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An Interactive Evolutionary Parametric Optimization of EDM on D2 Hot Die Steel by using Grey-Taguchi Technique

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Abstract: Electro discharge machining is one of the crucial non-traditional machining processes which widely used for arduous materials and for that material that could not be possible to machine with standard machining procedures such as composites along with inter- metallic products. EDM functions within the ignite erosion approach identical to having an electrical short which burns up a small hole inside the metal which come in contact. In EDM method both perform portion substance and the electrode substance must be conductors involving energy that is electricity. Complicated single profiles utilized in prosthetics, bio- medical purposes may be done with EDM. Likewise Electro Discharge Machining (EDM) involves in production of complicated shapes, micro openings along with substantial reliability in numerous electrically conductive products along with high- durability temperature-resistant components. In this paper investigated the optimization of process parameter of EDM machine to get the maximum MRR and minimum TWR. The aim of this paper to study the performance of electrodes of Copper Brass and Aluminium on D2 (Hot die steel) with EDM process.

Keywords: EDM, MRR, TWR, ANOVA, OA, S/N

I. INTRODUCTION

A properly designed and executed experiment is of the extreme importance for originating clear and accurate conclusions as of the experimental observations. Design of experiment is measured to be a very useful plan for accomplishing these tasks. The science of statistical experimental design originates with the work of Sir Ronald Fisher in England in 1920s. Fisher investigates the basic principle of investigational design and the associated data-analysis technique called Analysis of Variance (ANOVA) through his efforts to improve the yield of manufacturing operations. The theory and applications of experimental design and the associated technique of response surface methodology have been advanced by many statistical researchers as Box and Hunter, Box and Draper, Hicks. Various types of matrices are used for planning experiments to study a number of decision variables. In the middle of them, Taguchi's Method makes heavy use of orthogonal-arrays. Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan industrialized a method based on "orthogonal-array" experimentations which gives a great deal concentrated "variance" for the experiment with "optimum settings" of be in charge of parameters. Thus manage of DOE with optimization of control parameters to obtain BEST results was achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of glowing balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of preferred output, serve as objective functions for optimization, help in data analysis and prospect of optimum results. Now a day's Taguchi's methodology is widely used methods all over the globe for research resolutions, particularly to optimize the machining characteristics. In this paper an attempt has been made to put jointly some of the work done with Taguchi's Methodology. When the MRR is high and TWR is low, the machining time and the tooling cost reduce. This calls for multi-objective optimization of the parameters, which can be complete with various techniques such as Genetic Algorithm, Ant colony optimization, etc. Grey Relation Analysis (GRA) is one such technique that helps in obtaining the best set of input parameters that result in achieving all the objectives. As the name suggests, GRA finds the optimized result in the grey region between white region, which contains complete information, and black region that contains no information. Thus for an extensive set of input conditions, GRA provides the optimized operating levels that can be set to achieve all objectives uniformly. To find out the optimum parametric condition which mostly affects the performance measures, optimization technique based on Design of Experiments (DOE) can also be applied [1, 2]. Optimization of the parameters using DOE is one of the techniques used in manufacturing sectors to arrive for the best manufacturing situation, which is an essential need for industries towards manufacturing of quality products at lower cost [3]. Taguchi method is useful for the optimization to study the influence of EDM parameters on the machining characteristic such as MRR & TWR. To find the contribution of each input parameter and errors towards the variation of responses, Analysis of Variance (ANOVA) technique is used [4, 5]. Thus by influential the contribution of the parameters towards the responses, the influence of individual parameters on the response change can be resolute, thereby enabling the user to focus on the important factor that is most likely to cause a change in the responses.

II. EXPERIMENTAL DETAILS

A. *Tool material*

In EDM electrode material plays an significant role. During study, the electrode material is measured as a variable. In the presentstudy, three different electrodes are used as tool material for machining. The electrode materials used are brass, aluminium and copper.

B. *Work material*

The chemical composition of the work material D2 (HOT DIE STEEL) is shown in Table I and fig.1.Shows that the workpiece before and after the machining.

TABLE I
COMPOSITION OF D2 (HOT DIE STEEL)*

Composition	Percentage (wt %)	Composition	Percentage (wt %)
Carbon	0.459%	Vanadium	0.214%
Silicon	0.868%	Tungsten	0.0313%
Manganese	0.332%	Lead	0.0013%
Nickel	0.348%	Tin	0.0101%
Chromium	6.40%	Calcium	0.00016%
Molybdenum	1.00%	Zinc	0.0129%
Sulphur	0.01%	N	0.0147
Phosphorus	0.0189	B	0.00097%
Iron	90.00%	As	<0.0010%
Cobalt	0.0179%	Nb	0.0076%
Copper	0.144	Aluminium	<0.00050
Titanium	0.0025%		

*Percentage of Composition Based on The Spectroscopy Test.

Fig. 1 Work piece before and after machining

III.RESEARCH METHODOLOGY

The collection of optimum machining parameters in EDM is an important step. Taguchi Optimization method is single parameter optimization based on the signal to noise ratio [6].Grey relational analysis is applied to optimize the parameters having multiresponses through grey relational grade. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The steps involved are:

A. Selection of process parameters and response

The process parameters and levels preferred for the experiments are shown in Table II

TABLE II LEVEL VALUES OF INPUT FACTORS

Control Factors	I Level	II Level	III Level
Peak Current (I_p) amp	4	8	12
Pulse on time (T_{on}) µsec.	500	1000	1500
Electrode Material	Brass	Aluminium	Copper

B. Design of Experiment

Experiments are performed, randomly, according to the L_9 orthogonal array created by Minitab-17 software; on D2 (HOT DIE STEEL).For each experiment, a separate electrode is selected. The machining time is 10 minutes for every experiment. The machining time is noted from the timer of the machine. The electrode wear rate is calculated by weight difference between the electrodes using an automatic weighing machine with 300g capacity with a precision of 10mg. The observations along with the details of the values of various parameters for evaluating TWR, MRR based on the L_9 orthogonal array are shown in Table III

TABLE III DESIGN OF EXPERIMENT

S.No	Peak Current (A)	Pulse On Time (µsec)	Electrode Material
1	4	500	COPPER
2	8	1000	BRASS
3	12	1500	ALUMINIUM
4	4	1000	ALUMINIUM
5	8	1500	COPPER
6	12	500	BRASS
7	4	1500	BRASS
8	8	500	ALUMINIUM
9	12	1000	COPPER

IV. RESULT AND DISCUSSION

A. Observation and Calculation for MRR and TWR

After the experimental procedure, different response factors like MRR, TWR calculated from the experimental data are tabulated in Table.

Table IV S/N Ratio for MRR and TWR

Sr.No.	MRR (g/min)	TWR(g/min)
1	0.0875	0.0648
2	0.2993	0.0305
3	0.018	0.0129
4	0.1218	0.0225
5	0.1019	0.1645
6	0.3796	0.0215
7	0.4005	0.0175
8	0.1238	0.0307
9	0.1846	0.1688

B. Calculation of the Normalized value of MRR &TWR

In this step of the grey relational analysis, pre-processing of the data was first performed for normalizing the raw data for analysis. This is shown in Table-V, Yi, Xi is normalized by the following formula to avoid the effect of adopting different units and to reduce the variability. The normalized output parameter (MRR) corresponding to the larger-the-better criterion can be expressed by equation-1.

$$X_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (1)$$

Then for the output parameters (TWR), which follow the lower-the-better criterion can be expressed by equation-2.

$$Y_i(k) = \frac{\max\ y_i(k) - y_i(k)}{\max\ y_i(k) - \min\ y_i(k)} \quad (2)$$

Where

xi (k),Xi(k) & yi (k),Yi(k) are the sequence after the data preprocessing and comparability sequence respectively, k=1;i=1, 2, 3…, 9 for experiment numbers 1 to 9.

Table V Normalized Value for MRR and TWR

Expt. No.	Normalized MRR (Xi)	Normalized TWR (Yi)
Reference Sequence	1.0000	1.0000
1	0.1685	0.6671
2	0.6819	0.8871
3	0.0000	1.0000
4	0.2516	0.9384
5	0.2034	0.0276
6	0.8766	0.9448
7	1.0000	0.9705
8	0.2565	0.8858
9	0.4039	0.0000

C. Calculation of Deviation Sequence

The grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results. Before that the deviation sequence for the reference and comparability sequence were found out. These are given in Table V and the grey relational coefficient is given in Table VI the deviation sequence can be expressed by equation-3.

$$\Delta oi = \left| xo^*(k) - xi^*(k) \right| \quad (3)$$

Where Δoi is the deviation sequence of the reference sequence xo*(k) and the comparability sequence xi*(k) and comparability value is taken as 1 for all the experiments.

Table VI Deviation sequence for MRR and TWR

DEVIATION SEQUENCES	Δoi(MRR)	Δoi(TWR)
Exp. No. 1	0.8315	0.3329
Exp. No. 2	0.3181	0.1129
Exp. No. 3	1.0000	0.0000
Exp. No. 4	0.7484	0.0616
Exp. No. 5	0.7966	0.9724
Exp. No. 6	0.1234	0.0552
Exp. No. 7	0.0000	0.0295
Exp. No. 8	0.7435	0.1142
Exp. No. 9	0.5961	1.0000

D. Calculation of Grey Relational Coefficient And Grade

After data pre-processing is carried out, a grey relational coefficient can be calculated with the pre-processed sequence. It expresses the relationship between the ideal and actual normalized experimental results. The grey relational coefficient is defined as follows by equation-4.

$$\xi_i(k) = \frac{\Delta \min - \xi \Delta \max}{\Delta_{0i}(k) - \xi \Delta \max} \quad (4)$$

Where

Δoi (k) is the deviation sequence of the reference sequence x*(k) and the comparability sequence is xi*(k), ξ distinguishing or identification coefficient. If all the parameters are given equal preference & taken as 0.5 [7].The grey relational coefficient for each experiment of the L_9 OA can be calculated using equation and same is expressed in Table VII. After obtaining the grey relational coefficient, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance Characteristic. The overall evaluation of the multiple performance characteristics is based on the grey relational grade that is given by equation-5 [8].

$$\gamma_i = \frac{1}{n}(\xi_{i\,MRR} + \xi_{i\,TWR}) \quad (5)$$

Where i_{th} the grey relational grade for the i_{th} experiment and n is the number of performance characteristics which is taken as 2 for MRR and TWR, Table VII shows the grey relational grade for each experiment using L_9 OA. The higher grey relational grade represents that the corresponding experimental results are closer to the ideally normalized value. Experiment 1 has been multiple performance characteristics among nine experiments because it has the highest grey relational grade. It can be seen that in the present study, the optimization of the complicated multiple performance characteristics of EDM of D2 (HOT DIE STEEL) has-been converted into optimization of a grey relational grade.

E. Calculation of Main effect and ANOVA

Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels 1, 2 and 3 can be calculated by averaging the grey relational grade for the experiment 1 to 3, 4to 6 and 7 to 9 as respectively as shown in Table VIII

Table VII Grey Relational Coefficient and Grade

Expt. No.	Grey Relational Coefficient		Grey Relational Grade $\gamma_i = \frac{1}{n}(\xi_{i\,MRR} + \xi_{i\,TWR})$	Rank
	$\xi_{i\,MRR}$	$\xi_{i\,TWR}$		
1	0.3755	0.6003	0.4879	7
2	0.6112	0.8158	0.7135	3
3	0.3333	1.0000	0.6667	4
4	0.4005	0.8903	0.6454	5
5	0.3856	0.3396	0.3626	9
6	0.8021	0.9006	0.8514	2
7	1.0000	0.9443	0.9722	1
8	0.4021	0.8141	0.6081	6
9	0.4562	0.3333	0.3948	8

Table VIII RESPONSE TABLE FOR GREY RELATIONAL GRADE

SYMBOL	MACHINING PARAMETERS	GREY RELATIONAL GRADE			MAIN EFFECT (MAX-MIN)	RANK
		LEVEL 1	LEVEL 2	LEVEL 3		
A	CURRENT	-3.427*	-5.355	-4.331	1.927	2
B	T_{ON}	-3.984*	-4.936	-4.193	0.952	3
C	MATERIAL	-3.882	-1.525	-7.706*	6.181	1
Total Mean Value of The Grey Relational Grad γ_m= -4.371						
* Levels of optimum grey relational grade						

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The mean of the grey relational grade for each level of the other machining parameters namely Peak current, pulse on time and electrode material can be computed in the same behavior. The mean of the grey relational grade for each level of the machining parameters is summarized and shown in Table VIII. In addition, the total mean of the grey relational grade for the nine experiments is also calculated and presented in Table VIII

Fig.2. shows the grey relational grade obtained for different process parameters. The mean of the grey relational grade for each parameter is shown by a horizontal line. Basically, the larger the grey relation grade is, the closer will be the product quality to the ideal value. Thus, the larger grey relational grade is desired for optimum performance. Therefore, the optimal parameters setting for better MRR and lesser TWR are (A1B1C3) as presented in Table VIII. The optimal level of the process parameters is the level with the highest grey relational grade.

Furthermore, ANOVA has been performed on grey relational grade to obtain contribution of each process parameter affecting the two process characteristics jointly and is discussed in the forthcoming section ANOVA for a grey relational grade is presented in Table IX. Percentage contributions for each term affecting grey relational grade are shown in Fig.3, Fig.3 clearly shows that Material & Current are the dominant parameter that affects grey relational grade and hence contributes in improving MRR and reducing TWR It can be seen from Figures 2 and 3 that current & material are the most significant factor that affects the grey relational grade. Metal removal is directly proportional to the amount of energy applied by the current.

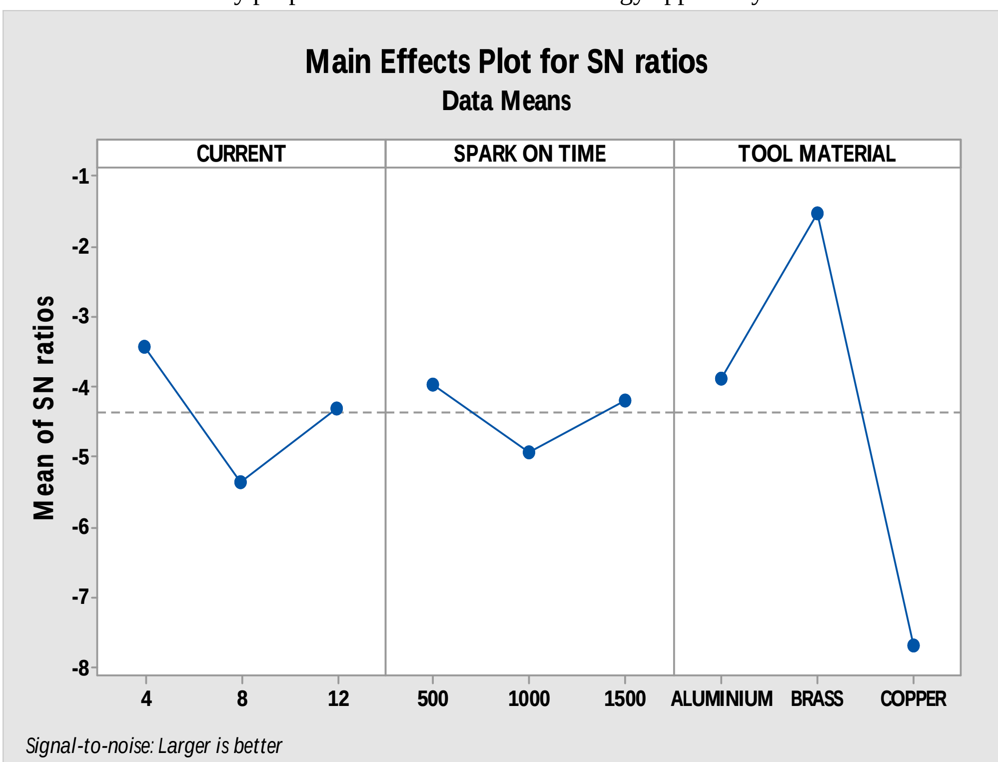

Fig.2 Main effect plot

Table IX Analysis Of Variance for Grey Relational Grade

Parameter	DOF	Sum of squares	Adj SS	Mean Squares	F ratio	P	PERCENTAGE CONTRIBUTION
CURRENT	2	5.5790	5.5790	2.7895	13.78	0.068	8.47
T-ON	2	1.5036	1.5036	0.7518	3.71	0.212	2.28
MATERIAL	2	58.3841	58.3841	29.1921	144.18	0.007	88.63
Residual Error	2	0.4049	0.4049	0.2025			0.62
Total	8	65.8716					100.00%

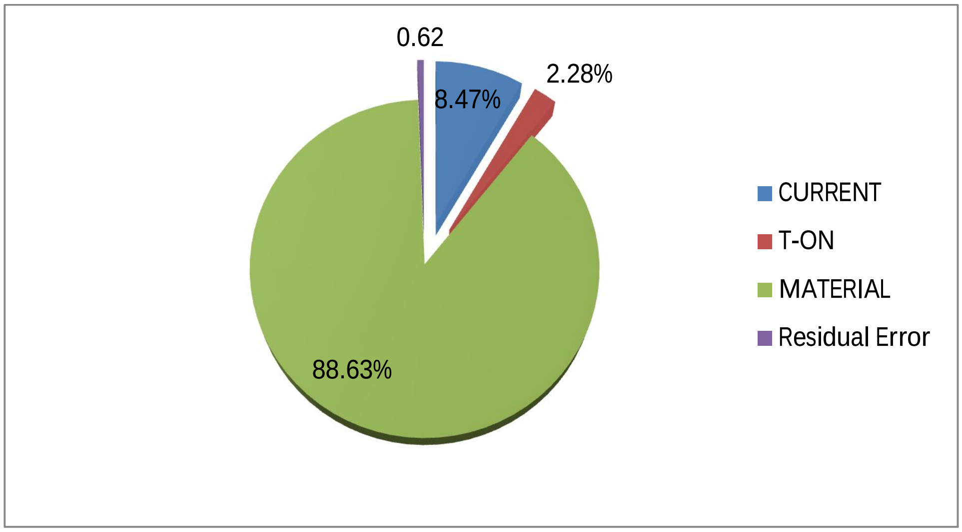

Fig.3Percentage contribution of parameters

V. CONFIRMATION TEST

Confirmation test has been carried out to verify the improvement of performance characteristics (MRR & TWR) in D2 (HOT DIE STEEL) using EDM the best possible parameters are selected for confirmation test as represented in Table X

Table X Theoretical and grey optimal level

CONDITION DESCRIPTION	OPTIMAL MACHINING PARAMETERS	
	MACHINING PARAMETERS IN THE SEVENTH TRIAL OF OA	GREY THEORY PREDICTION DESIGN
LEVEL	A1B3C1	A1B1C1
MRR (g/min)	0.4005	0.4321
TWR (g/min)	0.0175	0.0146
Improvement In MRR=0.0316 g/min (approx.7.89%) Improvement In TWR= 0.0029g/min(approx.19.86%)		

Table X which shows the comparison of the experimental results using the initial (OA, A1B3C1) and optimal (grey theory prediction design, A1B1C1) machining parameters.

Based on Table, MRR is accelerated from 0.4005 to 0.4321g/min; the TWR is decreased from 0.0175 to 0.0146 g/min. The corresponding improvements in MRR and TWR are 7.89 % and 19.86 % respectively. It is clearly shown that the multiple performance characteristics in the EDM process are greatly enhanced through this study.

VI. CONCLUSION

The GRA based on the Taguchi method's response table has-been proposed as a way of studying the optimization of EDM process parameters for D2 (HOT DIE STEEL). The optimal machining parameters have been determined by the grey relational grade for Multiperformance characteristics that are MRR and TWR. Nine experimental runs based on OA's have been performed. The following conclusions can be drawn from this study.

The work has successfully evaluated the feasibility of EDM of D2 (HOT DIE STEEL)

From the response table of the average grey relational grade, it is found that the largest value of grey relational grade for discharge current, pulse on time and material are 5A, 500µs and Brass respectively. These are the recommended levels of controllable process factors when better MRR and lesser TWR are concurrently obtained.

The ANOVA of the grey relational grade for multi-performance characteristics reveals that the material and current are the most major parameter.

Based on the confirmation test, the improvements in MRR and TWR are 7.89% and 19.86% respectively.

It is shown that the performance characteristics of the EDM process such as MRR and TWR are improved together by using the method proposed by this study. The effectiveness of this approach has been successfully recognized by validation experiment.

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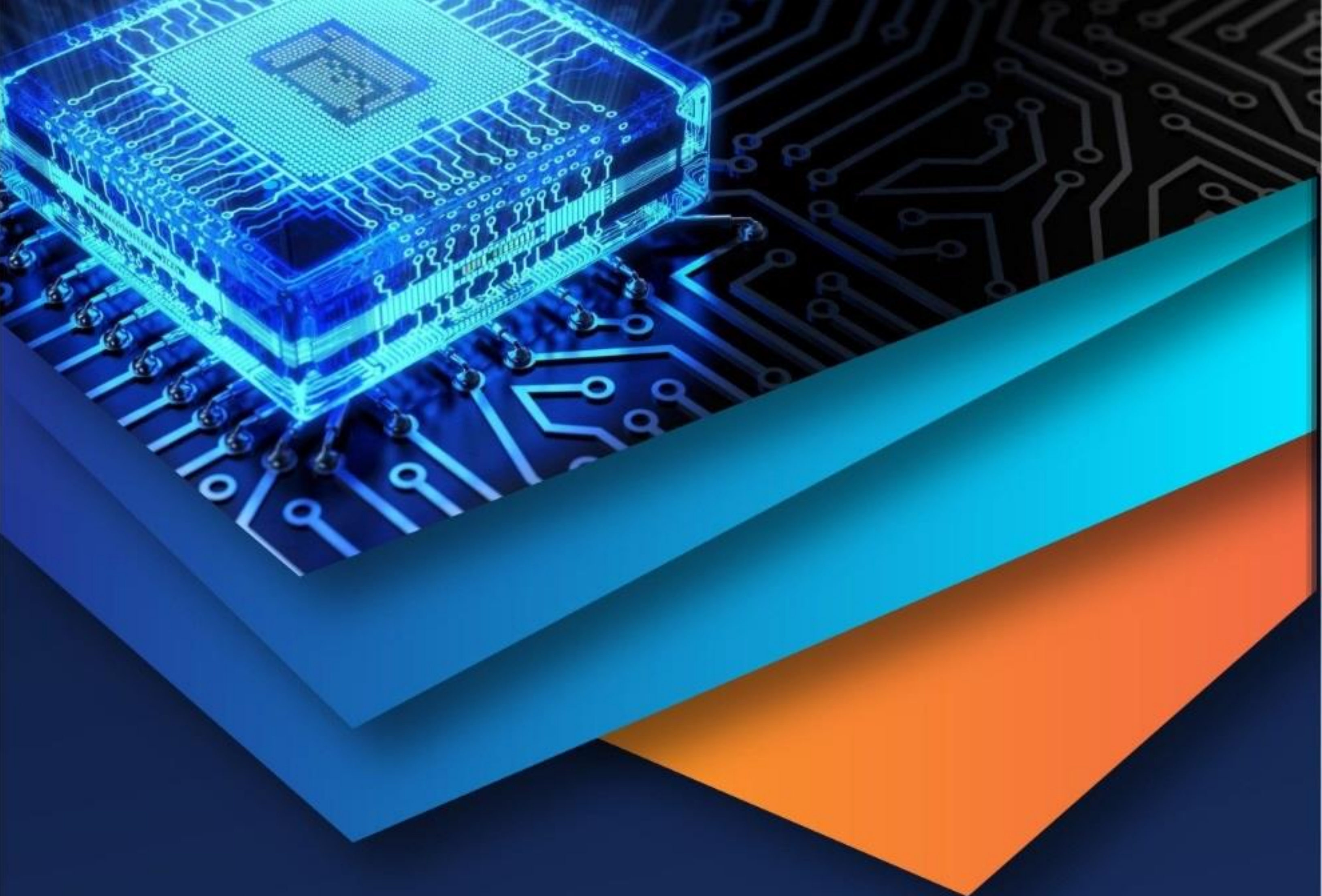

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