine mode 550×300 with EDM oil as dielectric medium.

![Figure1. Workpiece material](image)
2.2. Experimental Procedure

The 12 mm diameter copper tool is selected as tool material. Copper tool is connected with positive power supply terminal and work table connected with negative power supply terminal as shown in fig 2. Three most influencing process parameters of EDM such as current (A), pulse on time (Ton) and Gap voltage (V) were taken as input parameters with three different levels. Surface Roughness (Ra, Rz and Rq) were chosen as response parameter. The dielectric fluid is circulated at pressure 0.5Kg/cm2 at maintaining the constant pulse off time 10 and 18 duty cycle per min.

![Electric discharge machining](image2.png)

**Figure 2.** Electric discharge machining

2.3. Experiment Work

By setting these provided parameters on the EDM machine is operated. Set the first parameter as given in the Table 1. Those are called Process Parameters. After setting those parameters, place the tool on the required position for the given time. After doing this, change the parameters and do the process once again. Repeat the process for 27 times. Then measure the surface roughness.

2.4 Measurement of the Surface Roughness

Once the process is completed, then the work pieces were subjected to the Surface Roughness measurement. The surface roughness should be measured for all the work pieces on the machined surface. Surface roughness is measured using the MITUTOYO Surface roughness tester SJ-210 shown in fig 3. First the SJ210 is set into calibration mode. Then the probe of SJ210 is fixed on the machined surface of the work piece, then start the tester the probe will move traverse and back. After that the reading will be shown in the monitor attached to the probe detector. Thus the three trails are taken and their average is tabulated.

![Surftest SJ-210](image3.png)

**Figure 3.** Surftest SJ-210
Table 1. Experimental values of Surface Roughness

| SI.No | Input parameters | Response Parameters |
|-------|------------------|---------------------|
|       | Current (A)      | Voltage (V)         | Pulse on time (µs) | Surface Roughness | Surface Roughness |
|       |                  |                     |                    | Aluminium         | Magnesium         |
| 1.    | 5                | 50                  | 10                 | 3.771            | 4.592            | 18.053            | 1.718            | 2.065            | 7.305            |
| 2.    | 5                | 50                  | 20                 | 3.881            | 4.674            | 17.473            | 1.414            | 1.706            | 5.634            |
| 3.    | 5                | 50                  | 30                 | 4.202            | 4.961            | 18.113            | 1.593            | 1.921            | 6.459            |
| 4.    | 5                | 55                  | 10                 | 3.290            | 4.145            | 16.052            | 1.620            | 1.942            | 6.849            |
| 5.    | 5                | 55                  | 20                 | 4.250            | 5.156            | 20.089            | 1.788            | 2.134            | 7.397            |
| 6.    | 5                | 55                  | 30                 | 3.618            | 4.489            | 16.804            | 1.593            | 1.921            | 6.459            |
| 7.    | 5                | 60                  | 10                 | 3.641            | 4.420            | 17.472            | 1.851            | 2.206            | 7.590            |
| 8.    | 5                | 60                  | 20                 | 3.733            | 4.547            | 17.447            | 1.569            | 1.866            | 6.368            |
| 9.    | 5                | 60                  | 30                 | 4.375            | 5.210            | 19.239            | 1.515            | 1.796            | 6.121            |
| 10.   | 10               | 50                  | 10                 | 4.111            | 4.911            | 18.684            | 1.710            | 2.077            | 7.122            |
| 11.   | 10               | 50                  | 20                 | 4.607            | 5.590            | 21.258            | 1.726            | 2.073            | 7.365            |
| 12.   | 10               | 50                  | 30                 | 4.490            | 5.377            | 19.239            | 1.515            | 1.906            | 6.608            |
| 13.   | 10               | 55                  | 10                 | 3.704            | 4.516            | 18.015            | 1.651            | 1.983            | 7.055            |
| 14.   | 10               | 55                  | 20                 | 4.479            | 5.307            | 19.137            | 1.864            | 2.168            | 7.023            |
| 15.   | 10               | 55                  | 30                 | 4.492            | 5.347            | 19.714            | 1.402            | 1.681            | 5.952            |
| 16.   | 10               | 60                  | 10                 | 4.297            | 5.180            | 19.464            | 1.488            | 1.808            | 6.295            |
| 17.   | 10               | 60                  | 20                 | 4.583            | 5.455            | 19.770            | 1.811            | 2.528            | 7.380            |
| 18.   | 10               | 60                  | 30                 | 4.107            | 5.030            | 18.754            | 1.305            | 1.541            | 5.696            |
| 19.   | 15               | 50                  | 10                 | 4.539            | 5.536            | 20.787            | 1.413            | 1.759            | 5.780            |
| 20.   | 15               | 50                  | 20                 | 4.814            | 5.734            | 21.163            | 1.199            | 1.480            | 5.174            |
| 21.   | 15               | 50                  | 30                 | 4.327            | 5.195            | 19.164            | 1.424            | 1.743            | 6.034            |
| 22.   | 15               | 55                  | 10                 | 4.278            | 5.056            | 18.525            | 1.599            | 1.895            | 6.785            |
| 23.   | 15               | 55                  | 20                 | 4.925            | 5.897            | 21.816            | 1.588            | 1.974            | 6.857            |
| 24.   | 15               | 55                  | 30                 | 5.642            | 6.749            | 23.599            | 1.103            | 1.393            | 4.814            |
| 25.   | 15               | 60                  | 10                 | 4.033            | 4.964            | 18.331            | 1.398            | 1.686            | 5.649            |
| 26.   | 15               | 60                  | 20                 | 5.491            | 6.480            | 23.154            | 1.533            | 1.874            | 6.797            |
| 27.   | 15               | 60                  | 30                 | 5.533            | 6.699            | 24.497            | 1.127            | 1.342            | 4.636            |

3. Result and Discussion

After completing the experiments readings were noted. With the help of the readings S/N ratio is calculated with the help of Taguchi Method. In this method the four parameters are fixed and they are called Factors. The four factors are Voltage, current, Pulse on time and pressure. They are noted as A, B, C and D. Then the levels are calculated. After it the average levels are calculated and find their difference. Difference values are ranked at last.

3.1 Calculation of S/N ratio

\[
\Lambda = \frac{S/N = -10 \times \log(\Sigma Y^2)}{----------- (1)}
\]

By using this formula Ra, Rq, and Rz is calculated, once completing it, then the level1, level2 and the level 3 for the factors A,B,C and D is calculated with the help of the S/N ratio for each and every parameters is calculated using formula 1 and shown in table 2. After this the average and the rank of the respective factors are calculated.
Table 2. calculated S/N ratios for Aluminium and Magnesium

| S/N Ratio | Input parameters | S/N Ratio |
|-----------|------------------|-----------|
| Voltage (V) | Current (A) | Surface Roughness – Aluminium | Surface Roughness – Magnesium |
| Pulse on time (µs) | Ra | Rq | Rz | Ra | Rq | Rz |
| 1. | 5 | 50 | 10 | -11.529 | -13.240 | -25.131 | -4.702 | -6.300 | -17.273 |
| 2. | 5 | 50 | 20 | -11.779 | -13.394 | -24.848 | -3.007 | -4.641 | -15.016 |
| 3. | 5 | 50 | 30 | -12.470 | -13.911 | -25.160 | -4.043 | -5.672 | -16.203 |
| 4. | 5 | 55 | 10 | -10.343 | -12.350 | -24.111 | -4.192 | -5.765 | -16.713 |
| 5. | 5 | 55 | 20 | -12.568 | -14.246 | -26.059 | -5.049 | -6.584 | -17.381 |
| 6. | 5 | 55 | 30 | -11.169 | -13.042 | -24.508 | -4.147 | -5.567 | -16.447 |
| 7. | 5 | 60 | 10 | -11.224 | -12.909 | -24.847 | -5.348 | -6.871 | -17.605 |
| 8. | 5 | 60 | 20 | -11.440 | -13.155 | -24.834 | -3.911 | -5.420 | -16.080 |
| 9. | 5 | 60 | 30 | -12.819 | -14.337 | -25.780 | -3.728 | -5.088 | -15.737 |
| 10. | 10 | 50 | 10 | -12.280 | -13.823 | -25.429 | -4.658 | -6.347 | -17.052 |
| 11. | 10 | 50 | 20 | -13.269 | -14.949 | -26.550 | -4.741 | -6.331 | -17.343 |
| 12. | 10 | 50 | 30 | -13.044 | -14.611 | -25.684 | -3.606 | -5.601 | -16.401 |
| 13. | 10 | 55 | 10 | -11.374 | -13.094 | -25.113 | -4.353 | -5.948 | -16.970 |
| 14. | 10 | 55 | 20 | -12.032 | -14.497 | -25.637 | -5.407 | -6.720 | -16.930 |
| 15. | 10 | 55 | 30 | -13.048 | -14.562 | -25.896 | -2.933 | -4.511 | -15.494 |
| 16. | 10 | 60 | 10 | -12.663 | -14.286 | -25.785 | -3.450 | -5.146 | -15.980 |
| 17. | 10 | 60 | 20 | -13.224 | -14.736 | -25.920 | -5.157 | -8.056 | -17.361 |
| 18. | 10 | 60 | 30 | -12.271 | -14.032 | -25.462 | -2.310 | -3.756 | -15.111 |
| 19. | 15 | 50 | 10 | -13.139 | -14.863 | -26.356 | -3.001 | -4.905 | -15.238 |
| 20. | 15 | 50 | 20 | -13.650 | -15.169 | -26.511 | -1.579 | -3.405 | -14.310 |
| 21. | 15 | 50 | 30 | -12.723 | -14.312 | -25.650 | -3.072 | -4.816 | -15.613 |
| 22. | 15 | 55 | 10 | -12.624 | -14.076 | -25.355 | -4.079 | -5.552 | -16.631 |
| 23. | 15 | 55 | 20 | -13.849 | -15.413 | -26.775 | -4.015 | -5.905 | -16.723 |
| 24. | 15 | 55 | 30 | -15.029 | -16.584 | -27.458 | -0.854 | -2.881 | -13.650 |
| 25. | 15 | 60 | 10 | -12.113 | -13.917 | -25.264 | -2.908 | -4.535 | -15.039 |
| 26. | 15 | 60 | 20 | -14.794 | -16.232 | -27.293 | -3.709 | -5.457 | -16.646 |
| 27. | 15 | 60 | 30 | -14.859 | -16.520 | -27.782 | -1.036 | -2.557 | -13.322 |

Figure 4 shows the main effects plot for S/N ratio for aluminium. It is observed that better surface finish can be obtained at lower current (5A), medium Voltage (55V) and lower pulse on time (10µs).

![MainEffectsPlotforSNratios](image_url)

Figure 4. Main effects plot for S/N ratio for Aluminium (Ra, Rq and Rz)

Figure 5 shows the main effects plot for S/N ratio for aluminium. It is observed that better surface finish can be obtained at higher current (15A), high voltage (60V) and high pulse on time (30µs).

![MainEffectsPlotforSNratios](image_url)
4. Conclusion

After completing the calculation by using the TAGUCHI Method, the results are tabulated and the optimal parameters for the machining operation of Magnesium are determined.

- It is found that for Ra, Rq and Rz the most influencing factor is Current followed by the pulse on time and voltage.
- It can be proved with the help of the tables 3 and 4 calculated by the Taguchi Method and with the ranks determined by the method.
- The optimal result for Ra, Rq and Rz obtained, when the parameters are 15A, 60 V and 30 µs.

For Aluminium

Table 3. Influencing factor and rank for Magnesium

| Factor | Influence factor and rank of Ra | Influence factor and rank of Rq | Influence factor and rank of Rz |
|--------|---------------------------------|---------------------------------|---------------------------------|
| Level 1 | A -4.24 B -3.6 C -4.07          | A -5.77 B -5.34 C -5.71         | A -16.50 B -16.05 C -16.50     |
| Level 2 | A -4.07 B -3.89 C -4.06         | A -5.82 B -5.49 C -5.84         | A -16.52 B -16.33 C -16.42     |
| Level 3 | A -2.69 B -3.5 C -2.85          | A -4.45 B -5.21 C -4.49         | A -15.24 B -15.88 C -15.33     |
| Difference | 1.54 B 0.38 C 1.21 | A 1.38 B 0.28 C 1.34         | A 1.27 B 0.45 C 1.17         |
| Delta | 0.49 B 0.12 C 0.38 | 0.46 B 0.09 C 44.66         | 0.44 B 0.15 C 0.40         |
| rank | 1 3 2                  | 1 3 2                  | 1 3 2                  |

Table 4. Influencing factor and rank for Aluminium

| Factor | Influence factor and rank of Ra | Influence factor and rank of Rq | Influence factor and rank of Rz |
|--------|---------------------------------|---------------------------------|---------------------------------|
| Level 1 | A -11.70 B -12.65 C -11.92 | A -13.40 B -14.25 C -13.62 | A -25.03 B -25.70 C -25.27 |
| Level 2 | A -12.70 B -12.56 C -13.07 | A -14.29 B -14.21 C -14.64 | A -25.72 B -25.66 C -26.05 |
| Level 3 | A -13.60 B -12.82 C -13.05 | A -15.23 B -14.46 C -14.66 | A -26.49 B -25.89 C -25.93 |
| Difference | 1.94 B 0.26 C 1.15 | 1.83 B 0.25 C 1.04         | 1.46 B 0.23 C 0.78         |
| Delta | 0.58 B 0.077 C 0.34 | 0.59 B 0.08 C 0.33         | 0.59 B 0.09 C 0.32         |
| rank | 1 3 2                  | 1 3 2                  | 1 3 2                  |

Figure 5. Main effects plot for S/N ratio for Magnesium (Ra, Rq and Rz)
It is found that for $R_a$, $R_q$ and $R_z$ the most influencing factor is current followed by pulse on time, pressure and voltage.

It can be proved with the help of the tables 3 and 4 calculated by Taguchi Method and with the ranks determined by the method.

The optimal result for $R_a$, $R_q$ and $R_z$ obtained, when the parameters are 5 A, 55 V and 10 $\mu$s.

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