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Influence of Performance Indicators on Maraging Steels during Spark Erosion Machining

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Abstract: Superior levels of strength and hardness of Maraging Steel (MDN 250) leads to difficulty in machining. For machining to be effective, performance indicators must be optimized. This study discusses the Taguchi approach, which is used to optimize electrical discharge machining (EDM) performance indicators and estimate the effect of process parameters on MDN 250 steel. Material removal rate (MRR), Surface roughness (SR) and Squareness were among the process performance indicators that were evaluated. The most important variables influencing EDM performance are discharge current and pulse duration from the previous research studies. The results of the present investigation show that pulse duration and current are important factors in EDM operations to get précised machined components.

Keywords: Maraging steel, Material Removal Rate, Pulse duration, Surface Roughness and Squareness.

Introduction:

High strength and toughness for service at cryogenic and ambient temperatures are the excellent features of Maraging Steels (MDN 250).Because of these properties, this material is used for various applications, such as Components for rockets, missiles and aircrafts, hot forging, dies, extrusion tooling etc. One crucial production technique for cutting hard metals and alloys is electrical discharge machining (EDM) [1]. Dies, molds, and finished components for medical, automotive, and aerospace components are often manufactured using this method of production [2]. By optimizing the process parameters, this technique can achieve a required surface finish and dimensional precision [3]. Surface roughness (SR), tool wear rate (TWR), and material removal rate (MRR) are basically used for calculating EDM performance [2]. Discharge current, pulse on and off times, arc gap, and duty cycle are crucial EDM machining parameters that impact process efficiency indicators [4].

Researchers have reported a significant amount of work on measuring EDM performance for different types of steels based on MRR, TWR, and SR. The impact of process factors on MDN 250 steel's EDM was examined by Rao et al. [5]. While MRR and SR are process parameters, they have taken into account discharge current, duty factor, and pulse on time as performance metrics. However, parametric optimization was not carried out in their investigation. In order to forecast the behavior of the MDN 250 steel, they also expanded their research and created a hybrid model for SR [6]. Nikalje et al. [7] investigated the optimum parameters using Taguchi method on MDN 300.He concluded that the parameters pulse on time and current are most significant factors than pulse off time which is insignificant in most of the cases as mentioned in the previous studies .Wu et al. [8]. investigated on square blind holes machined by EDM on Titanium Alloy .In his study ,the meso deep square holes were machined by special method named as Step-by-Step process to increase the precision of square blind holes which are predrilled in circular shape and no optimization was done on this process. Choosing the right combination of machining settings is crucial for EDM in order to get the best machining performance metrics [9]. Typically, operator experience or information supplied by the EDM manufacturers chooses the parameters for machining. The efficiency of machining is inconsistent when such information is employed during EDM. Only the most widely used steels can benefit from the manufacturer's data on parameter settings. Special materials such as composites, ceramics, and Maraging steels do not have such data. Performance metrics must be experimentally optimized for these materials. The increased number of machining factors makes it challenging to optimize the settings of the EDM process. The procedure is greatly impacted by small adjustments to a single parameter. Therefore, it is crucial to comprehend the impact.

In this work, the optimization of the EDM performance indicators for Square blind holes using Taguchi method on MDN 250 is done. Only few researchers have investigated on meso deep square blind holes. All elements of design that influence the product's functional characteristics deviating from the intended values must be taken into account while using this method. Methods that reduce undesired and uncontrollable elements that can lead to functional deviations must also be taken into consideration .With this approach, the impacts of each parameter on the identified quality attributes can be assessed independently of other parameters and interactions. One of the most widely used optimization techniques is the Taguchi approach, which successfully reduces the impact of the cause of variation while demanding the least amount of experimental expenditures.

Material and Methods:

The Maraging Steel block MDN 250 having dimensions of 50mmx100mmx120mm was used as work piece material.EDM machining was done using a copper tool and Kyros ferrolac 3M as the dielectric medium. The positive polarity was used during the experiments. Initially the circular holes are drilled with dimensions of Φ4.5×40 mm on the work piece using EDD (Electrical Discharge Drilling) and machined to a square hole using copper electrodes with 4.8 mm as square side. A spark gap of 0.2 mm was given to move in vertical direction on EDM during machining. The experiments were conducted considering current, pulse duration, and at constant pulse off time as input variables. These experiments aimed to analyze the effects of current and pulse duration on 20mm deep square blind holes. The output parameters Material Removal Rate (MRR), Squareness and Surface Roughness (SR) were measured. In Fig.1 the experimental setup was shown.

Table 1: Chemical composition of MDN 250 steel

Alloying element	C	Si	Mn	S	P	Cr	Ni	Co	Mo	Ti	Al	Fe
% wt	0.03	0.10	0.10	0.01	0.01	0.50	17-19	7.0-8.50	4.60-5.20	0.30-0.50	0.05-0.15	62-65

Table 2: Properties of MDN 250 steel

Property	**Quantity**
Material Density	8.1 g/cm3
Specific heat	452 J/kg° K
Melting point temperature	1,413–1,454° C
Thermal conductivity	25.5 W/m K
Yield tensile strength	655 MPa
Hardness	30 BHN

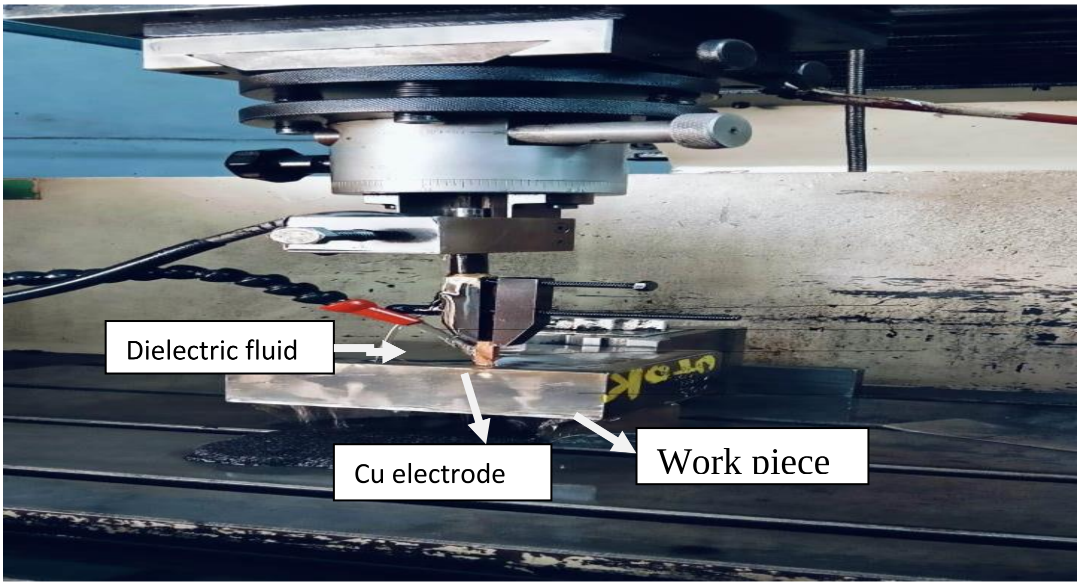

Fig.1: Experimental Setup

Here, Taguchi L9 array is used to design the experiments for better performance. The following table gives the details of different factors and their levels.

Table 3: Matrix of Parameters and their levels

level	Pulse On Time (Ton) µs	Current I A
1	6	12
2	7	15
3	8	18

The work piece weight loss (WWL) over a certain machining time in minutes is known as the MRR. Surface's roughness or smoothness is indicated by its SR. The roughness average (Ra), which is an arithmetic average of a work piece surface's peaks and valleys measured from the evaluation length centerline, was used to measure it in this study. A Zeiss surface roughness tester (Make: Surcom 130A) was used to measure it. The Co-ordinate Measuring Machine (CMM) is used to measure the dimensions of the square hole. Squareness of the machined holes is measured using the formula

$$\text{Squareness (sq.ness)} = \frac{\text{Major axis}}{\text{Minor axis}} \qquad (1)$$

Table 4 : Experimental Results

Run	**Pulse duration Ton µs**	**Current I A**	**Pulse Off Time µs**	**MRR mm3 /min**	**SR (Ra) µm**	**Squareness(ₒ)**
1	6	12	6	13.09	4.025	0.999
2	6	15	6	15.29	4.065	1.001
3	6	18	6	17.95	5.751	0.998

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4	7	12	6	10.74	7.097	0.995
5	7	15	6	12.00	7.496	0.985
6	7	18	6	13.09	7.820	1.004
7	8	12	6	8.00	8.002	1.002
8	8	15	6	8.96	8.399	0.991
9	8	18	6	10.76	8.609	0.992

RESULTS AND DISCUSSIONS

The impact of machining parameters on performance indicators are assessed under ideal conditions in the Taguchi method. It is used to identify the optimum machining parameters to minimize Squareness and SR and maximize MRR.

SIGNAL-TO-NOISE (S/N R) ANALYSIS

The MRR, Squareness and Surface Roughness experimental data were further converted into a signal-to-noise ratio (S/N) ratio. The Taguchi technique measures the quality feature that deviates from the desired value using the S/N ratio.

The S/N ratio η is defined as

$$\text{S/N Ratio} = -10 \text{ Log10 [MSD]} \qquad (2)$$

Where MSD is the mean square deviation for the output characteristic.

For MRR (Material Removal Rate) where maximization is desirable, the S/N ratio is calculated using the formula

$$\text{S/N Ratio} = -10 \text{ Log10 [MSD]} \qquad (3)$$

Where MSD (for Maximization) = $1/MRR_i^2$

Where MRR_i is the MRR value at *i*th test

For Surface Roughness and Squareness where minimization is desirable, the S/N ratio is calculated using the formula

$$\text{S/N Ratio} = -10 \text{ Log10 [MSD]} \qquad (4)$$

Where MSD (for minimization) = SR_i^2 or Sq_i^2

where SR_i^2 is the SR value at *i*th test or Sq_i^2 is the squareness value at *i*th test.

Table 5: S/N Ratios values of MRR, SR and Squareness

Run	Ton(µs)	Current I (A)	S/N ratio values(dB)		
			MRR	Surface Roughness	Squareness
1	6	12	22.3387929	-12.095317	0.00869023
2	6	15	23.6881497	-12.181211	-0.04332124

3	6	18	25.0812891	-15.194867	0.01738917
4	7	12	20.6200856	-17.021496	0.04353838
5	7	15	21.5836249	-17.496591	0.13127539
6	7	18	22.3387929	-17.864135	-0.0346742
7	8	12	18.0617997	-18.063970	-0.0173544
8	8	15	19.0461602	-18.484551	0.0785269
9	8	18	20.6362454	-18.699054	0.0697665

Analysis for MRR

Maximization of material removal rate from work-piece considered in order to achieve better EDM performance. The mean S/N ratios of MRR is calculated at each level of Pulse duration (TON) using the equation (2) and tabulated as below.

Table 6: S/N Ratios values for MRR

Level	T_{ON}	I
1	23.70	20.34
2	21.514	21.439
3	19.24	22.685
Max-min	4.46	2.345
Rank	1	2

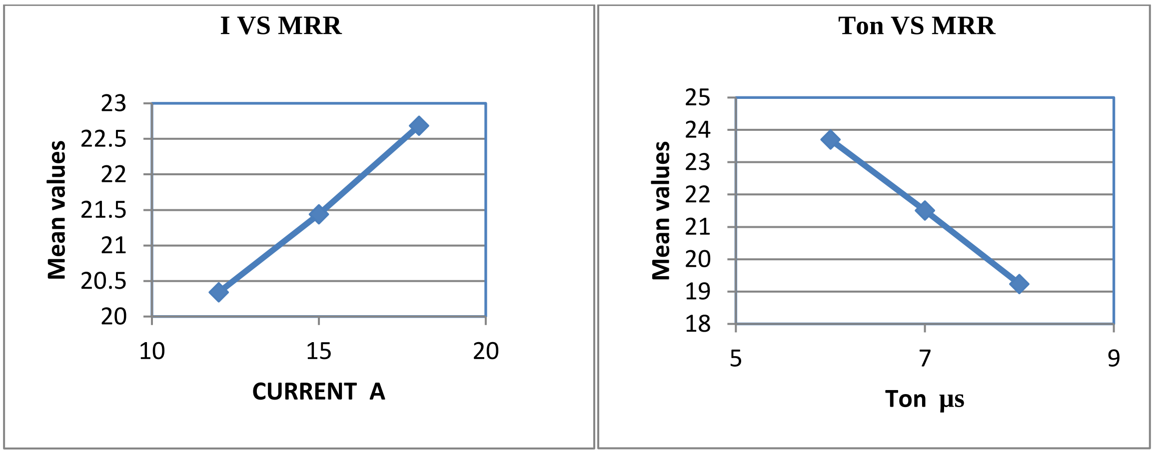

Fig 2: S/N graphs for MRR

The S/N response graph indicates that factors at level 1(Pulse on Time 6µs) and at level 3 (current 18A) gives maximum Material Removal Rate. According to table 6, pulse duration plays significant role followed by discharge current. The amount of heat energy supplied to the electrode and work piece is determined by the pulse's duration. The quantity of energy applied during this time is directly correlated with the quantity of material removal from the work piece. Thus, Pulse on Time has the most significant impact and contribution. According to its contribution and significance, the discharge current is regarded as the second factor since it governs the quantity of heat energy needed to remove material from the work piece and electrode.

Analysis for Surface Roughness:

For Surface Roughness (SR), the criteria “Smaller –is-better(S/N ratio)” were used. From table 7, it is observed that the lowest value of each parameter indicates the optimal level to get best value for SR. The S/N response graph indicates that factors at level 1(Pulse on Time 6µs) and at level 1(current 12 A) gives minimum Surface Roughness. According to Table 7 and Figure 3, the most significant factor is pulse on time, whereas discharge current has a little impact on SR.The pulse on time determines the period that the heat energy is available for material removal. A larger amount of sparks sharing this energy causes the crater's size to decrease. Surface polish is enhanced as a result. As a result, the importance and contribution of timely pulses are greatest for SR.

Table 7: Mean value of S/N ratios for Surface Roughness

Level	TON	I
1	-13.157	-15.73
2	-17.46	-16.05
3	-18.41	-17.25
Max-min	5.253	1.52
Rank	1	2

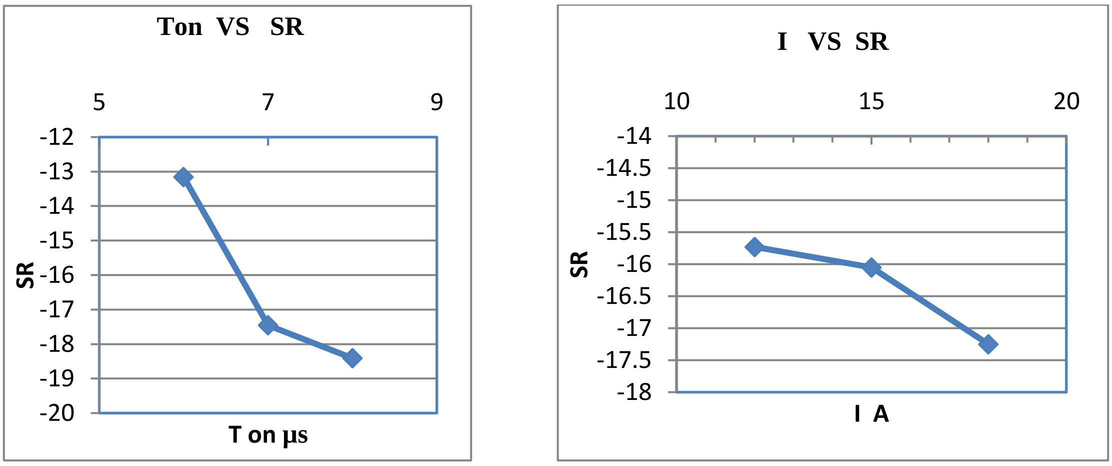

Fig 3: S/N graphs for Surface Roughness.

Analysis for Squareness:

For Squareness, the criteria “Smaller -is-better(S/N ratio)” were used. From table 8, it is observed that the lowest value of each parameter indicates the optimal level to get best value for Squareness. Therefore, the best optimized values for Squareness are at pulse on time (Ton) 6µs and current I-12A. According to Table 8 and Figure 4, the most significant factor is pulse on time, despite discharge current has a negligible impact on squareness.

Table 8: Mean value of S/N ratios for Squareness

Level	TON	I
1	0.0057	0.0116
2	0.0467	0.0554
3	0.0436	0.0174
Max-Min	0.041	0.0438
Rank	1	2

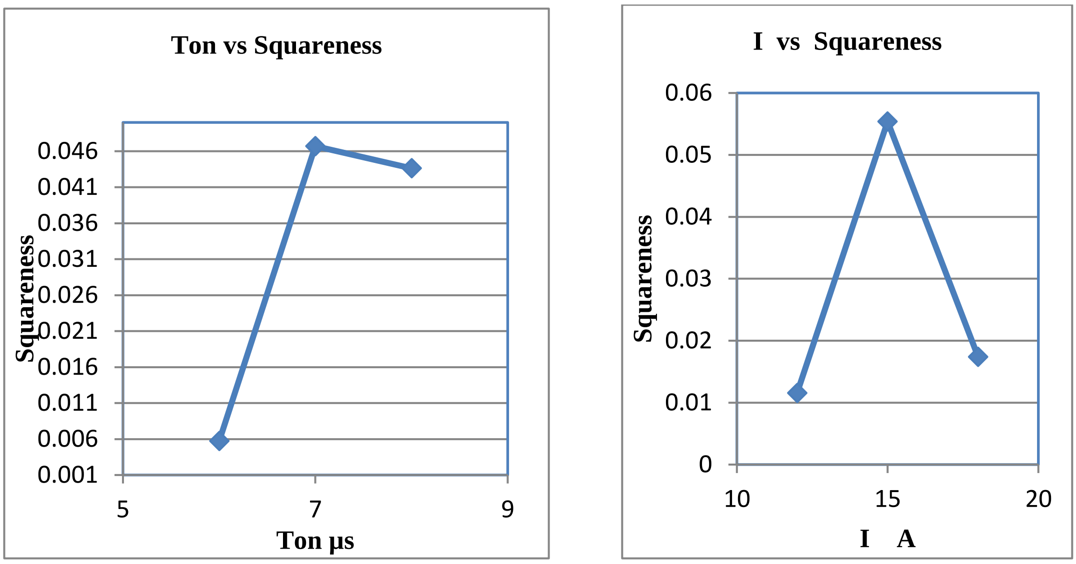

Fig 4: S/N graphs for Squareness

Conclusions

In this study, Taguchi analysis was used to examine the effects and optimization of process parameters for MDN 250 steel on die sinking EDM. According to the results, the discharge current and Pulse-on-time are essential factors of EDM operations. Pulse duration have much effect for all the performance indicators Material Removal Rate, Surface Roughness and Squareness.

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