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Machining of Inconel -718 by EDM using Taguchi Method for Optimization of Material Removal Rate & Surface Roughness

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Abstract: Inconel super alloy are used in many industrial applications . it's hard to machine these materials which are having excellent mechanical properties with high strength at elevated temperature and hard to machine in traditional machining process, so non-traditional machining are in demand. The present study is carry out on the machining of Inconel 718 alloy on CNC - EDM using copper and graphite electrodes. Experimental design were planned on Taguchi L9 Orthogonal array, where the input process parameters are Current, Pulse-ON, Pulse-OFF, for the process optimization of Material removal rate, Surface Roughness. Analysis of variance (ANOVA) is employed to indicate the level of significance of machining parameters.
Keywords: Inconel 718, Taguchi L9 OA, Surface Roughness, Material Removal rate, ANOVA-Significant factor.

I. INTRODUCTION

Inconel materials are used in many industries like aero-space, medical instruments, and nuclear plants because of good mechanical properties. Electrical discharge machining (EDM) is an alternative method for machining Inconel alloys in required shapes w.r.t to the tool design. Therefore, EDM is capable of efficiently machining of various parts with hardness properties. Electrical discharge machining (EDM) are been used to machining of tough material and complex materials in the industries. In EDM process material removal is by the action of spark discharges between the electrode tool and the work piece. The spark discharges per second take place and it discharge produces a tiny crater by melting and vaporization, thus reproducing the shape of the tool in to the work piece. A dielectric fluid flushes out the ‘chips’ that is the products of the discharge. Many complex shapes can be reproduced in the work piece. The Present work deals with the machining of Inconel alloy 718 with process parameters of current, time-on, time-off and experiments were planned on taguchi L9 orthogonal array with 3 levels each to find the Material removal rate response by Signal to noise ratio and significance of each parameters performance by ANOVA.

II. EXPERIMENTAL DETAILS

A. Work Piece Material

Inconel 718 steel having size of 80 mm x 80 mm x 10 mm thick and the properties with Composition in percentage by weight are given in table 1. with copper electrode and graphite electrode of 10mm diameter for machining.

Table 1. Composition of Inconel 718

Elements	N	Ti	Al	Cr	Mo	N	Fe
Composition	55	21	0.8	21	3.3	5.5	Balance

Table 2. Selected process parameters for machining conditions of Inconel 718

Parameters	Level 1	Level 2	Level 3
Current	4	6	8
Pulse –On	5	7	9
Pulse -Off	2	3	5

The current, pulse on time and pulse off time the input machining conditions of the EDM for machining INCONEL 718 the outcome response of machining effectiveness is material removal rate. Design of Experiments was based on the factors and levels using taguchi L9 Orthogonal array with input parameters and their levels shown in Table 2 .Table 3 shown the Experiments were carried out according to the taguchi L9 Orthogonal array.

Table 3. Shows the L 9 Orthogonal array experimental for EDM of Inconel 718 by using copper and graphite electrode

Expt. No	Current	Pulse-On	Pulse-Off
1	4	5	2
2	4	7	3
3	4	9	5
4	6	5	3
5	6	7	5
6	6	9	2
7	8	5	5
8	8	7	2
9	8	9	3

III. RESULTS & DISCUSSIONS

Table 4. Experimental results of Inconel 718 by EDM with copper and graphite electrode

Expt. No	MRR with Copper Electrode (mm/min)	Surface Roughness with Copper Electrode (µm)	MRR with Graphite Electrode (mm/min)	Surface Roughness with Graphite Electrode (µm)
1	0.066	3.421	0.085	3.142
2	0.069	3.314	0.074	3.533
3	0.125	3.275	0.092	3.989
4	0.128	2.912	0.098	4.059
5	0.169	3.528	0.132	3.803
6	0.173	2.901	0.138	4.636
7	0.300	4.315	0.183	4.125
8	0.386	3.874	0.198	4.576
9	0.467	3.363	0.293	4.551

Higher Material Removal Rate (MRR) is calculated by dividing the difference between the weight of work piece before (wb) and after (wa) machining, against the machining time (tn). With copper and graphite electrodes on machining of Inconel 718 as Table 4. shows

$$MRR = \frac{\text{Before machining - After Machining weight of work piece}}{\text{Machining Time}}$$

A. *Optimization of Material Removal Rate*

1) *Signal to noise Ratio of MRR with copper electrode on Inconel 718*

Table 5. Response table for S/N ratios of MRR with copper electrode on Inconel 718

Level	Current	Pulse-on	Pulse-off
1	-17.66	-15.96	-15.61
2	-15.51	-15.59	-15.36
3	-13.38	-15.00	-15.58
Delta	4.28	0.96	0.25
Rank	1	2	3

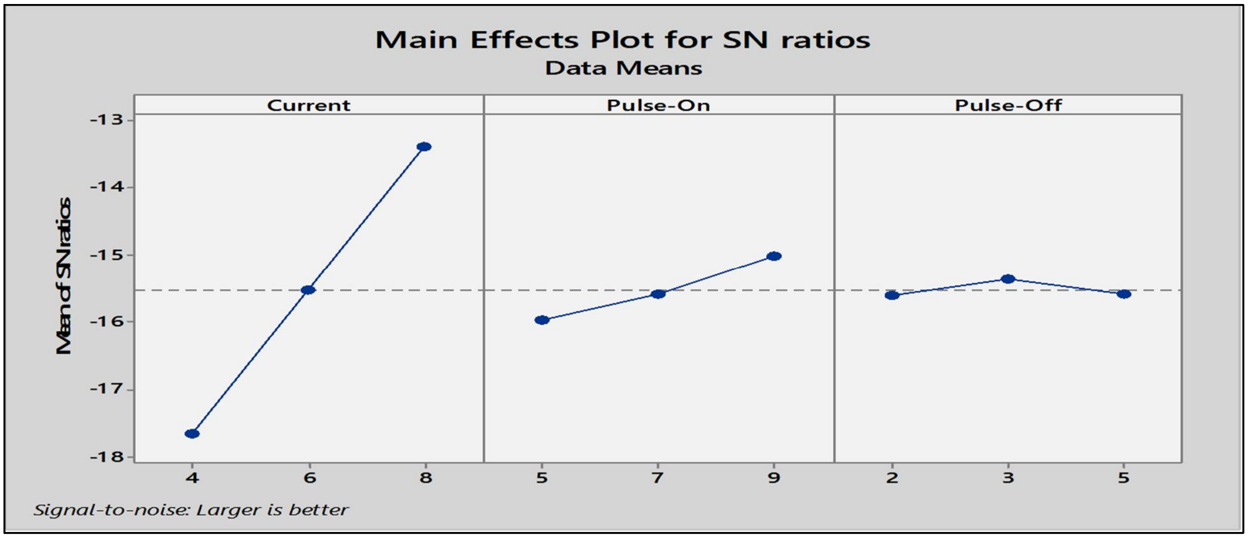

Fig.1. Graph S/N Ratios of MRR with copper electrode machining on Inconel718

From Table.5. shows the S/N Ratios of MRR with copper electrode machining on Inconel 718 w.r.t input parameters of Current, Pulse-ON, and Pulse-OFF and the optimum combination is A3B3C2 from Fig.1 for Material removal rate for which higher the better is consider.

2) ANOVA for of MRR with copper electrode by EDM on Inconel718

Table 6. ANOVA of MRR with copper electrode

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Current	2	0.01064	0.00532	61.79	0.016	92.11
Pulse-On	2	0.00064	0.00032	3.69	0.213	5.51
Pulse-Off	2	0.00010	0.00005	0.61	0.623	0.90
Error	2	0.00017	0.00009			1.49
Total	8	0.01155				100

From Table 6. the ANOVA for of MRR with copper electrode by EDM on Inconel 718 in which the most contribution percentage factor is current 92.11%, which shows the highest value in machining process followed by less pulse-on 5.51% and pulse-off 0.90%.,and error contribution 1.49%.

3) Signal to noise Ratio of MRR with Graphite electrode on Inconel 718

Table 7. S/N Ratios of MRR with graphite electrode on inconel718

Level	Current	Pulse-on	Pulse-off
1	-21.02	-16.28	-15.81
2	-14.55	-15.87	-15.47
3	-11.73	-15.15	-16.02
Delta	9.29	1.13	0.54
Rank	1	2	3

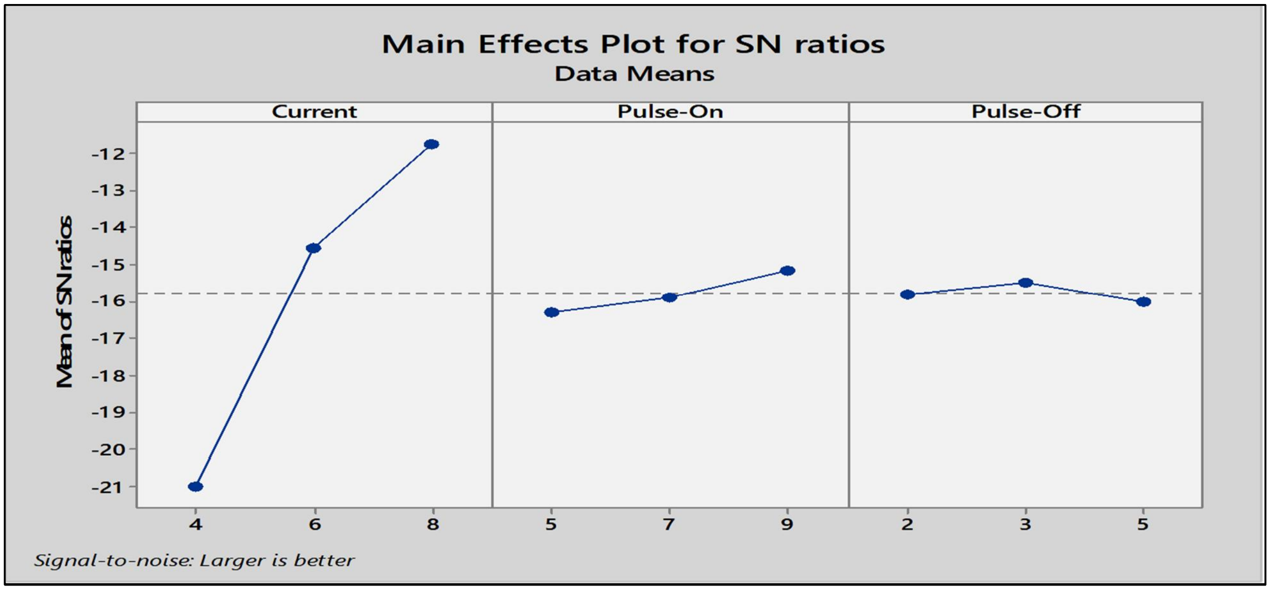

Fig.2. Graph S/N ratios of MRR with graphite electrode machining on inconel 718

From Table 7. shows the S/N Ratios of MRR with graphite electrode machining on Inconel 718 w.r.t input parameters of Current, Pulse-ON, and Pulse-OFF and the optimum combination is A3B3C2 from graph Fig 2.for Material removal rate for which higher the better is consider .

4) ANOVA for of MRR with Graphite electrode by EDM on Inconel 718

Table 8. ANOVA of MRR with Graphite electrode

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Current	2	0.04435	0.02218	149.06	0.007	95.76
Pulse-On	2	0.00118	0.00059	3.96	0.202	2.54
Pulse-Off	2	0.00049	0.00024	1.63	0.38	1.05
Error	2	0.00030	0.00015			0.64
Total	8	0.04632				100.00

From Table 8. the ANOVA for of MRR with Graphite electrode by EDM on Inconel 718 in which the most contribution percentage factor is current 95.76%,which shows the highest value in machining process followed by less pulse-on 2.54% and pulse-off 1.05%.,and error contribution 0.64%.

B. Optimization of Surface Roughness

1) Signal to noise Ratio of Surface Roughness with copper electrode on Inconel 718

Table 8. Response table for S/N ratios of Surface Roughness with copper electrode on Inconel 718

Level	Current	Pulse-on	Pulse-off
1	-10.465	-10.889	-10.566
2	-9.828	-11.040	-10.075
3	-11.66	-10.030	-11.318
Delta	1.837	1.010	1.243
Rank	1	3	2

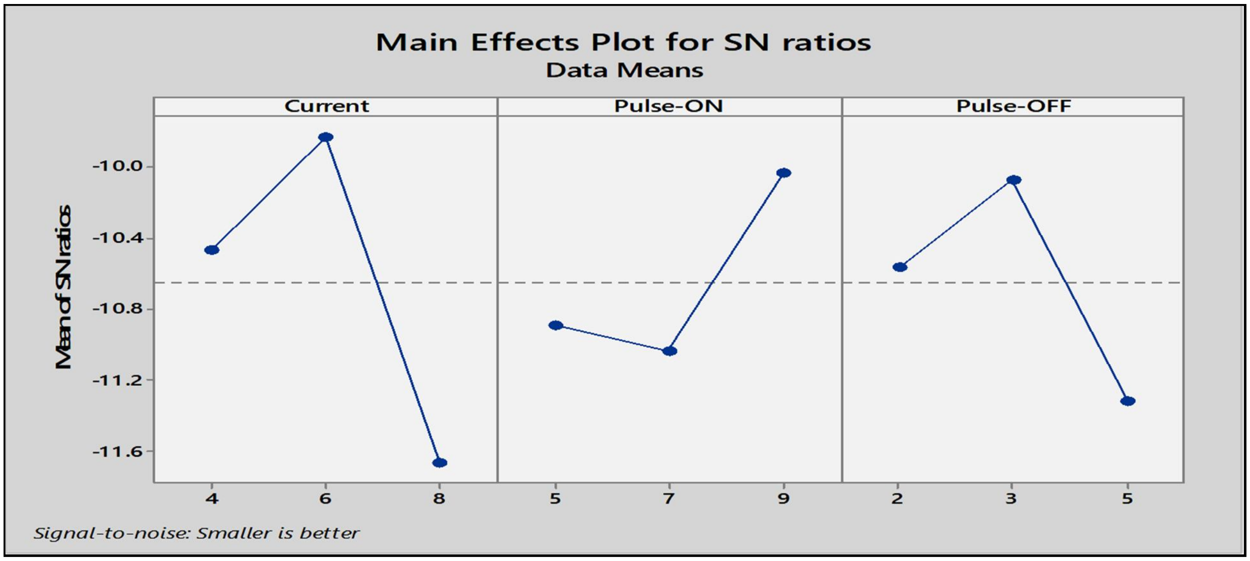

Fig.3. Graph S/N Ratios of Surface Roughness with copper electrode machining on Inconel718

From Table 8. shows the S/N Ratios of Surface Roughness with copper electrode machining on Inconel 718 w.r.t input parameters of Current, Pulse-ON, and Pulse-OFF and the optimum combination is A2B3C2 from graph Fig 3.for Surface Roughness for which smaller the better is consider

2) ANOVA for of Surface Roughness with Copper Electrode by EDM on Inconel718

Table 9. ANOVA of Surface Roughness with copper electrode

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Current	2	0.85709	0.42855	23.34	0.041	54.24
Pulse-On	2	0.29109	0.14555	7.93	0.112	18.42
Pulse-Off	2	0.39515	0.19758	10.76	0.085	25.01
Error	2	0.03672	0.01836			2.32
Total	8	1.58006				100.00

From Table 9. the ANOVA for of MRR Surface Roughness with copper electrode by EDM on Inconel 718 in which the most contribution percentage factor is current 54.24%,which shows the highest value in machining process followed by less pulse-on 18.42% and pulse-off 25.01%.,and error contribution 2.32%.

3) Signal to noise Ratio of Surface Roughness with Graphite electrode on Inconel 718

Table 10. Response table for S/N ratios of Surface Roughness with Graphite electrode on Inconel 718

Level	Current	Pulse-on	Pulse-off
1	-10.97	-11.47	-12.16
2	-12.36	-11.93	-12.10
3	-12.89	-12.83	-11.98
Delta	1.92	1.36	0.18
Rank	1	2	3

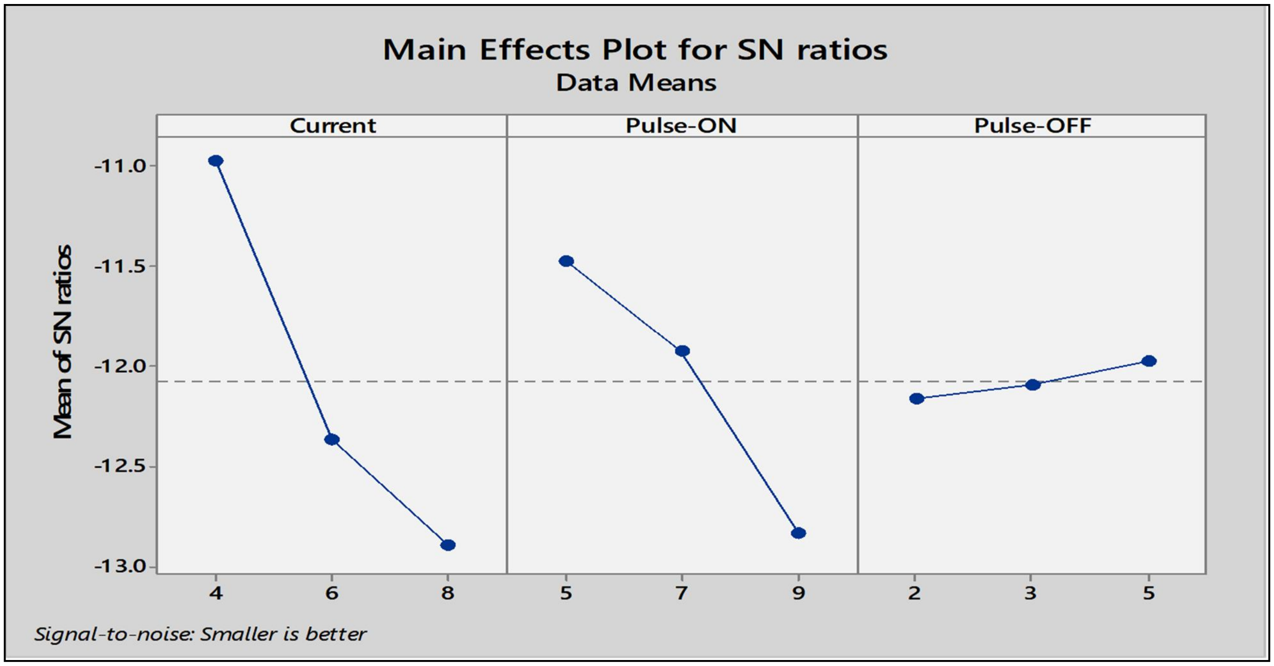

Fig.4. Graph S/N Ratios of Surface Roughness with Graphite electrode machining on Inconel718

From Table 10. shows the S/N Ratios of Surface Roughness with Graphite electrode machining on Inconel 718 w.r.t input parameters of Current, Pulse-ON, and Pulse-OFF and the optimum combination is A1B1C3 from graph Fig 3.for Surface Roughness for which smaller the better is consider

4) ANOVA for of Surface Roughness with copper Graphite by EDM on Inconel 718

Table 11. ANOVA of Surface Roughness with Graphite electrode

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Current	2	1.18109	0.59055	5.27	0.160	58.093
Pulse-On	2	0.59595	0.29798	2.66	0.273	29.312
Pulse-Off	2	0.03184	0.01592	0.14	0.876	1.566
Error	2	0.22423	0.11212			11.029
Total	8	2.03311				100.000

From Table 11. the ANOVA for of Surface Roughness with Graphite electrode by EDM on Inconel 718 in which the most contribution percentage factor is current 58.09%,which shows the highest value in machining process followed by less pulse-on 29.31% and pulse-off 1.56%.,and error contribution 11.02%.

In Surface Roughness, it is clearly shows that its do not match with taguchi L9 array experiment so there is need to do confirmation test by the equation as follows.

$$Y_{opt} = m + \left(m_{Aopt} - m\right) + \left(m_{Bopt} - m\right) + \left(m_{Copt} - m\right).$$

Where 'm' is the mean of surface roughness of copper and graphite electrode, and mAopt , mBopt , mCopt are the experimental combination of A2B3C2 & A1B1C3

IV. CONCLUSIONS

In this study Material removal rate, Surface Roughness is the most important performance measure using taguchi L-9 design of experiments. In order to improve productivity in EDM machining of Inconel 718, the optimum level of copper and graphite are calculated as follows

1) For Material removal rate of Inconel 718 with copper and graphite electrode is showing maximum removal rate.
a) The optimum combination is A3B3C2 i.e. Current 8Amps, Pulse-On 9µs, Pulse-Off 3µs is 0.467 mm/min and 0.293 mm/min which is matching within the taguchi L9 Orthogonal Array of Design of Experiment.
2) From ANOVA current is the most significant factor which is contributing in MRR w.r.t electrodes of copper 92.11% and graphite 95.76 % and error estimation is 0.64% for graphite and 1.49% for copper electrode
3) For Surface Roughness of Inconel 718 with copper and graphite electrode.
a) The optimum combination is A2B3C2 i.e. Current 6Amps,Pulse-On 9µs,Pulse-Off 5µs is 4.315µm with copper electrode
b) The optimum combination is A1B1C3 i.e. Current 4Amps,Pulse-On 5µs,Pulse-Off 5µs is 4.315µm and 4.10µm with graphite electrode
c) Surface Roughness values which is not matching within the taguchi L9 Orthogonal Array of Design of Experiment so confirmation test values are taken into consideration.
4) From ANOVA current is the most significant factor which is contributing in Surface Roughness w.r.t electrodes of copper 54.24% and graphite 58.09% and error estimation is 11.02%.for graphite and 2.32% for copper electrode

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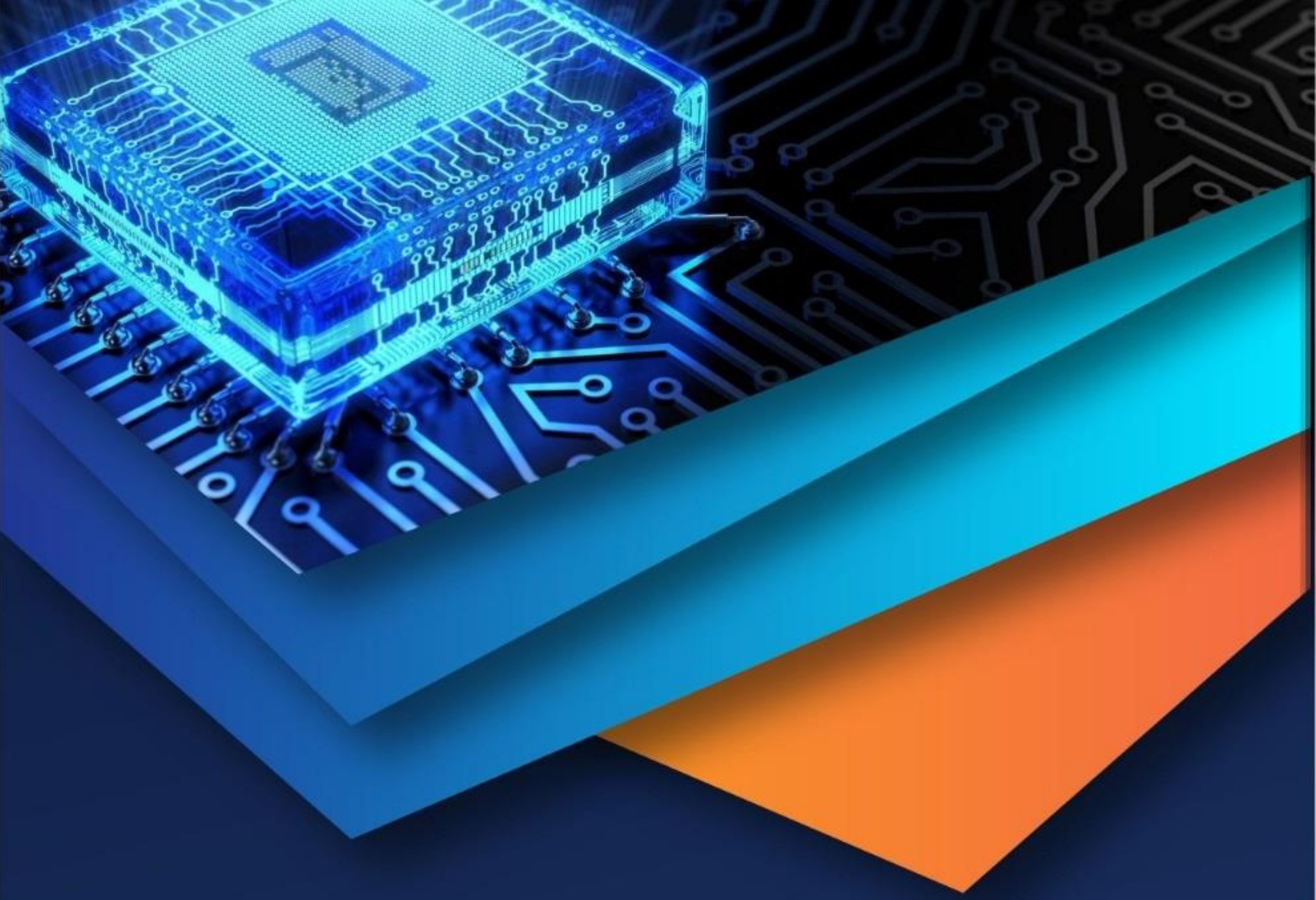

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