IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

OPTIMIZATION OF THE PROCESS PARAMETERS USING GREY RELATIONAL ANALYSIS IN MACHINING OF SQUARE HOLES BY USING DIE-SINKING EDM

[1]Pothuganti Naveena, [2]K. Sai Anusha, [3]K. Archana

[1]Assistant Professor, [2] Assistant Professor, [3] Assistant Professor

[1]Department of Mechanical Engineering,

[1]St. Martin's Engineering College, Hyderabad, India

Abstract: In the present days of competitive world, the industries are trying to meet the market demand and increase the profits with optimal costs of the products being manufactured. Machining of hard metals, complex shapes with traditional manufacturing is difficult and it also results in extreme tool wear and damage of workpiece material. To overcome such drawbacks, unconventional machining processes such as Electric Discharge Machining (EDM) can be used to machine hard metals. In this project a prototype model of Die-Sinking EDM set-up is used consisting of different modules namely, pulse generation and control unit, tool-feed control unit. Square holes are machined on Zinc and Copper workpieces with Stainless Steel tool of size $9mm^2$ by using deionized water as dielectric fluid under different machining conditions by varying control factors like voltage and duty cycle. These experiments are carried out based on Taguchi's Design of Experiments and Grey Relational Analysis is used for the optimization. An attempt has been made in this paper to investigate the optimal combination of process parameters, voltage, duty cycle.

***Index Terms* - Electric Discharge Machining (EDM); EDM prototype; MRR; TWR; Machining time; voltage; duty cycle; Grey Relational Analysis; Grey Relational Grade.**

I. INTRODUCTION

Electric Discharge machining (EDM) is a non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharge (created by electric pulse generators at short interval) between a tool, called electrode and the part to be machined in the presence of dielectric fluid. In other words it can be said that, in this procedure metal is removed from work piece due to erosion caused by rapidly formed spark discharge between tool and work piece. As improved speed and precision are desirable performance attributes for any manufacturing process, the growing demand for exotic materials and improved production capacity has significantly raised customer expectations for hole-drilling capabilities within the general production market. In response to this demand EDM hole-drilling technologies are diversified and matured to meet specific requirements of accuracy, quality and production volume for various applications. There are various types of products that can be produced using EDM with high precision and good surface quality, such as dies and moulds, parts for aerospace, automotive industry and surgical components. EDM has been replacing drilling, milling, grinding and other traditional machining operations and is now a well established machining option in many manufacturing industries throughout the world.

1.1 Die-Sinking EDM Process

Die-Sinking EDM is referred to by different names such as Sinker EDM, cavity type EDM or volume EDM. The system consists of an electrode and workpiece submerged in dielectric fluids. Both the electrode and workpiece are connected in an electrical circuit system with a power supply or generator.

The power supply between the two connections generates electrical potential over the parts. As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming a plasma channel and a small spark jumps. Several hundred of thousand sparks occur per second, with the actual duty cycle carefully controlled by the set-up parameters. The Die-Sinking machining process can be vertical, or horizontal. Several electrically conductive materials can be machined through die sinking method. There are many factors that influence the Die-Sinking EDM process but if they are wrongly selected it may lead to harmful consequences like short-circuiting. Hence there is a need to develop a very careful and methodical way of developing a mathematical model and to maximize the efficiency of the process to find out the optimum process parameters like voltage (V), duty cycle (%), and for these process parameters many optimization techniques have been developed and put into practice.

II. EXPERIMENTATION

The experiments are conducted on Zinc and Copper workpieces with Stainless Steel tool of size 9 mm^2 by using deionized water as dielectric fluid under different machining conditions by varying control factors like voltage and duty cycle. The Figure 2.1 shows the Zn, Copper workpieces and the Stainless Steel tool used.

a b c

Fig. 2.1 (a) Zinc workpiece; (b) Copper workpiece; (c) Stainless Steel tool with cross sectional view

2.1 Experimental set-up

A prototype of Die-Sinking EDM which is used in the present work is shown in the following Fig. 2.2

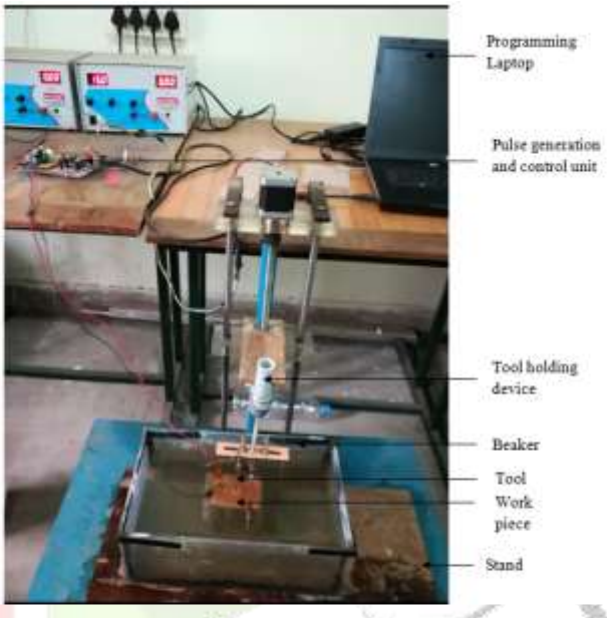


Fig. 2.2 Prototype of Die-Sinking EDM set-up

The EDM set-up consists of,

a) **Pulse Control Unit**: Control of total pulses which are sent to the tool holder is regulated by this unit.
b) **Power Supply Unit**: A Power Supply Unit (PSU) converts main AC to low voltage regulated DC.
c) **Dielectric medium**: It prevents pump cavitation, a problem associated with a high elevation difference between pump and the fluid surface.
d) **Tool Feed Control**: The tool feed controller maintains a proper inter-electrode gap between the tool and the work piece to sustain spark discharges.

2.2 Level of Experiments

The two machining parameters at three different levels considered for multiple performance characteristics in this work are shown in Table 2.1.

Table2.1 Machining parameters and their levels

Machining parameters	Unit	Levels		
		Level1	Level2	Level3
Voltage	V	30	40	50
Duty cycle	%	50	60	70

2.3 Design of Experiments

Design of experiments is an effective tool to design and conduct the experiments with minimum resources. Orthogonal Array is a statistical method of defining parameters that converts test areas into factors and levels. Test design using Orthogonal Array creates an efficient and concise test suite with fewer test cases without compromising test coverage.

Nomenclature of arrays:
$L_a(b^c)$; L= Latin square
a= number of rows
b= number of levels
c= number of columns (factors)
Number of levels = b= 3,
Number of factors = c= 2, then
Orthogonal Array = $L_9(3^2)$

In this work, L9 Orthogonal Array design matrix is used to set the control parameters to evaluate the process performance for two work materials. The Table 2.2 shows the design matrix used in this work.

Table 2.2 Design matrix of L9 Orthogonal Array

Exp. No	Workpiece material		Parameters	
			A	B
1	Zn	Copper	1	1
2	Zn	Copper	1	2
3	Zn	Copper	1	3
4	Zn	Copper	2	1
5	Zn	Copper	2	2
6	Zn	Copper	2	3
7	Zn	Copper	3	1
8	Zn	Copper	3	2
9	Zn	Copper	3	3

A square hole is produced by EDM process with the help of Stainless steel electrode on Zinc and Copper workpieces for each combination of parameters considered according to the Orthogonal Array. The workpiece and tool electrode are weighed before and after the machining by using the electronic weigh-balance to calculate the Metal Removal Rate and the Tool Wear Rate.

2.4 Experimental details

Total of 9 experiments are conducted using deionized water as dielectric on Zinc and Copper workpieces by considering the machining conditions and control parameters that as shown in Table 2.3.

Table2.3 Machining conditions and control parameters

Machining conditions			
Workpiece materials	Zinc (Zn), Copper (Cu)		
Thickness of workpiece	1 mm		
Electrode (Tool) material	Stainless Steel		
Size of electrode	9 mm^2		
Control parameters			
Voltage (V)	Level 1 30	Levlel 2 40	Level 3 50
Duty cycle (%)	50	60	70
Sensor value	390	470	560

2.5 Metal Removal Rate

MRR can be calculated by using the machining time. Formula used for calculation of MRR is as follows.

$$MRR = \frac{Wjb - Wja}{\rho \times T} \quad (1)$$

Where,
W_{jb} =Initial weight of work piece before machining in gm
W_{ja} =Final weight of work piece after machining in gm

ρ = Density of the work material in gm/mm^3
T=Machining time in minutes

2.6 Tool Wear Rate

TWR can be calculated by using the machining time. Formula used for calculation of TWR is as follows.

$$TWR = \frac{Wtb - Wta}{\rho \times T} \qquad (2)$$

Where,
W_{tb}= Initial weight of tool before machining in gm
W_{ta}:= Final weight of tool after machining in gm
ρ = Density of tool material
T= Machining time in minutes

2.7 Experimental results

Experiments are conducted as per L9 Orthogonal Array and square holes are machined on Zinc and Copper workpieces. MRR and TWR are calculated using the Equations (1) and (2). The Experimental results are shown in the Tables 2.4.

Table 2.4 Experimental results

Exp. No	Voltage(V)	Duty Cycle (%)	Machining time (min)		MRR (mm^3/min)		TWR (mm^3/min)	
			Zn	Copper	Zn	Copper	Zn	Copper
1	30	50	7.44	107.21	1.5812	0.1669	0.174	0.1211
2	30	60	5.17	87.45	2.1672	0.2776	0.251	0.297
3	30	70	3.30	71.36	3.8197	0.2822	0.393	0.364
4	40	50	4.28	95.67	2.2906	0.304	0.303	0.1357
5	40	60	3.08	79.24	3.6378	0.3035	0.422	0.1639
6	40	70	2.48	66.34	5.6478	0.4721	0.524	0.1958
7	50	50	3.70	82.19	4.5423	0.2382	0.351	0.158
8	50	60	3.00	65.29	5.6022	0.3084	0.433	0.1989
9	50	70	2.40	50.76	8.7535	0.3967	0.541	0.5117

The Figure 2.2 shows the images of square holes that are machined on Zinc workpiece for the different inputs, voltage and duty cycle, where H_1 and H_2 are sides of the square holes in mm.



1. H_1=3.49, H_2=3.48   2. H_1=3.01, H_2=3.02   3. H_1=3.20, H_2=3.21

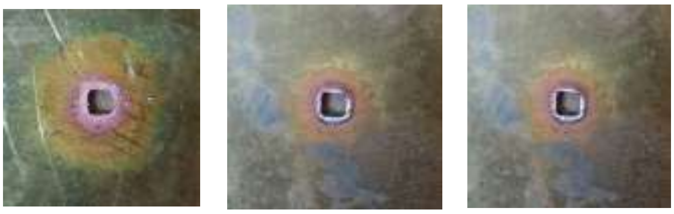


4. H_1=3.18, H_2=3.20   5. H_1=3.01, H_2=3.02   6. H_1=3.01, H_2=3.02

7. H_1=3, H_2=3.01 8. H_1=3.19, H_2=3.20 9. H_1=3.19, H_2=3.50

Fig. 2.2 Square hole images after machining

The Figure 2.3 shows the images of square holes that are machined on Copper workpiece for the different inputs, voltage and duty cycle, where H_1 and H_2 are sides of the square holes in mm.



1. H_1=2.99, H_2=2.99 2. H_1=2.98, H_2=2.95 3. H_1=2.97, H_2=2.98

4. H_1=2.93, H_2=2.95 5. H_1=3.4, H_2=3.04 6. H_1=2.89, H_2=2.91

7. H_1=3.01, H_2=2.99 8. H_1=2.88, H_2=2.89 9. H_1=2.97, H_2=2.96

Fig. 2.3 Square hole images after machining

The Figure 2.3 shows the images of square holes that are machined on Copper workpiece for the different inputs, voltage and duty cycle, where H_1 and H_2 are sides of the square holes in mm.

III. OPTIMIZATION OF PROCESS PARAMETERS

Taguchi based Grey Relational Analysis is generally adopted for solving multi-attribute decision making problems (multi-response optimization). Grey Relational Analysis (GRA), also called Deng's Grey Incidence Analysis model, is developed by a Chinese Professor Julong Deng of Huazhong University of Science and Technology. It is one of the widely used models of Grey system theory. GRA uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. The steps involved in the Grey Relational Analysis are as follows.

3.1 Signal-to-Noise ratios (S/N Ratios)

The transformation of response values to S/N ratios is the initial step. For the computation of S/N ratios, equations of ‘larger the better’, ‘smaller the better’ and ‘nominal the better’ are used. Subsequent analysis is carried out on the basis of these S/N ratio values. The S/N ratios for Zn and Cu are as shown in Table 3.1 and Table 3.2

Type 1: Larger the better, $S/N_{LB} = -10 \log_{10} \left[\frac{1}{n} \sum \frac{1}{Y_{ij}^{2}} \right]$ (3)

Type 2: Smaller the better, $S/N_{SB} = -10 \log_{10} \left[\sum \frac{Y_{ij}^{2}}{n} \right]$ (4)

Type 3: Nominal the better, $S/N_{NB} = 10\log_{10}[\frac{1}{S^2}]$ (5)

Where, Y_{ij} is the value of the response
'j' in the i^{th} experiment condition, with i=1, 2, 3, …n; j= 1,2…k
and S^2 are the sample mean and variance.

Table3.1 Signal-to-Noise ratios for Zn

Exp. No	Workpiece Material	S/N ratios		
		Machining time(dB)	MRR (dB)	TWR (dB)
1	Zn	-17.431	3.979	15.164
2	Zn	-14.269	6.718	11.999
3	Zn	-10.370	11.641	08.101
4	Zn	-12.629	7.199	10.359
5	Zn	-9.771	11.217	07.502
6	Zn	-7.889	15.038	05.618
7	Zn	-11.36	13.145	09.094
8	Zn	-9.542	14.967	07.270
9	Zn	-7.604	18.844	05.334

Table3.2 Signal-to-Noise ratios for Cu

Exp. No	Workpiece Material	S/N ratios		
		Machining time(dB)	MRR (dB)	TWR (dB)
1	Cu	-40.6047	-15.5491	18.33452
2	Cu	-38.8352	-11.1328	10.54441
3	Cu	-37.0691	-10.9904	8.778311
4	Cu	-39.6155	-10.3428	17.34533
5	Cu	-37.9789	-10.3569	15.7087
6	Cu	-36.4355	-6.5191	14.16532
7	Cu	-38.2964	-12.4624	16.02619
8	Cu	-36.2969	-10.2182	14.02675
9	Cu	-34.1104	-8.03173	5.819647

3.2 Normalization of S/N Ratios

In the second step of the Grey Relational Analysis, S/N ratios are normalized. Y_{ij} is normalized as Z_{ij} ($0 \leq Z_{ij} \leq 1$) by using the following formulae. The equation for the Normalized S/N ratio corresponding to the larger the better criterion can be expressed as,

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1,2,..n)}{\max(y_{ij}, i = 1,2,..n) - \min(y_{ij}, i = 1,2,..n)} \quad (6)$$

The equation for the Normalized S/N ratio corresponding to the larger the better criterion can be expressed as,

$$Z_{ij} = \frac{\max(y_{ij}, i = 1,2,\ldots,n) - y_{ij}}{\max(y_{ij}, i = 1,2,\ldots,n) - \min(y_{ij}, i = 1,2,\ldots,n)} \quad (7)$$

The Normalized S/N ratios for Zn and Cu are as shown in Table 3.3 and Table 3.4.

Table3.3 Normalized S/N ratios for Zn

Exp. No	Workpiece Material	Normalized S/N ratios		
		Machining time(dB)	MRR (dB)	TWR (dB)
1	Zn	1.0000	0.0181	0.0000
2	Zn	0.6783	0.0000	0.3217
3	Zn	0.2815	0.1178	0.7185
4	Zn	0.5113	0.3478	0.4887
5	Zn	0.2205	0.8167	0.7795
6	Zn	0.0290	1.0000	0.9710
7	Zn	0.2815	0.3816	0.7185
8	Zn	0.1972	0.3466	0.8028
9	Zn	0.0000	0.9931	1.0000

Table3.4 Normalized S/N ratios for Cu

Exp. No	Workpiece Material	Normalized S/N ratios		
		Machining time(dB)	MRR (dB)	TWR (dB)
1	Cu	1.0000	0.0000	0.0000
2	Cu	0.7275	0.4891	0.6225
3	Cu	0.4556	0.5048	0.7636
4	Cu	0.8477	0.5766	0.0790
5	Cu	0.5957	0.5750	0.2098
6	Cu	0.3580	1.0000	0.3331
7	Cu	0.6446	0.3418	0.1844
8	Cu	0.3367	0.5903	0.3442
9	Cu	0.0000	0.8325	1.0000

3.3 Grey Relational Coefficients

The Grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The deviation sequences are to be calculated before the Grey Relational Coefficients. The Grey Relational Coefficient can be expressed as,

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \qquad (8)$$

Where, Δ_{0i} (k) is the deviation sequence.

$$\Delta_{0i}(k) = \left|\left| y_0(k) - y_i(k) \right|\right| \qquad (9)$$

$$\Delta_{\min} = \min_{\forall j \in i} \ \min_{\forall k} \left|\left| y_0(k) - y_j(k) \right|\right| \qquad (10)$$

$$\Delta_{\max} = \max_{\forall j \in i} \ \max_{\forall k} \left|\left| y_0(k) - y_j(k) \right|\right| \qquad (11)$$

Where, y_0 (k) denotes the comparability sequence, ζ is distinguishing or identified coefficient; ζ = 0.5 is generally used.
The deviation sequences for Zn and Cu are as shown in the Table 3.5 and Table 3.6.

Table 3.5 Deviation sequences for Zn

Exp.No	Workpiece material	Deviation sequences		
		Machining time	MRR	TWR
1	Zn	0	0.9819	1
2	Zn	0.3217	1	0.6783
3	Zn	0.7185	0.8822	0.2815
4	Zn	0.4887	0.6522	0.5113
5	Zn	0.7795	0.1833	0.2205
6	Zn	0.9710	0	0.0290
7	Zn	0.7185	0.6184	0.2815
8	Zn	0.8028	0.6534	0.1972
9	Zn	1	0.0069	0

Table 3.6 Deviation sequences for Cu

Exp.No	Workpiece material	Deviation sequences		
		Machining time	MRR	TWR
1	Cu	0	1	1
2	Cu	0.2725	0.5109	0.3775
3	Cu	0.5444	0.4952	0.2364
4	Cu	0.1523	0.4234	0.9210
5	Cu	0.4043	0.4250	0.7902
6	Cu	0.6420	0	0.6669
7	Cu	0.3554	0.6582	0.8156
8	Cu	0.6633	0.4097	0.6558
9	Cu	1	0.1675	0

The Grey Relational Coefficients for Zn and Cu are calculated by using the deviation sequences and are shown in the Table 3.7 and Table 3.8.

Table 3.7 Grey Relational Coefficients for Zn

Exp .no	Workpiece Material	Grey Relational Coefficients		
		Machining time	MRR	TWR
1	Zn	1.0000	0.3333	0.3333
2	Zn	0.6085	0.3800	0.4244
3	Zn	0.4103	0.5078	0.6398
4	Zn	0.5057	0.3896	0.4945
5	Zn	0.3908	0.4935	0.6940
6	Zn	0.3399	0.6613	0.9454
7	Zn	0.4475	0.5660	0.5666
8	Zn	0.3838	0.6572	0.7175
9	Zn	0.3333	1.0000	1.0000

Table 3.8 Grey Relational Coefficients for Cu

Exp .no	Workpiece Material	Grey Relational Coefficients		
		Machining time	MRR	TWR
1	Cu	1	0.3333	0.3333
2	Cu	0.6473	0.4946	0.5698
3	Cu	0.4787	0.5024	0.6790
4	Cu	0.7665	0.5415	0.3519
5	Cu	0.5529	0.5405	0.3875
6	Cu	0.4378	1	0.4285
7	Cu	0.5845	0.4317	0.3801
8	Cu	0.4298	0.5497	0.4326
9	Cu	0.3333	0.7490	1

3.4 Grey Relational Grade

The Grey Relational Grade is determined by averaging the Grey Relational Coefficients corresponding to each performance characteristic. Grey Relational Grades are given in the Table 3.9 and Table 3.10 for Zn and Cu respectively. The Grey Relational Grade can be expressed as

$$\gamma_i = \left(\frac{1}{n}\right) \Sigma\, \xi_i\,(k) \qquad (12)$$

Where, γ_i is the grey relational grade for the j^{th} experiment and k is the number of performance characteristics.

Table 3.9 Grey Relational Grades for Zn

Exp .no	Workpiece Material	Voltage (V)	Duty cycle (%)	Grey Relational Grade
1	Zn	30	50	0.5555
2	Zn	30	60	0.4710
3	Zn	30	70	0.5193
4	Zn	40	50	0.4633
5	Zn	40	60	0.5261
6	Zn	40	70	0.6489
7	Zn	50	50	0.5267
8	Zn	50	60	0.5862
9	Zn	50	70	0.7778

Table 3.10 Grey Relational Grades for Cu

Exp .no	Workpiece Material	Voltage (V)	Duty cycle (%)	Grey Relational Grade
1	Cu	30	50	0.5556
2	Cu	30	60	0.5705
3	Cu	30	70	0.5534
4	Cu	40	50	0.5533
5	Cu	40	60	0.4937
6	Cu	40	70	0.6221
7	Cu	50	50	0.4654
8	Cu	50	60	0.4707
9	Cu	50	70	0.6941

IV. RESULTS AND DISCUSSION

The Figure 4.1 shows the effect of process parameters (voltage and duty cycle) on Machining time for Zinc-DI water.

a b

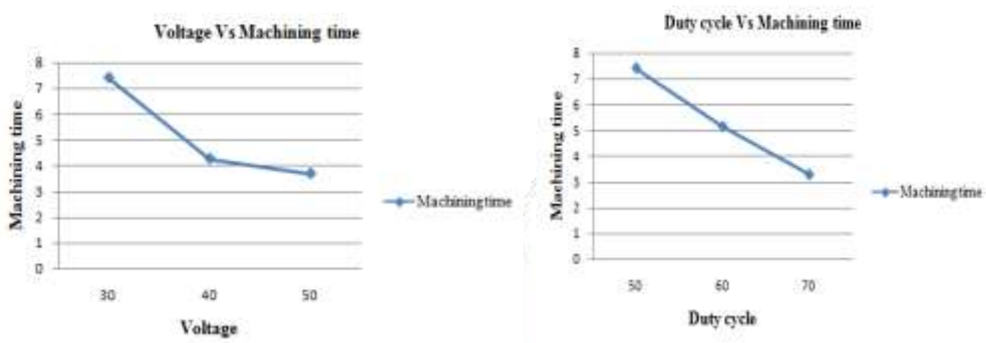


Fig. 4.1 Effect of process parameters (a) Voltage and (b) Duty cycle on Machining time

The Figure 4.1 shows the graphs plotted between (a) Voltage and Machining time, (b) Duty cycle and Machining time. The graphs show that machining time decreases with increase in voltage as well as duty cycle.
The Figure 4.2 shows the effect of process parameters (voltage and duty cycle) on MRR.

a b

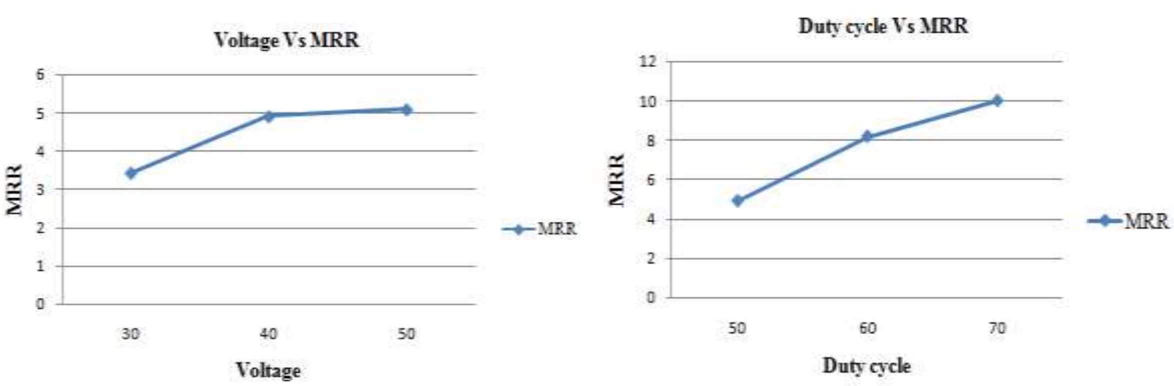


Fig. 4.2 Effect of process parameters (a) Voltage and (b) Duty cycle on MRR

The Figure 4.2 shows the graphs plotted between (a) Voltage and MRR, (b) Duty cycle and MRR. The graphs show that MRR increases with increase in voltage as well as duty cycle.

The Figure 4.3 shows the effect of process parameters (voltage and duty cycle) on TWR.

a b

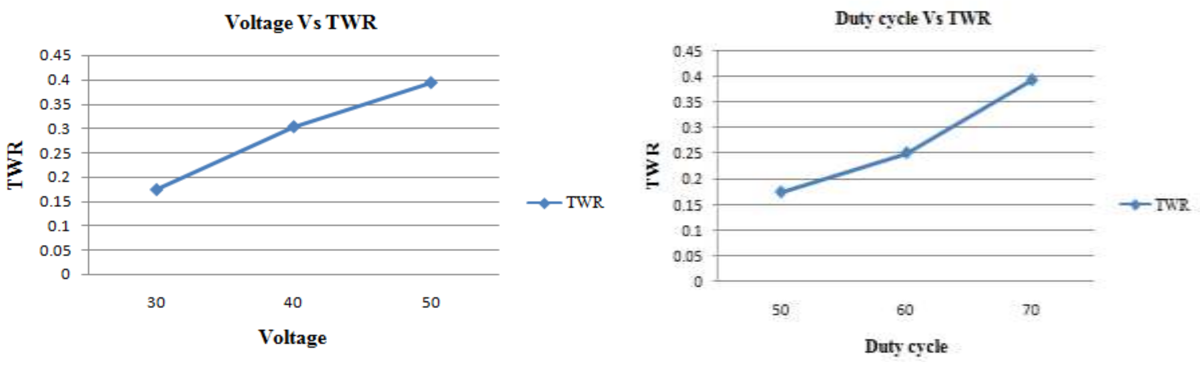


Fig. 4.3 Effect of process parameters (a) Voltage and (b) Duty cycle on TWR

The Figure 4.3 shows the graphs plotted between (a) Voltage and TWR, (b) Duty cycle and TWR. The graphs show that TWR increases with increase in voltage as well as duty cycle.

The Figure 4.4 shows the effect of process parameters (voltage and duty cycle) on Machining time for Cu-DI water.

a b

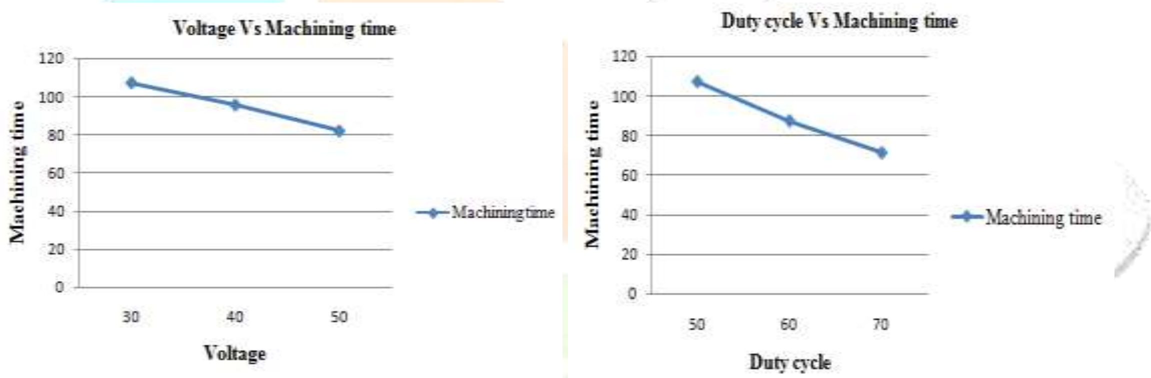


Fig. 4.4 Effect of process parameters (a) Voltage and (b) Duty cycle on Machining time

The Figure 4.4 shows the graphs plotted between (a) Voltage and Machining time, (b) Duty cycle and Machining time. The graphs show that machining time decreases with increase in voltage as well as duty cycle.

The Figure 4.5 shows the effect of process parameters (voltage and duty cycle) on MRR

a b

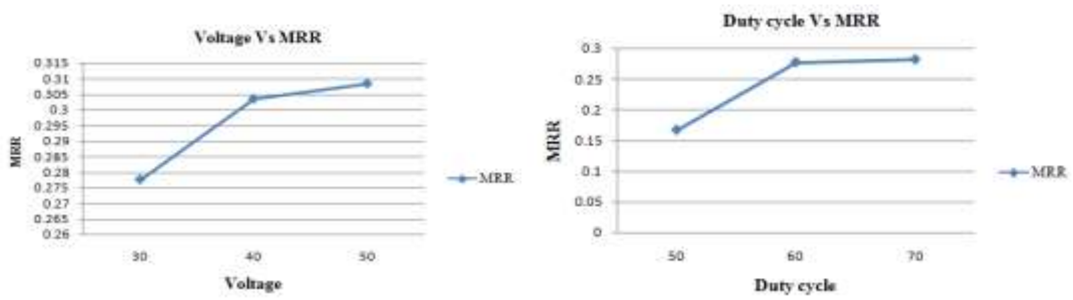


Fig. 4.5 Effect of process parameters (a) Voltage and (b) Duty cycle on MRR

The Figure 4.5 shows the graphs plotted between (a) Voltage and MRR, (b) Duty cycle and MRR. The graphs show that MRR increases with increase in voltage as well as duty cycle.

The Figure 4.6 shows the effect of process parameters (voltage and duty cycle) on TWR.

a b

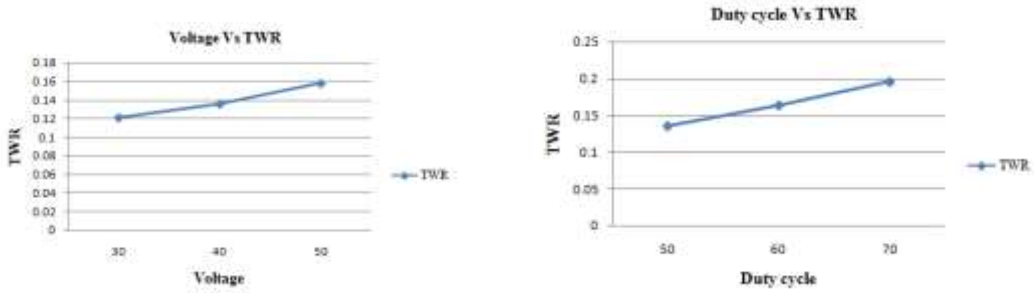


Fig. 4.6 Effect of process parameters (a) Voltage and (b) Duty cycle on TWR

The Figure 4.6 shows the graphs plotted between (a) Voltage and TWR, (b) Duty cycle and TWR. The graphs show that TWR increases with increase in voltage as well as duty cycle.

The Figure 4.7 shows the graph plotted between experiment numbers and Grey Relational Grades of Zn and Cu

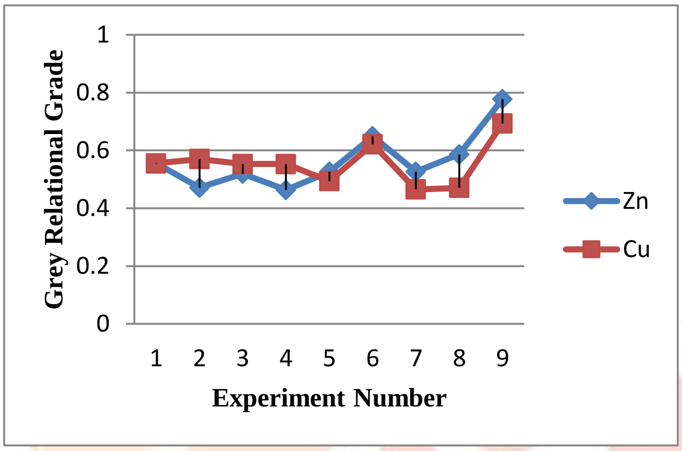


Fig. 4.7 Grey Relational Grades of Zn and Cu

The higher the Grey Relational Grade [12], the better the performance characteristics. Experiment 9 from Table 3.9 for Zn shows the highest Grey Relational Grade, indicating the optimal process parameter set of A3B3 has the good multiple performance characteristics among the nine experiments and the experiment 7 from Table 3.10 for Cu shows the highest Grey Relational Grade, indicating the optimal process parameter set of A3B3 has the good multiple performance characteristics, which can be compared with predicted values. The Figure 4.7 shows that Grey Relational Grade of Zn from Experiment 9 is the highest. The Table 4.1 for Zinc and the Table 4.2 for Cu show the comparison of the experimental results using the orthogonal array A3B3 with the predicted values. The predicted values for Zn are obtained by,

Predicted Response = Average of A3 + Average of B3– Mean of response (Y_{ij}) (13)

Table 4.1 Comparison between experimental and predicted values (Zn)

	Optimal process parameters	
	Experimental	Predicted
Level	A3B3	A3B3
Machining time (min)	2.4	1.7989
MRR (mm^3/min)	9.9206	8.5939
TWR (mm^3/min)	0.5411	0.5602

The comparison shows that, the experimental and the predicted values are nearer to each other.
The predicted values for Cu are obtained by,

Predicted Response = Average of A3 + Average of B3– Mean of response (Y_{ij}) (14)

Table 4.2. Comparison between experimental and predicted values (Cu)

	Optimal process parameters	
	Experimental	Predicted
Level	A3B3	A3B3
Machining time (min)	50.51	50.76
MRR (mm^3/min)	0.3976	0.3925
TWR (mm^3/min)	0.5117	0.4082

The comparison shows that, the experimental and the predicted values are nearer to each other.

V. CONCLUSIONS

An indigenous set-up of model Die-Sinking Electrical Discharge Machine is utilized to bring-out machining of through holes on Zinc workpiece. The following conclusions are drawn from the present work:

- Through holes are machined on Zinc and Cu workpiece, both of thickness 1 mm and Stainless Steel electrode of size 3mm^2 with deionized water as dielectric medium by varying the control parameters like work piece material, voltage and duty cycle.
- The optimal parameter combination for Zn is determined as A3B3 where, Voltage=50V and Duty cycle=70%.
- The optimal parameter combination for Cu is determined as A3B3 where, Voltage=50V and Duty cycle=70%.
- Zn can be preferred for machining using Die-Sinking EDM over Cu, as the Grey Relational Grade of A3B3 combination (in case of Zn) is the highest of all the Grey Relational Grades of Zn and Cu.

References

[1] Elman Jameson C, "Electric Discharge Machining", Society of Manufacturing Engineers (SME), pp 75-76, 2001.
[2] Kuldeep Ojha, Garg R K and Singh K K "Sinking EDM and WEDM in metal matrix composite materials", Volume 50, Issue 5-8, pp 611-624, 2010.
[3] Pawade M M and Banwait S S , "An Exhaustive Review of Die Sinking Electric Discharge Machining Process and Scope for Future Research", International Journal of Mechanical and Mechatronics Engineering(IJMME), Volume 7, Issue 6, 2013.
[4] Kao J Y, Tsao C C, Wang S S and Hsu C Y," Optimization of the EDM parameters on machining Ti–6Al–4V with multiple quality characteristics", The International Journal of Advanced Manufacturing Technology (IJAMT), Volume 47, Issue 7-4, pp 395-402, 2010.
[5] Pravin Kubade R and Jadhav V S, "An Experimental Investigation of Electrode Wear Rate (EWR), Material Removal Rate (MRR) and Radial Overcut (ROC) in EDM of High Carbon-High Chromium Steel (AISI D3)" IJEAT, ISSN: 2249 – 8958, Volume 1, Issue 5, 2012.
[6] Banker K S, Oza A D and Dave R B "Material Removal Rate, Tool Wear Rate and Surface Roughness Analysis of EDM process", International Journal for Scientific Research and Development, Volume 1, Issue 3, 2013.
[7] Deng, J. L , "Basic methods of Grey system", Journal of Grey System, Volume 1, pp 1-24, 1987.
[8] Ng David, K.W., "Grey system and grey relational model", ACM SIGICE Bulletin, Volume 20(2), pp 1–9, 1994.
[9] Pan,L.K., Wang,C.C., Wei,S.L., and Sher,H.F., "Optimizing multiple quality characteristics via Taguchi method based grey analysis", Journal of Material Processing Technology, Volume 182, pp 107–116, 2007.
[10]Aruna, K, Somashekhar, S.H, Singaperumal, M, "Optimization of process parameters during micromachining of Copper plate using Micro-Electric Discharge Machining", International conference at NIT Calicut (Copen-8), pp 222-227, 2018.
[11]K Aruna, R Bhargav, P Hema, "Fabrication of Die-Sinking Electric Discharge Machine for machining of holes on Copper plate", Manufacturing Technology Today (MTT), Volume 17, pp 11-18, 2018.
[12] Kopac, J., and Krajnik, P., "Robust design of flank milling parameters based on grey-Taguchi method", Journal of Material Processing Technology, Volume 191, pp 400–403, 2007.