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Taguchi Design Optimization of the AA6063 CNC End Milling Process with Minimum Quantity Lubrication and SiO_2 Based Nanofluid

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Abstract: In this experiment, Minimum Quantity Lubrication is a new age technology that is tested for the end milling operation of Aluminum alloy. Aeronautics and automation use AA6063 T6 tempered alloy extensively. The use of an aerosol of SiO2-based nanofluid with pressurised air produced an excellent surface finish. OVAT analysis was used to determine the various parameters for the experiment. For the design and optimization of the multi-responses, the Taguchi method with grey relation analysis was used.

Keywords: Minimum Quantity Lubrication, AA6063, T6, End Milling, Nanofluid, SiO2

I. INTRODUCTION

The machining surface has variable roughness qualities after the metal removal procedure. The surface roughness of the workpiece is heavily influenced by the spindle's rotating speed, the feed rate in machining, and the depth of cut. A coolant, often known as a lubricant, applied during machining influences surface roughness. The coolant is used to remove heat from the cutting surface, to carry away chips, and to act as a lubricant during machining. Metalworking fluid is another name for coolant (MWF). Straight oil, synthetic oil, soluble oil, and semi-synthetic oil are the four primary forms of metalworking fluid [1]. Straight oils are non-emulsifiable cutting fluids that contain high-pressure additives such as chlorine and sulphur. Synthetic cutting fluids are concentrated water-based liquids. When combined with water, it produces a transparent or translucent solution. Synthetic cutting oil has an advantage over emulsifiable cutting oil in that it is easily treated for disposal.

When water is added to soluble oils, a white emulsion forms; this is concentrated mineral oil. Biocide is a necessary component for soluble oils that prevents odours (Palco India) [2]. Semi-synthetic oils are complete synthetic oils derived from petroleum. Synthetic polymers are utilised as additives in semi-synthetic oil, while emulsifiers are employed to keep lubricants suspended. About 30% oil is utilised, and a micro-emulsion is created by adding water; particle size is smaller than a micron [3]. Traditional lubricating and cooling techniques have serious difficulties; the liquids often employed have an environmental effect, human health is compromised during usage and disposal, and the work environment is constantly dirty. Minimum Quantity Lubrication (MQL) is a cutting-edge technique that employs a little amount of lubricating oil to create an aerosol with high-pressure air. The efficacy of MQL varies depending on the workpiece material and machining method. Recent breakthroughs in MQL include additives, ionic liquids, and nanofluids.

II. LITERATURE REVIEW

Solankee et al. in 2017 studied the effect of ZnO nanofluid in the turning operation of EN-31 steel. Researchers used vegetable oil such as sunflower, soybean, groundnut, and palm oil. The best result was shown by soybean and groundnut oil, further research was carried out using these two oil. The result clearly shows that the MQL technique gives an excellent result to traditional flood lubrication. Optimization of the parameters was done by the Taguchi method. The graphical representation of the result was done [4]. Tosun and Huseyinoglu (2010) studied the surface roughness of milling AA7075-T6 alloy. MQL was prepared with boron oil and water and its volumetric concentration was varied and supplied in atomized form. Spindle speed, feed rate and cutting speed affects the surface finish [5].

High spindle speed reduces surface roughness. Built-up edges are eliminated by increasing cutting speed. Surface roughness and feed rate are directly proportional. Increased material removal rate (MRR) and surface finishing are conflicting. Achieving the best MRR with an excellent surface finish is difficult. For high productivity increased cutting speed and feed rate lead to high temperature that reduces tool life.

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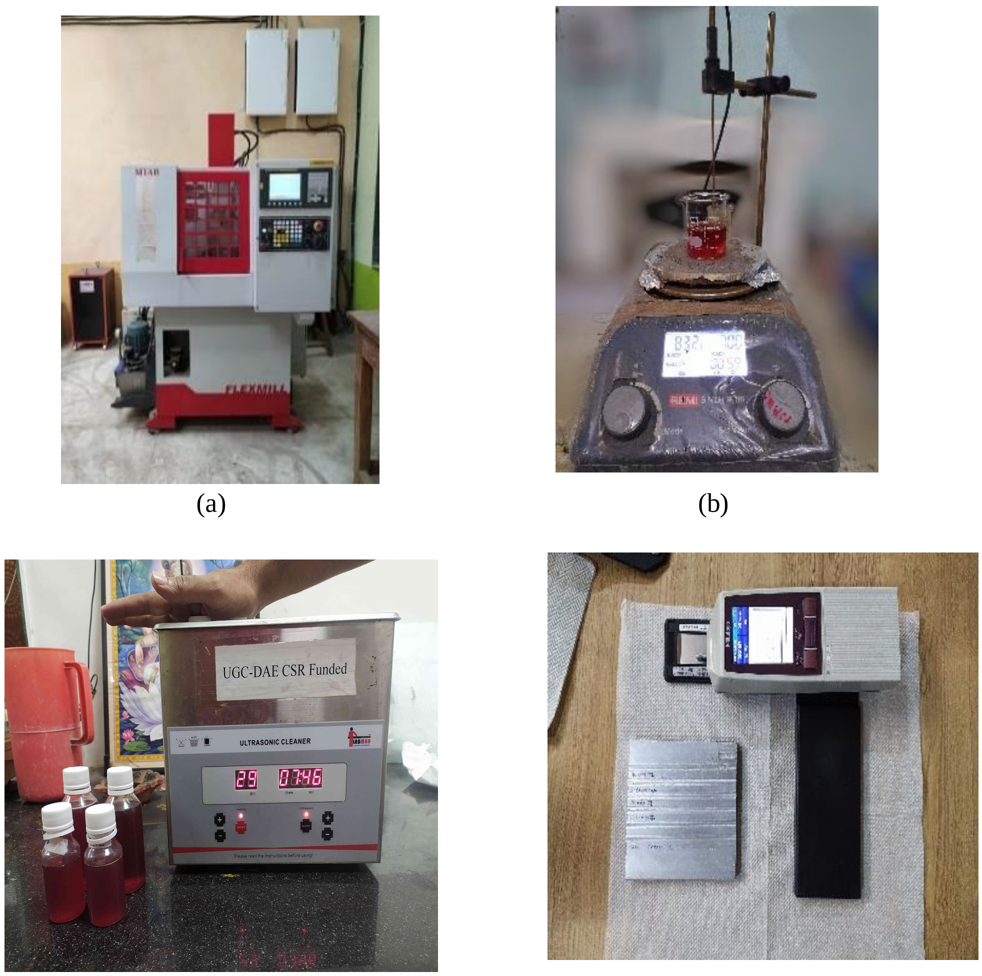
III. EXPERIMENTAL SETUP

The workpiece material for the experiment was AA6063-T6 alloy. Due to its excellent strength-to-weight ratio, this aluminum alloy finds wide application in the aerospace, aircraft and automation industry. A 10 mm thick flat bar of the alloy was used. The composition of metals in the alloy is as follows:

Table 1 Composition of AA6063 alloy

Element	Mg	Si	Fe	Cu	Mn	Zn	Ti	Cr	Al
% Wt	0.45-9	0.2-0.6	0.35	0.1	0.1	0.1	0.1	0.1	Balance



(a) (b)

(c) (d)

Fig 2 (a) MTAB Flexmill (b) REMI 5MLH PLUS magnetic stirrer (c) LABMAN sonicator (d) calibration of Mitutoyo SJ-210, workpiece

The nanofluid was prepared with help of a magnetic stirrer and sonication bath. The paste of SiO2 nanoparticles and alkyl phenol ethoxylate (APE) was formed. Later it was mixed with 20W40 engine oil. The APE surfactant slows down the settling velocity of suspended nanoparticles in the fluid. Using 20W40 allows extended shelf life to the fluid, in previous research it was found that vegetable oil tends to get oxidized after a few hours of storage.

The design of the experiment was done using the L27 orthogonal array of the Taguchi method. The OVAT analysis was done for the experiment. The rotational speed of the spindle, feed of the table and depth of cut were observed as the most influencing parameters. The concentration of nanofluid was determined by a critical literature survey. The three levels for the experiment were chosen as follows:

Table 2 Three-level input parameter

Input parameters	Level 1 (low)	Level 2 (Mid)	Level 3 (High)
Conc. Of SiO_2 (% w/v)	0.33	0.66	1
Spindle speed (n) (rpm)	2000	3000	4000
Feed rate (V_f) (mm/min)	200	400	600
Depth of cut (a_p) (mm)	0.2	0.4	0.6

The obtained experimental data is as follows:

Table 3 Experimental data

Sr. No.	% Conc	Speed	Feed	DOC	Surface Roughness	Material Removal Rate
1	0.33	2000	200	0.2	0.304	192.0
2	0.33	2000	200	0.2	0.365	190.2
3	0.33	2000	200	0.2	0.307	186.9
4	0.33	3000	400	0.4	0.447	701.8
5	0.33	3000	400	0.4	0.421	683.4
6	0.33	3000	400	0.4	0.432	702.6
7	0.33	4000	600	0.6	0.612	1469.4
8	0.33	4000	600	0.6	0.558	1512.6
9	0.33	4000	600	0.6	0.553	1481.5
10	0.66	2000	400	0.6	0.514	1067.0
11	0.66	2000	400	0.6	0.503	1086.3
12	0.66	2000	400	0.6	0.500	1075.9
13	0.66	3000	600	0.2	0.389	552.5
14	0.66	3000	600	0.2	0.377	546.9
15	0.66	3000	600	0.2	0.379	573.6
16	0.66	4000	200	0.4	0.472	354.0
17	0.66	4000	200	0.4	0.457	345.8
18	0.66	4000	200	0.4	0.460	347.8
19	1	2000	600	0.4	0.461	1004.2
20	1	2000	600	0.4	0.512	987.7
21	1	2000	600	0.4	0.513	948.6
22	1	3000	200	0.6	0.463	532.5
23	1	3000	200	0.6	0.484	520.8
24	1	3000	200	0.6	0.536	525.1
25	1	4000	400	0.2	0.459	363.0
26	1	4000	400	0.2	0.482	365.0
27	1	4000	400	0.2	0.422	366.1

The surface roughness of the work pieces was calculated by using the Mitutoyo SJ-210 surface tester. This surface tester was equipped with a detachable probe and the instrument was calibrated before beginning the test. For the measurement of material removal rate (MRR) time was noted down by using the stopwatch.

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IV. OPTIMIZATION

The optimization of multiple performances characteristics using Grey Relation Analysis. In first step normalization of the responses were done. The deviation sequences and grey relation coefficient were calculated and the overall evaluation of multiple response is based on grey relation grade [6].

Table 4 Grey Relation Analysis

	Normalized Values		Deviation Sequences		Grey Relation Coefficent		GRG	Rank
Sr No.	SR	MRR	SR	MRR	SR	MRR		
1	1	0.003835	0.000	0.996	1	0.231452027	0.615726	4
2	0.802401	0.002458	0.198	0.998	0.779858441	0.231206375	0.505532	9
3	0.992496	0	0.008	1.000	0.989394047	0.230769231	0.610082	5
4	0.536268	0.388355	0.464	0.612	0.601513132	0.329075595	0.465294	17
5	0.621311	0.374489	0.379	0.626	0.648935677	0.324145099	0.48654	14
6	0.583792	0.388975	0.416	0.611	0.627123202	0.329299493	0.478211	15
7	0	0.9674	1.000	0.033	0.411764706	0.901984733	0.656875	3
8	0.175088	1	0.825	0.000	0.459042745	1	0.729521	1
9	0.192596	0.976523	0.807	0.023	0.464374606	0.927422199	0.695898	2
10	0.318744	0.663856	0.681	0.336	0.50678499	0.471591462	0.489188	13
11	0.354512	0.678428	0.645	0.322	0.520257143	0.482647232	0.501452	11
12	0.364266	0.670591	0.636	0.329	0.524056587	0.476637855	0.500347	12
13	0.725197	0.275759	0.275	0.724	0.718093698	0.292899726	0.505497	10
14	0.764216	0.27158	0.236	0.728	0.748036158	0.291709542	0.519873	7
15	0.757713	0.291696	0.242	0.708	0.74287354	0.29752924	0.520201	6
16	0.455312	0.126022	0.545	0.874	0.56238989	0.255541484	0.408966	25
17	0.504086	0.119866	0.496	0.880	0.585326513	0.254208482	0.419767	21
18	0.494331	0.121379	0.506	0.879	0.580590727	0.254534647	0.417563	23
19	0.490354	0.616486	0.510	0.384	0.578681901	0.438908061	0.508795	8
20	0.325272	0.604017	0.675	0.396	0.509191594	0.431044846	0.470118	16
21	0.322771	0.57457	0.677	0.425	0.508266828	0.41354761	0.460907	18
22	0.486102	0.260716	0.514	0.739	0.576654854	0.288660295	0.432658	20
23	0.416067	0.251882	0.584	0.748	0.545199909	0.286227357	0.415714	24
24	0.245982	0.255091	0.754	0.745	0.481424656	0.287106394	0.384266	27
25	0.497608	0.132807	0.502	0.867	0.582172895	0.257026855	0.4196	22
26	0.422571	0.134306	0.577	0.866	0.547975461	0.257357354	0.402666	26
27	0.617668	0.135146	0.382	0.865	0.646751694	0.257542906	0.452147	19

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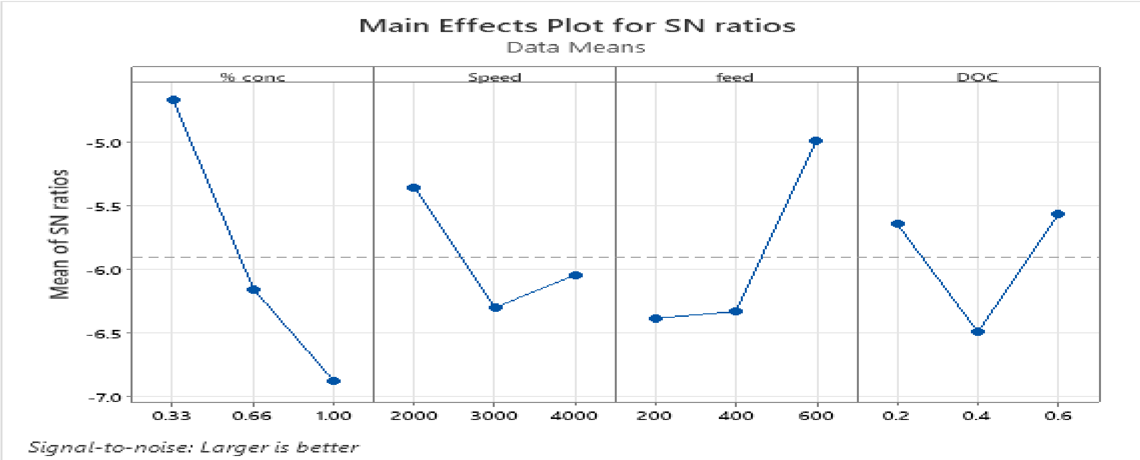

Fig 3 GRG main effect plot for SN ratios

Table 5: GRG Response Table

	Level 1	Level 2	Level 3	Max-Min	Rank
% Conc	-4.6685	-6.15861	-6.88227	2.21377	1
Speed	-5.35887	-6.30306	-6.0476	0.94419	3
Feed	-6.3867	-6.33424	-4.98859	1.39811	2
DOC	-5.6472	-6.49368	-5.56865	0.92503	4

The above mention graph generated using larger is the better condition and thus the value of optimum input parameters are %Conc1Feed3 Speed1DOC3. These values are same as GRG response table value.

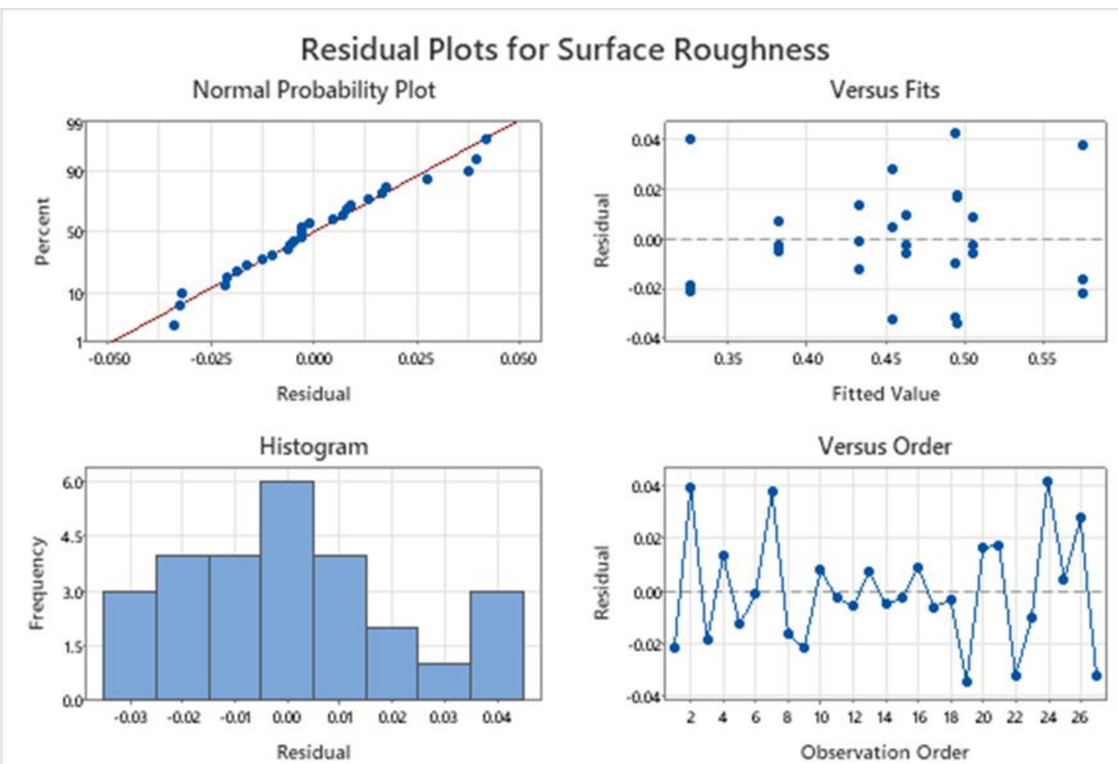

Fig 4 Residual Plot for surface roughness

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Table 6 Analysis of variance

Source	DF	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	83.99%	87.348	21.8369	28.86	0.000
% conc	1	11.46%	11.916	11.9161	15.75	0.001
Speed	1	12.25%	12.742	12.7425	16.84	0.000
feed	1	9.38%	9.753	9.7527	12.89	0.002
DOC	1	50.90%	52.936	52.9363	69.96	0.000
Error	22	16.01%	16.647	0.7567		
Lack-of-Fit	4	6.73%	7.000	1.7499	3.26	0.035
Pure Error	18	9.28%	9.648	0.5360		
Total	26	100.00%				
R-sq : 83.99% R-sq(adj): 81.08% R-sq (pred): 73.94%						

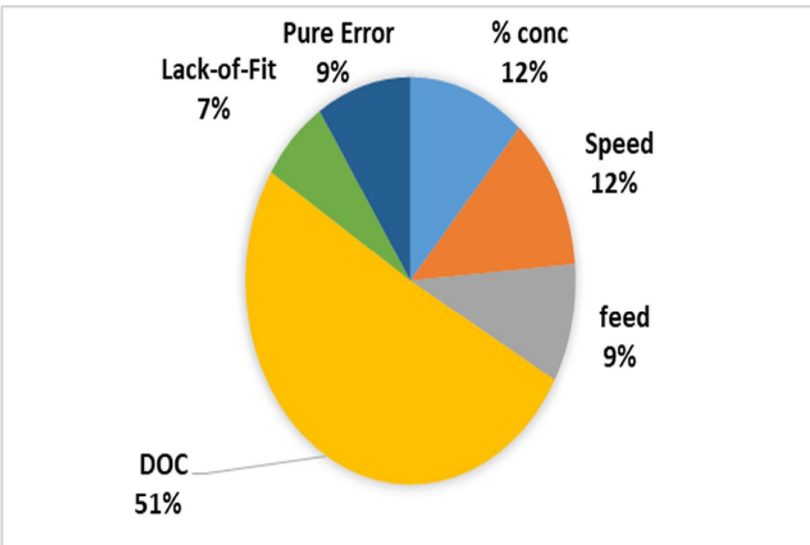

Fig 5 Pie chart of Contribution

The analysis of variance shows the effect of parameters on surface roughness. Depth of cut is concluded as the most affecting parameter. The following pie chart shows the graphical representation of ANOVA.

V. CONCLUSION

From the experimentation of end milling AA6063 by using the HSS tool and SiO2 based nanofluid by MQL technique significant results were obtained. The regression analysis of the model by the Taguchi method resulted in 84% fitting of the results. The main contributing parameter to the surface roughness was the depth of cut. The concentration of fluid, speed of the spindle and feed rate of the table showed equal contributions to the results. As the concentration of fluid was increasing it resulted in a better surface finish. The optimum cutting condition obtained after grey relation analysis were, the concentration of 1%, speed of the spindle at 3000 rpm, table feed rate of 400 mm/min, and depth of cut was 0.4 mm. The predicted surface roughness was 0.478 microns and the result obtained for the confirmation test was 0.457 microns. 4.39% deviation was observed in the optimum machining condition.

VI. ACKNOWLEDGEMENT

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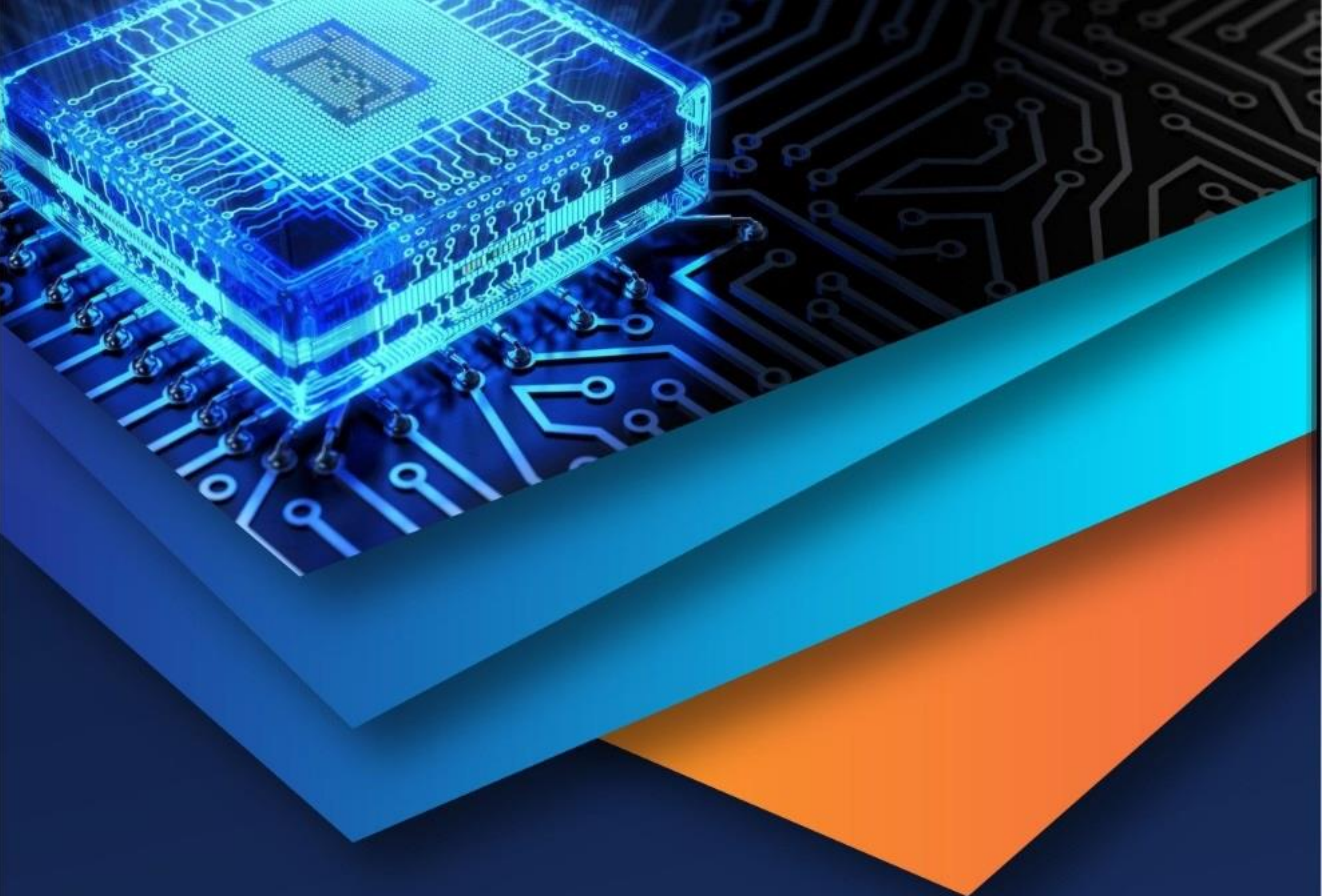

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