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# Experimental Investigations of EDM Parameters on Machining Square Blind Holes in Maraging Steels

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## *Abstract*

*Square blind holes have certain qualities that make them useful in fields where accuracy and efficiency are crucial, like aerospace, automotive, molding, and general manufacturing industries where structural integration is required in precise assembly. It is challenging to machine square blind holes with traditional machining due to geometrical complexity as precision is required for sharp corners which is difficult to get at the corners due to tool wear. Electrical discharge machining is an advanced machining technique used for machining electrically conductive and difficult to cut materials. The primary goal of present work is to evaluate and quantify the output and input parameters during Electric Discharge Machining of square blind holes with varying depths at each level. Here, the experiments were conducted on Maraging steel MDN 250 material which is widely used in aerospace and allied industries because of its unique properties. The material is known for its good malleability while having exceptional strength and hardness. During experimentation, the depth of the hole was varied while maintaining the input parameters Current, Pulse on Time and duty cycle constant. The output responses that were taken into consideration were the Electrode Wear Rate, machining time, squareness, taperness, and surface roughness. It was noted that the Tool Wear decreased as the hole depth was increased. Squareness values are significant which affects the relative motion between machined parts, which is critical for their functionality. The taperness remains relatively low, suggesting effective control over the machining process. A non-linear relationship where specific depths significantly affect surface finish was noted. The achieved results can be useful in defense, aerospace and EDM industries to increase the productivity with precision.*

**Keywords:** Electrical discharge machining (EDM), electrode wear rate, square blind hole, squareness, taperness, surface roughness

## INTRODUCTION

In view of the increasing demand in aerospace and defense, high strength steels and related alloys are getting more and more prominent. Applications include gears, ordinance components, fasteners, gearboxes, extrusion press rams and tools in tube manufacture, suspension parts and wing components of aircraft, and machinery. A lot of effort is put towards overcoming the difficulties in machining steel and other hard-to-cut materials and composite materials. Maraging steel is one such material. The nickel, cobalt, and molybdenum group that Inco developed in the late 1950s includes maraging steel. Maraging steels are noted for maintaining their malleability while having exceptional strength and hardness. These steels belong to a unique class of low carbon, ultra-high strength steels, and they acquire their strength from the precipitation of intermetallic compounds rather than carbon.In gas turbines and jet engines, where high temperatures are met, such as in exhaust nozzles, it is commonly

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chose[1].To maintain the working temperature and boost operational efficiency, these parts need a large number of small diameter cooling holes (1-4 mm) with a high aspect ratio (length-to-diameter ratio). Because of its poor thermal characteristics, high toughness, high hardness, and high work hardening rate, Maraging Steels become increasingly difficult to drill small holes using standard drilling techniques as the aspect ratio of the hole increases.[2] Electrical discharge machining (EDM) is a feasible advanced machining technique for electrically conductive materials that offers the most cost-effective way to create holes with a length-to-diameter ratio of more than five [2].Unlike traditional machining process like milling, there is no direct contact between tool and workpiece which reduces tool wear and mechanical stresses on the workpiece irrespective of workpiece hardness.The efficiency of electrical discharge machining of special-purpose applications with composite electrode tools can be increased[3]. EDM has achieved an aspect ratio over 11 was on microdrilling of CFRP[4].

[3]Compared to circular hole machining, square hole machining is characterized by higher machining difficulty, a more complex machining process, lower production efficiency, and higher manufacturing costs. While machining circular holes, there is even distribution of sparks generated on the circular geometry which makes easy material removal evenly. Sengaretal.[5]demonstrated ona fabricated tool using a Reuleaux triangle which produces square holes of 40mm side on Mild steel(EN8) and achieved 98.7 % accuracy in motion mechanism.Quetal.[6]investigated that using pulsating electrolyte in ECM of titanium alloysusing square electrodes equipped with internal flushing holesachieved lower surface roughness values and improved MRR. Kagawa [7] proposed a method for producing square holes with stepped tubular square electrodes. Tutiketal.[8]utilized larger square tool electrodes for EDM in compliance with the orbital path. Ziada and Koshy [9] altered the Reuleaux triangle electrode's center and radius of the three arc edges, generating square holes with sharp corners by rotating and centering the electrode.Mathaietal.[10] investigated on a planetary drive mechanism to study the effects of different parameters on the wear rate, removal rate and surface roughness (Ra) of square hole components during EDM.Kumaretal.[11]examined how the silicon carbide concentration, pulse length, duty cycle, and current affected the CFRPs' surface roughness, squareness, and depth of holes. Aruna and Hiremath [12] focused on utilizing a unique copper multi-tool electrode to machine micro-square holes on a copper sheet.Kumarand Dhanabalan [13] examined and evaluated the form tolerances,squareness and flatnesswhile using EDM to produce a meso-deep hole on an Inconel-718 material plate.[4]Rao et al.[14] investigated that while machining of maraging steel (MDN 250) with EDM,the material removal rate and surface roughness increase with current and duty factor. Nikalje et al. [15] conducted EDM on MDN 300 steel and optimized the process parameters.and it was observed that thesurface with stronger microcracks, craters, and debris globules occured when the discharge current is high and long pulse duration.Kannan et al.[16-17] studies on machining of square holes on SiC and ZrSiO4 reinforced with Aluminium Alloy (AA7475) using laser by considering the various process process parameter effects.

[3]High electrode wear, poor machining efficiency, and insufficient chip removal are some of the difficulties that EDM encounters while square-hole machining. Blind holes are difficult to machine because there is accumulation of debris formed while machining the hole as there is only narrow gap to escape which results in inaccuracy of desired geometry. High tool wear, increased machining time and constrained depth are some of the challenges faced during blind hole machining unlike through holes where there is no entrapping of debris due to effective flushing.Based on the literature that is currently available,there hasn't been much research done particularly on electrical discharge machining (EDM) for making square blind holes in Maraging steels. Moreover, there is a dearth of knowledge in this context of precision machining tests. Consequently, an experimental investigation into the precise machining of square blind holes in Maraging Steel is carried out in this work. Examining the machining effectiveness and surface quality of these holes is the ultimate objective. For the purpose of precisely machining square hole structures, this study can offer insightful information and method references. Itcanalsoprovideideas for the structural design of related components and hold significant value for research related to Electrical discharge machining (EDM) of Maraging Steels particularly for high aspect ratio square holes.

## EXPERIMENTAL DETAILS

The Maraging steel block MDN 250 having dimensions of 50mmx100mmx120mm was used as work piece material. Maraging steel has a carbon content of 0.1%. To obtain the mechanical and physical strength, other components are added. In Maraging steel, nickel, cobalt, molybdenum, and titanium are the main alloying components. The ingots of Maraging steel were cut into blocks. In Fig.1 the workpiece and tool configuration was depicted.EDM machining was done using a copper tool and Kyros ferrolac 3M as the dielectric medium as shown in Figure 2. Initially the circular holes are drilled with dimensions of Φ4.5×40 mm to on the workpiece using EDD(Electrical Discharge Drilling) and made into a square hole using copper electrodes with 4.8 mm as square side .The machining on the workpiece with spark gap of 0.2mm was given to move in vertical direction on EDM. The experiments were conducted by adjusting depth in 6 levels and keeping input parameters like current, pulse-on-time, and duty factor constant by noting Machining Time for each hole .These experiments aimed to analyze the effects of current,pulse-on-time, duty factor on varying depth. The output parameters Electrode Wear rate (EWR), Squareness, Taperness, surface roughness (SR) was measured. The weight of the electrode was noted before and after machining each hole, using a digital balance. And the difference in weights represented the EWR. Surface roughness was assessed using a Talysurf instrument. Co-ordinate Measuring Machine (CMM) was used for measuring the hole dimensions.

## RESULTS AND DISCUSSIONS

The current study focused on evaluating the impact of current, depth of cut,pulse on-time, duty factor on EDM performance indicators such as TWR, Machining Time,Surface Roughness, Squareness, Taperness and surface variations under various experimental conditions.

### Variation of Machining Time and EWR With Varying Depth

At Constant Parameters current (10 A), pulse on time (7 µs), and duty factor (53.84%) varying the depth of the hole in increments of 5 mm from 5 mm to 30 mm the output parameters Machining Time and electrode wear rate were observed as noted in table 1.The weight of the electrodes was measured as shown in Figure 4. From Figure 3, it was observed that there is a positive correlation between the depth of the hole and the machining time. As the depth increases, the time required to machine the hole also increases. There is ainverse relation between the depth of the hole and the Electrode Wear Rate. The Electrode Wear Rate decreases with increase in depth of the hole.

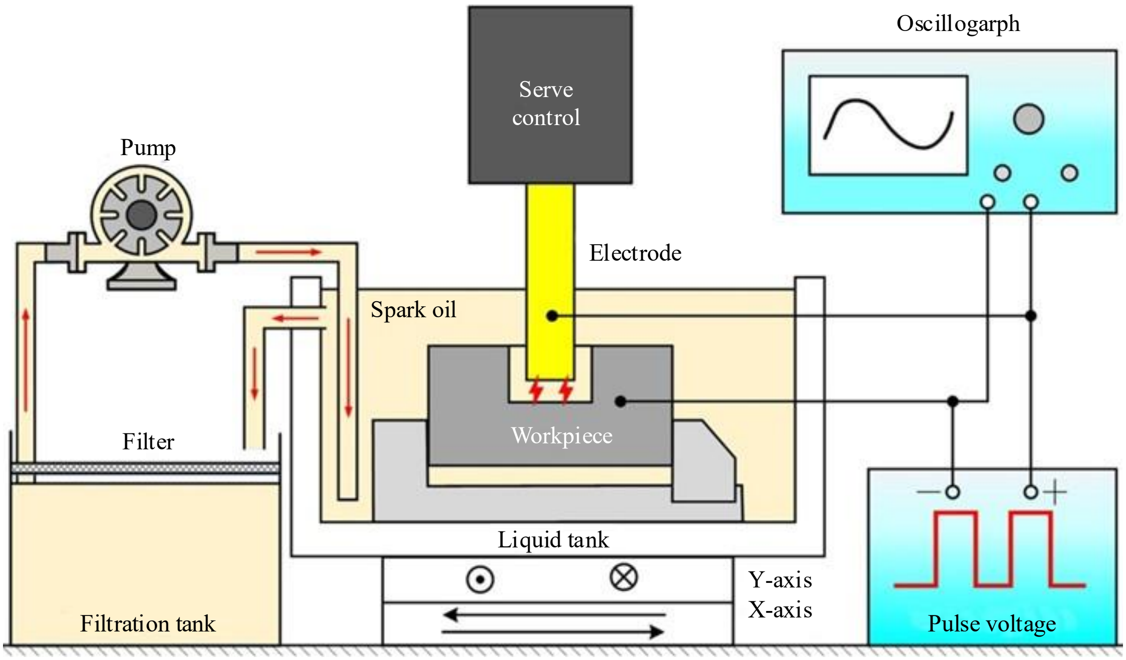

**Figure 1.** Machining system principle [14].

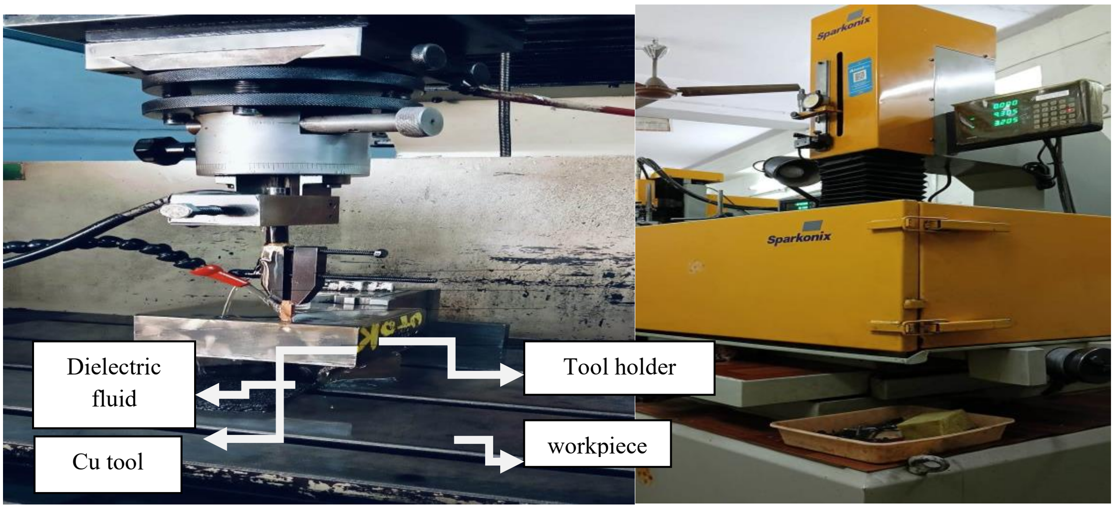

**Figure 2.** Experimental setup.

**Table 1.** Variation of Machining Time, EWR at constant I,Ton, duty factor.

| Exp.no. | Depth of Hole (mm) | Current(A) | Pulse On Time (µs) | Duty factor (%) | Machining time(min) | EWR(g/min) |
|---|---|---|---|---|---|---|
| 1. | 5 | 10 | 7 | 53.84 | 10 | 0.060 |
| 2. | 10 | 10 | 7 | 53.84 | 25 | 0.032 |
| 3. | 15 | 10 | 7 | 53.84 | 50 | 0.013 |
| 4. | 20 | 10 | 7 | 53.84 | 65 | 0.010 |
| 5. | 25 | 10 | 7 | 53.84 | 90 | 0.007 |
| 6. | 30 | 10 | 7 | 53.84 | 115 | 0.007 |

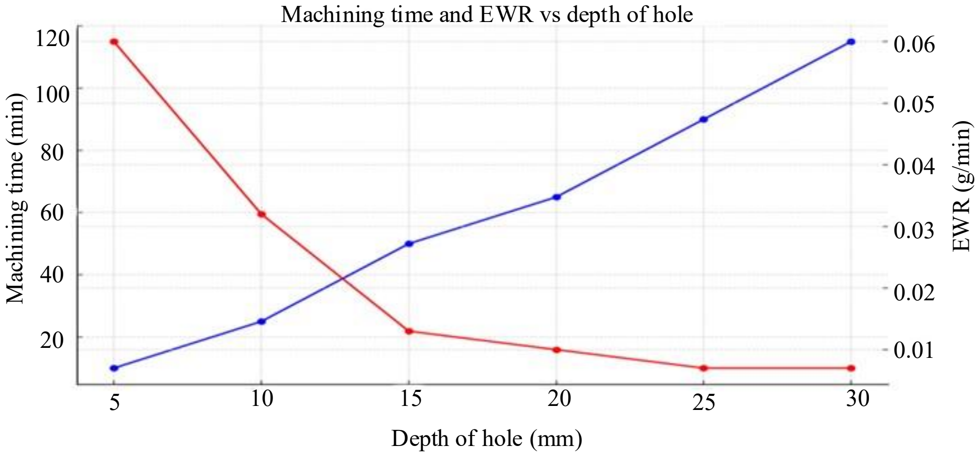

**Figure 3.** Graph between machining time, EWR Vs depth of hole.

**Figure 4.** Weighing of electrodes using digital weighing system.

These visualizations help in understanding the relationship between the depth of the hole and both machining time and EWR.

**Variation of Squareness and Taperness with Varying Depth**

The depth of the hole is a critical parameter in EDM, as it directly influences the functionality of the machined parts. The data indicates a varying depth of 5 mm increments to 30mm across the measurements, which is essential for applications requiring precision, such as micro-robotics and micro-detection systems .The squareness values provided ranging from 0.995 to 1.009 indicates a feasible range of values. A squareness value of 1 indicates a perfect square, while values close to 1 (like 0.995) indicate very slight deviations from this ideal. This is significant because squareness affects the relative motion between machined parts, which is critical for their functionality. After wire-cut of the workpiece as shown in Figure 5,Co-ordinate Measuring Machine (CMM) was used for measuring the squareness.Thedimensions of the square hole and it's squareness is calculated using Eq. 1. The squareness value ranges from zero to one.

$$Squareness\ (sq.ness = \frac{Major\ axis}{Minor\ axis} \tag{1}$$

The Taperness values ranging from 0.00515 to 0.007210 indicates the amount of variation from a perfect shape. Low taperness values are desirable as they indicate minimal tapering, which can affect the fit and function of components. The data in table 2 shows that the taperness remains relatively low, suggesting effective control over the machining process.

From the Figure 6, we can observe the following conclusions:

1. *Squareness*remainsfairly stable across varying depths, with slight fluctuations. It peaks around a depth of 10 mm and decreases slightly as depth increases.
2. *Taperness* shows a more noticeable variation compared to squareness. It starts relatively high at 5 mm, then decreases, reaching its lowest point around 15 mm, and then slightly increases again with depth.

These observations suggest that as the depth of the hole increases, taperness tends to fluctuate more significantly than squareness, which remains relatively constant. If further precision or consistency is required, especially in maintaining uniform taperness, the processes involved in creating deeper holes may need closer monitoring or adjustment.

**Figure 5.** Workpiece samples after wirecut.

**Table 2.** Variation of squareness and taper angle at constant I, ton, duty factor

| Exp.no. | Depth of hole mm | Current A | Pulse On time µs | Duty factor (%) | Squareness | Tapernessmm |
|---|---|---|---|---|---|---|
| 1. | 5 | 10 | 7 | 53.84 | 0.995 | 0.0072 |
| 2. | 10 | 10 | 7 | 53.84 | 1.010 | 0.0050 |
| 3. | 15 | 10 | 7 | 53.84 | 1.009 | 0.0016 |
| 4. | 20 | 10 | 7 | 53.84 | 1.000 | 0.0030 |
| 5. | 25 | 10 | 7 | 53.84 | 1.007 | 0.0050 |
| 6. | 30 | 10 | 7 | 53.84 | 1.006 | 0.0056 |

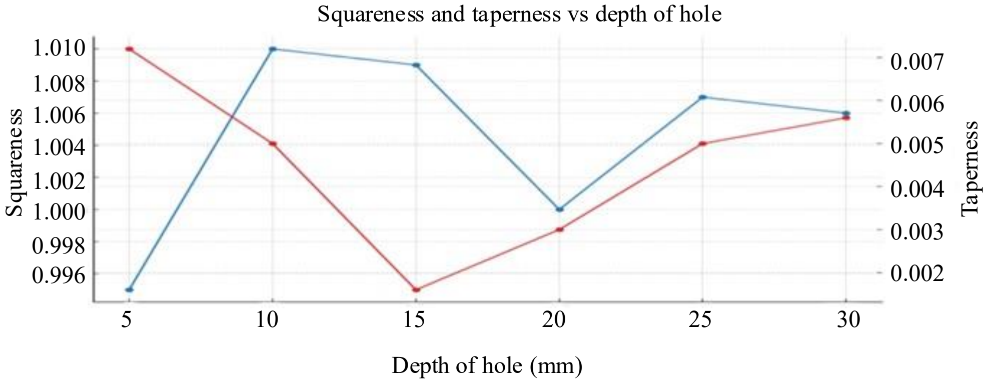

**Figure 6.** Graph between depth of hole, squareness and taperness.

### Variation of Surface Roughness with Varying Depth

Achieving low surface roughness in EDM machining requires careful optimization of process parameters, pulse duration, current, and duty cycle. Understanding these relationships is essential for improving the quality of machined surfaces in various applications.Surface roughness were measured using Talysurf instrumentas shown in fig.7 and noted in Table 3.

The graph in Figure 8 illustrates the relationship between surface roughness (Ra) and depth. The surface roughness Ra (measured in micrometers, µm) is depicted by the blue line, and the depth (possibly in millimeters, as suggested by the axis range) is depicted by the red line. Initially, both surface roughness and depth increase steadily. As depth reaches approximately 4 units, surface roughness peaks around 8 µm and then drops sharply, indicating a sudden improvement in surface finish, possibly due to a change in machining parameters or material properties at this depth. After this drop, the roughness rises again, indicating a possible increase in irregularities or defects at greater depths. This suggests a non-linear relationship where specific depths significantly affect surface finish.

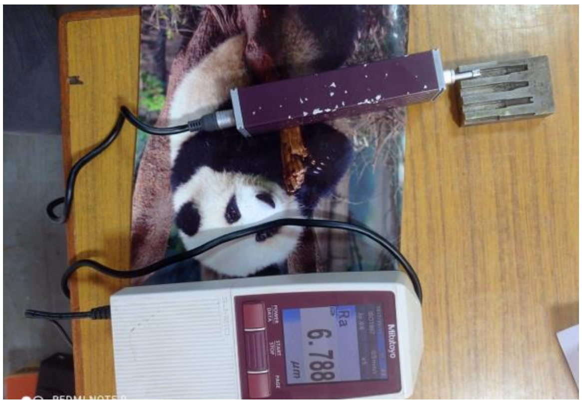

**Figure 7.** Surface roughness measurement of machined hole.

**Table 3.** Variation of surface roughness at constant i, ton, duty factor and varying depth.

| Exp.no. | Depth of hole mm | Current A | Pulse On time µs | Duty factor (%) | Surface roughness Ra (µm) |
|---|---|---|---|---|---|
| 1. | 5 | 10 | 7 | 53.84 | 5.851 |
| 2. | 10 | 10 | 7 | 53.84 | 6.702 |
| 3. | 15 | 10 | 7 | 53.84 | 7.372 |
| 4. | 20 | 10 | 7 | 53.84 | 7.941 |
| 5. | 25 | 10 | 7 | 53.84 | 6.512 |
| 6. | 30 | 10 | 7 | 53.84 | 7.453 |

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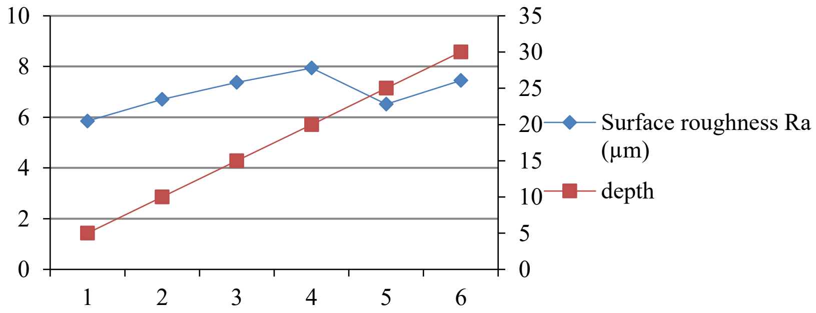

**Figure 8.** Graph between Surface Roughness vs Depth of hole.

## CONCLUSIONS

At Constant Parameters current (10 A), pulse on time (7 µs), and duty factor (53.84%) varying the depth of the hole in increments of 5 mm from 5 mm to 30 mm the output parameters Machining Time and electrode wear rate were observed.

1. Hole Depth and the time taken for machining the respected hole are interrelated on each other. As the depth increases, the time required to machine the hole also increases. There is a negative correlation between the depth of the hole and the EWR. The EWR decreases as the depth of the hole increases, eventually stabilizing at 0.007 g/min for depths of 25 mm and 30 mm.
2. The squareness values provided (ranging from 0.995 to 1.009) suggest a high level of precision in the machining process. A squareness value of 1 indicates a perfect square, while values close to 1 (like 0.995) indicate very slight deviations from this ideal. This is significant because squareness affects the relative motion between machined parts, which is critical for their functionality. The taperness values (ranging from 0.00515 to 0.007210) reflect the degree of deviation from a perfect cylindrical shape. Lowertaperness values are desirable as they indicate minimal tapering, which can affect the fit and function of components. The data shows that the taperness remains relatively low, suggesting effective control over the machining process.
3. Initially, both surface roughness and depth increase steadily. As depth reaches approximately 4 units, surface roughness peaks around 8 µm and then drops sharply, indicating a sudden improvement in surface finish, possibly due to a change in machining parameters or material properties at this depth. After this drop, the roughness rises again, indicating a possible increase in irregularities or defects at greater depths. This suggests a non-linear relationship where specific depths significantly affect surface finish. Understanding these patterns is crucial for optimizing machining processes to achieve desired surface characteristics.

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