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Parametric Study of Die Sinking EDM of H13 Steel using Taguchi Techniques

***[1]Sachin S Chaudhari, [1]A.M. Nikalje, [2]G.E. Chaudhari**

[1]*Government College of Engineering, Aurangabad, Maharashtra, India.*

[2]*J.T Mahajan College of Engineering, Faizpur, Maharashtra, India.*

*Corresponding Author Email: sachinschaudhari7@gmail.com

Abstract: *As for H13 die steel, it is distinguished by a high hardness and a unique surface characteristics that must be created during machining using non-standard methods. One of such non conventional manufacturing techniques involving the use of Electrical Discharge Machining (EDM) for machining complex or hard material parts. It indicates that EDM has progressed from a series of a tool and die process to an alternative micro-scale application machining process. The paper is aimed at elaborating mathematical models defining the link between the MRR and SR to measured input parameters (current, pulse-on time, pulse-off time, and Reference voltage) in hot work steel EDM. With a L9 orthogonal involving four variables at three levels were used. The values of the model quality factors analyzed by the ANOVA procedure show that the selected mathematical models describe the process performance within successfully studied range with high level of precision. To determine the optimal condition, Taguchi method was used to measure the performance impact of different process parameters and find out best mixing. Minitab V 21 software has been used for the analysis and explanations. A good agreement between experimental value and the predicted one was found.*

1. INTRODUCTION

In the Die Sinking EDM process, metal is removed using spark erosion. It is comprised of a power source that produces electrical pulses between the work-piece and the tool. The inter-electrode gap enables passage of dielectric oil that continues to be ionized until the voltage reaches its predetermined value. The regulated sparks generated by the ionized oil melt and evaporate the work-piece, while pressurized dielectric oil cools vaporised metal and removes it from gap. A filtration system is used to separate the suspended particles from the dielectric oil, which further goes through a chilling unit for removal of heat accumulated during erosion. The use of chilling unit ensures that the oil temperature remains constant, which is crucial to precision in the functioning of a machine (B. M. Schumacher, 2013)

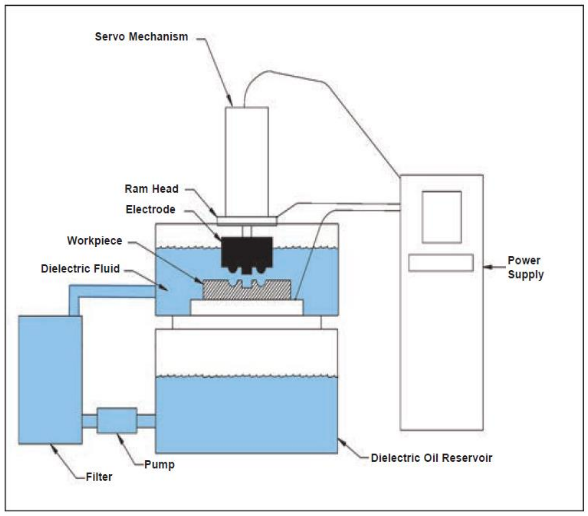

FIGURE 1. Die Sinking EDM (Sachin S Chaudhari, 2019)

Molding and dies are therefore sculptured using EDM, abbreviated as electrical discharge machining. It is also in application in the automotive dies, and press tool in industries (Newman, 2003). The history of EDM is a comparatively opening story, which began as early as the 1770s, when an English scientist has revealed the relaxation circuit, which allowed maintaining a gap between the tool and the work-piece, setting it with the help of servo. This finding resulted to decrement in the tonnage and integration of EDM to become more commercial (Kayacan, 2008). One other application of EDM that has been used since the 1940s is in reducing the orbital and planetary motion methods, pulse generator, computerized numerical control (CNC), and a self-designing control scheme. Yet since Russian scientists researched the erosive effect of the process of how it could be controlled for machining was not fully used by the scientist (Sommer C, 2005).

1.1 A concise overview of the literature is presented as follows:

The metastable EDM technique, for AISI H13 W.-Nr analyzed by (G.K.Bose, 2014), is dedicated to the deposition of powder mixture in VHRC and followed up with elemental analysis.1.2344 Grade: Orvar Supreme, and is intended to find the impact of machining parameters (discharge gap current, pulse on time, pulse off-time and spark gap). The Taguchi method was used for designing the experiments and analysis of variance (ANOVA) to analyze them. In this study, gap current and pulse on time were shown to affect material removal rate while surface roughness is influenced by the constant of pulsation. Lastly, the multi-response optimization was carried out using superimposed contour plots and desirability functions.

With regard to the effects of process parameters, namely current, voltage, pulse on time and off time as well as magnetic field by (Nalisetty Vimala, 2018), a study is undertaken concerning H 13 steel with regards to material removal rate (MRR), tool wear rate (TWR), and surface roughness (Ra).They used the Taguchi method and the ANOVA method for the parametric optimization processes on the way the MRR, TWR and subsurface roughness at the maximum. The primary finding of the study was that current proved to have the highest effect on MRR; pulse on time, voltage and pulse off time appeared to have a lesser boosting effect. Just as current was the most influential factor in TWR, pulse on time, pulse off time, and voltage are also factors, in the order decreasing from highest probable influence to the least. With respect to the deep roughening, it was established that the current is the superior parameter to roughness, followed by the pulse on time, the voltage and lastly the pulse off time.

(M. M. Bahgat, 2019) Attempted to determine the influence of different process parameter of H13 die steel materials using EDM. The parameters of the different processes that were investigated include the current, the pulse on-time and the electrode material. The researchers performed process evaluation for machining by using the parameters like MRR (material removal rate), EWR (electrode wear ratio), RA (surface roughness) as indicators of the process efficiency and quality. The Taguchi method and Minitab software was used for analysis for the analysis and as a result, it was established that the copper electrode gave the highest MRR and the lowest electrode wear ratio and that the brass electrode gave the lowest surface roughness. In his study, (Suresh Kumar Gurjar, 2015), the Die steel H13 tool steel is used for machining purposes. Since it was intended to eliminate the number of experiments the Taguchi approach was used along with the L9 orthogonal array. The study was also performed the Taguchi and ANOVA optimization of MRR and TWR in EDM. The conclusion was made that current appears to be the factor primarily influencing MRR/TWR in EDM to Die steel H13. For the MRR metric, the best-performing TC machining regime was 20amps, 150µs, and 0.4 mm/rev.

A study to determine the effect of process parameters on the machining of AISIH13 tool steel using the VMC performed by (T. Y. Saindane, 2016). This study showed that the increases in the values of ips and Ton resulted in a higher value of the SR value, H-13 steel. (Ankit Kumar, 2020) Wanted to explore the influence of major process parameters in terms of the peak current, pulse on time and feed rate, applied on material removal rate (MRR) using EDM drilling. The Optimization of response variables was done using the Taguchi technique. The results of the experiment showed that the highest percentage of one of the three factors that affected MRR was the current, followed by the pulse on time and feed rate. As they investigate another trend that was noted was that MRR increased whenever the value of the current was enhanced. (Ghayatadak, 2018) Concentrated on achieving optimal operating parameters of electrical discharge machining (EDM) in relation to the machining of H13 steel. The parameter evaluated was peak current, pulse interval, and breakdown voltage. So, design parameters were identified by the Taguchi technique to identify the optimum values for these parameters to achieve the desired machining characteristics for MRR and EWR, respectively. The last step after the results were obtained is the analysis using analysis of variance (ANOVA), which identified the importance of each process parameter on the EDM machining characteristics. Course of the study, it did indicate that pulse on time and peak current were major factors in both MRR and in EWR.

From the available literature, the task that requires serious improvement for applying the EDM technology for the production of hardened dies is the process low productivity. Moreover this kind of advanced solutions are absent for choosing cutting parameters leading to a higher efficiency of cutting when cutting dies using EDM with H13 Tool Steel.

However, in spite of numerous investigations of other materials EDM from corresponding literature, this remains one issue that has not been solved. The main reason behind this is that stochastic process mechanisms an inherent part of EDM are rather complicated (I. Mukherjee, 2006).

Thus, in this study, the Design of Experiments (DOE) method, the Taguchi method to build the model between input parameters (peak current, pulse-on time, pulse-off time, and reference voltage) and process outputs material removal rate (MMR) and surface roughness (SR). The results indicated hereby are suggestive in attaining desired process outputs in terms of machine chip rate and sensor compensation as well as cost-effective machining operations through apposite choice of above mentioned input parameters.

2. EXPERIMENTAL DESIGN:

2.1 Material:

The selected workpiece for this study is H13 die steel (the shape is circular around Ø36 mm) – a material that is well used for many hot and cold work tooling operations. First of all, its applicability is associated with its unparalleled strength and fatigue resistance, as well as its unique hardness, wear resistance and shape stability against loads at high temperatures. Table 1 provides the chemical composition of the workpiece material. Table 2 represents the material's properties both for the workpiece and the electrodes.
In this work, we used an electrode made of copper (99.98% purity) of size 10 mm which is considered as a regular electrode used in the EDM process.

TABLE 1. Chemical composition of H13 dies steel. (in weight %)

Alloy	Composition (in weight %)						
	Fe	C	Si	Cr	V	Mo	Mn
H13 die steel							
• Analyzed by S. M. Metallurgy Pvt Ltd Lab MIDC Aurangabad.							

TABLE 2. Mechanical properties of workpiece and electrode material.

Properties	H13 die steel	Copper
Density (g/mm^3)	$7.8/10^3$	$8.83/10^3$
Thermal Conductivity (W/mK)	41.9	408
Modulus of Elasticity (GPa)	205	117
Hardness (HRC)	52-54	38

The study employed the CHARMILLES ROBOFORM 20, which has improved the process parameters via the transistor circuit. The experimental trials for this study utilized EDM Oil as the dielectric fluid with immersed flushing. The process input parameters, Ip, Ton, Toff and Rf were measured and listed in Table 3. The Taguchi method was followed in planning the experimental design (L9 orthogonal array) with four control factors and three levels for each factor.

TABLE 3. The process parameters.

Variables	Unit	Setup Values
A.Peak current (Ip)	Amp (A)	4, 6, 8
B.Reference voltage (Rf)	Volt (V)	40, 60, 80
C.Pulse on-time (Ton)	Microseconds (µs)	25, 50, 100
D. Pulse off-time (Toff)	Microseconds (µs)	25, 50, 100
Dielectric Fluid		EDM oil
Flushing Pressure (kgf/cm^2)		0.5
Depth of cut	mm	0.2
Electrode polarity		Positive

2.2. Performance Variables.

2.2.1 Material Removal Rate (MRR)

The measurement of MRR was done by dividing the volume of the workpiece that was machined by the time it took to complete the machining process. Once each machining process was finished, the workpiece was carefully cleaned using compressed air from an air gun to ensure that it was free from debris and dielectric fluid.

2.2.1 Surface roughness (SR)

However, the SR of a workpiece is measured with quite a few techniques. In this case, surface roughness was calculated using arithmetic value of Ra and measured. On the other hand, the Mitutoyo Surftest SJ210 Hand-Held Roughness tester was used for determining the SR. Measurement was done for each individual experiment with the workpiece being measured five times and then average value was calculated for each experiment. Roughness measurements were recorded in several locations for each EDM condition on the machined surface. In each experiment, the weight of the workpieces and the electrodes before and after the process was measured precisely in a scale with a reproducible error of 0.001g This was carried out to establish the Material Removal Rate and overall Surface Roughness.

3. RESULT AND DISCUSSION

3.1 Experiment data

In this investigation, we measured and utilized four output parameters. The combinations of experimental machining parameters and their respective levels in the L9 design are detailed in Table 4. Moreover, this table presents the signal-to-noise ratio corresponding to each combination.

TABLE 4. S/N ratio for MMR and SR

Run	Peak current (Ip)	Reference voltage (Rf)	Pulse on-time (Ton)	Pulse off-time (Toff)	MRR (mm^3/min)	S/N ratio	SR (Ra)	S/N ratio
1	4	40	25	25	1.02423	0.2079	3.30575	-10.3854
2	4	60	50	50	1.24065	1.8730	4.05433	-12.1584
3	4	80	100	100	1.58408	3.9956	4.21900	-12.5042
4	6	40	50	100	1.64903	4.3446	5.01250	-14.0011

5	6	60	100	25	5.06740	14.0957	5.78025	-15.2389
6	6	80	25	50	1.32953	2.4740	5.17850	-14.2841
7	8	40	100	50	5.10874	14.1663	6.63125	-16.4319
8	8	60	25	100	1.68414	4.5276	6.13125	-15.7510
9	8	80	50	25	3.16348	10.0033	7.13800	-17.0715

3.2 Parameters effect on MRR.

The impact of various parameters on Material Removal Rate (MRR) is depicted in Figure 2, which shows the influence of peak current (Ip), reference voltage (Rf), pulse on-time (Ton), and pulse off-time (Toff). As shown in the results of Figure 1, an increase in Ip corresponds to higher MRR values. Moreover, it was observed that elevating Ton and Rf also enhances MRR, until Rf reaches a value of 60, after which MRR declines. Additionally, an increase in Toff leads to a decrease in MRR. The Signal-to-Noise (S/N) ratios for MRR were computed using Eq. (1). The Taguchi method was applied for analyzing the machining parameters based on the "larger is better" criterion (Ross, 1995). Figure 3 presents the main effect plot for MRR."

$$(S/N)_{LB} = -10 \log (MSD_{LB}) \qquad ....Eq.(1)$$

Where,

$MSD_{LB} = \frac{1}{n}\sum_{i=0}^{n}(Y_i^2)$ = Mean square deviation for larger the better response.

n = number of experiments.

y_i = the i^{th} measured value in row.

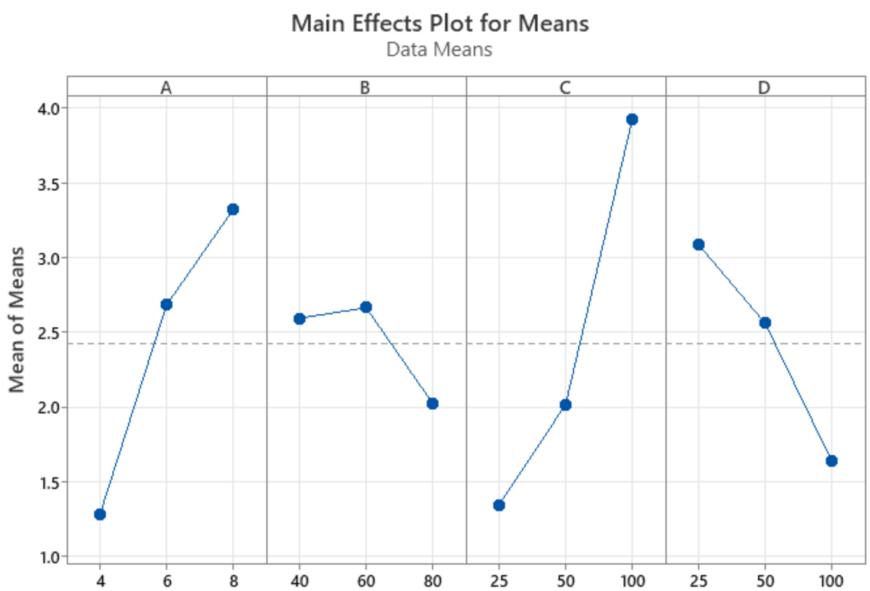

FIGURE.2 Process variables effect on MRR

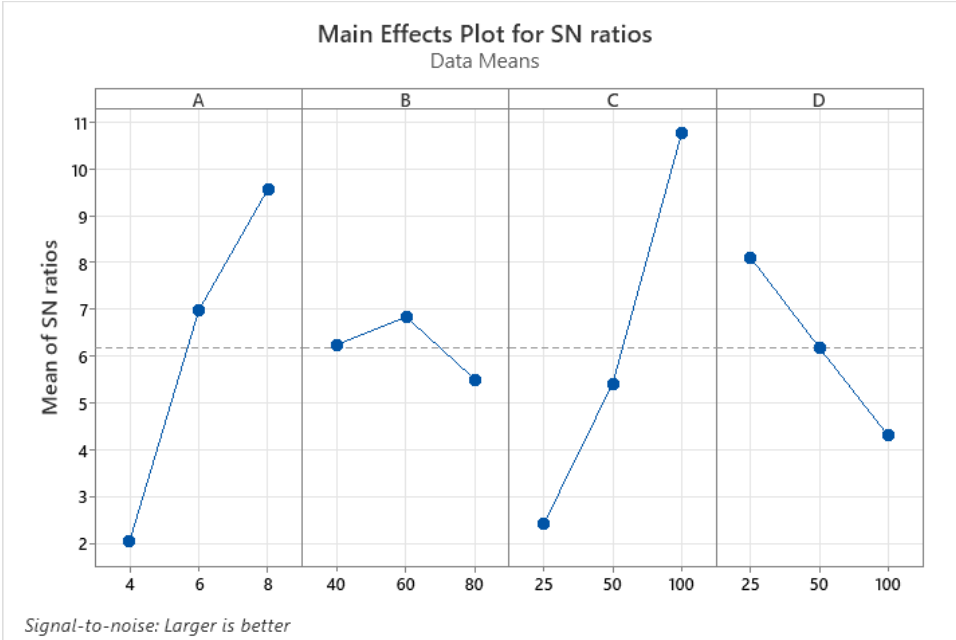

FIGURE.3 S/N ratio of MRR

The delta value signifies the difference between the higher and lower average values of each factor. As shown in Table 5, pulse on-time (Ton), peak current (Ip), pulse off-time (Toff), and reference voltage (Rf) are ranked 1, 2, 3, and 4, respectively, based on their larger delta values. Rank 1 denotes the factor with the greatest impact on MRR, followed by rank 2, indicating a factor with a moderate effect, and so forth.

The optimal MRR value for H13 die steel can be achieved using a copper electrode with Ton at 100µs, Ip at 8A, Toff at 25µs, and Rf at 60V, as depicted in Figure 2.

TABLE 5. Response Table for Signal to Noise Ratios for MRR

Level	A	B	C	D
1	2.025	6.240	2.403	8.102
2	6.971	6.832	5.407	6.171
3	9.566	5.491	10.753	4.289
Delta	7.540	1.341	8.349	3.813
Rank	2	4	1	3

Larger is better

The experimental data was analyzed through Analysis of Variance (ANOVA). The outcomes of this analysis are presented in Table 6, employing a confidence level of 95%. P-values below 0.05 suggest the rejection of the null hypothesis, indicating a significant effect of the respective factor. As indicated in Table 7, peak current (P=0.003), pulse on-time (P=0.001), and pulse off-time (P=0.010) exhibit the most substantial influence on MRR, while reference voltage does not significantly impact MRR.

TABLE 6. Analysis of Variance table for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	20.5411	97.11%	20.5411	5.1353	33.57	0.002
A	1	6.2167	29.39%	6.2167	6.2167	40.63	0.003
B	1	0.4845	2.29%	0.4845	0.4845	3.17	0.150
C	1	10.6293	50.25%	10.6293	10.6293	69.48	0.001
D	1	3.2106	15.18%	3.2106	3.2106	20.99	0.010

Error	4	0.6120	2.89%	0.6120	0.1530		
Total	8	21.1530	100.00%				
Model Summary for MRR			R-sq = 97.11%, R-sq(adj) = 94.21%, R-sq(pred) = 80.20%				

To acquire predictive quantitative relationships, it's crucial to formulate models for machining responses and process variables. In this investigation, mathematical models were developed from experimental data using MINITAB-21 software. The response functions for MRR established through regression equations derived from the observed data, as illustrated below.

Regression Equation for MRR is:
MRR = -0.689 + 0.5089 A - 0.01421 B + 0.03485 C - 0.01916 D

3.3 Parameters effect on SR.

The data depicted in Figure 4 indicates that increasing the Peak Current (Ip), pulse on-time (Ton), and reference voltage (Rf) values leads to an increase in Signal-to-Noise Ratio (SR). Conversely, it was noted that SR decreases with an increase in pulse off-time (Toff). The Signal-to-Noise (S/N) ratios for SR were computed using Eq (2).

$$(S/N)_{SB} = -10 \log (MSD_{SB}) \qquad \text{................Eq.(2)}$$

Where,

$MSD_{SB} = \frac{1}{n}\sum_{i=0}^{n}\left(\frac{1}{Y^2{}_i}\right)^2$ = Mean square deviation for larger the better response.

FIGURE 4. Process variables effect on SR

Utilizing the Taguchi technique, the machining parameter results were analyzed based on the "smaller is better" criteria (Ross, 1995). Both Table 7 and Figure 5 display the S/N ratios for the various factor levels. Figure 5 reveals that the optimized value for SR is achieved at Ip=8A, Rf=40V, Ton=25, and Toff=100µs, resulting in the highest SR for H13 die steel. Additionally, Table 8 presents the results of the ANOVA test, indicating that all process parameters significantly impact SR, as evidenced by P-values for all variables being less than 0.05.

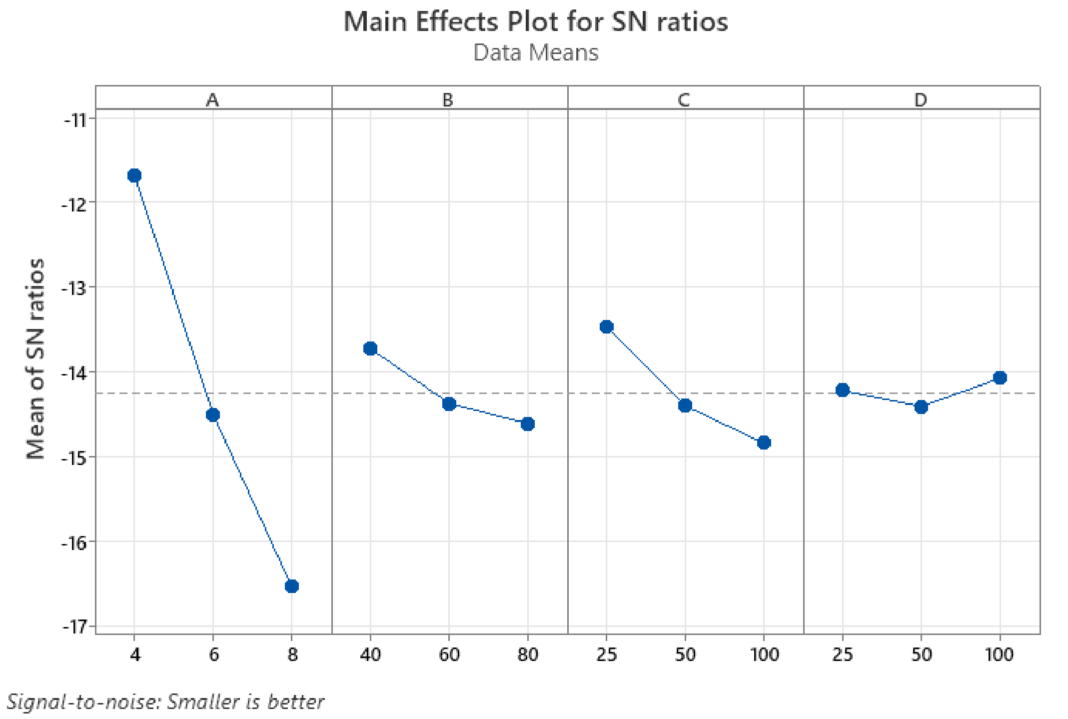

FIGURE 5. S/N ratio for SR.

TABLE 7. Response Table for Signal to Noise Ratios

Level	A	B	C	D
1	-11.68	-13.73	-13.47	-14.23
2	-14.51	-14.38	-14.41	-14.42
3	-16.55	-14.62	-14.85	-14.09
Delta	4.86	0.89	1.38	0.33
Rank	1	3	2	4

Smaller is better

TABLE 8. Analysis of Variance for SR.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	12.6553	98.41%	12.6553	3.1638	61.86	0.001
A	1	11.5410	89.74%	11.5410	11.5410	225.65	0.000
B	1	0.4192	3.26%	0.4192	0.4192	8.20	0.046
C	1	0.5715	4.44%	0.5715	0.5715	11.17	0.029
D	1	0.1236	0.96%	0.1236	0.1236	2.42	0.195
Error	4	0.2046	1.59%	0.2046	0.0511		
Total	8	12.8599	100.00%				
Model Summary for SR			R-sq = 98.41%, R-sq(adj) = 96.82%, R-sq(pred) = 88.45%				

The response functions for SR established through regression equations derived from the observed data, as illustrated below.

Regression Equation

SR = 0.066 + 0.6935 A + 0.01322 B + 0.00808 C - 0.00376 D

4. CONCLUSIONS

This research explored the influence of process parameters on material removal rate (MRR) and surface roughness (SR) in die-sinking electrical discharge machining (EDM) of H13 die steel. Analysis of variance (ANOVA) conducted on the collected data revealed that peak current (Ip) is the most significant factor affecting MRR, followed by pulse on-time and pulse off-time. For SR, all input variables demonstrated significant impact. These findings guided the determination of optimal process parameters for die-sinking EDM of H13 die steel. A peak current of 8A, reference voltage of 40V, pulse on-time of 25, and pulse off-time of 100µs were recommended for achieving the highest MRR. Similarly, for minimizing SR%, the same parameters were suggested. Regardless of the performance metric, higher Signal-to-Noise (S/N) ratios indicate superior performance. Optimal machining parameters are identified based on the level with the highest S/N ratio value. The Taguchi method proves to be an effective approach for pinpointing these optimal machining parameters, requiring minimal trial iterations.

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