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Study of Mechanical Properties of Al6063 Reinforced in ZrO_2 and Charcoal Hybrid Composite using Stir Casting Process

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Abstract: This study focused on increasing the mechanical properties of the Al6063. Al6063 reinforced with ZrO_2 and charcoal using the three different percentages (2% ZrO_2 + 1% charcoal; 4% ZrO_2 + 1% charcoal; 6% ZrO_2 + 1% charcoal). The Al-ZrO_2-charcoal Metal matrix composite produced by the stir casting method. Tensile strength, microhardness and corrosion characteristics of the hybrid material compared with AL6063 alloy. The tensile strength, microhardness and corrosion resistance of the hybrid material are signficantly improved compared to Al6063. The overall maximum tensile strength, microhardness and better corrosion resistance found in 6% ZrO_2 + 1% charcoal metal matrix compared to Al 6063 and other combinations.
Keywords: Metal matrix composite, ZrO2, Charcoal, stir casting, tensile, micro hardness, corrosion test.

I. INTRODUCTION

Metal Matrix Composites (MMCs) are emerged as potential material in the metal industry during the last two decade. Available monolithic materials have limitations in their strength, stiffness, and density. MMCs have enhanced properties over monolithic materials and they are relatively low cost. MMCs are used in various applications such as automobile, aerospace and marine industries due to their improved strength, better stiffness, high specific modulus, less weight, low co-efficient of the thermal expansion etc., than the monolithic materials. Composite material is made from two or more constituent materials with significantly different physical or chemical properties. The combined MMCs of the metal and ceramic materials showed better mechanical properties compared to other composites. Aluminium- Aluminium composites usage has increased due to easy availability, high strength to weight ratio, easy machinability, durable, ductile and malleability. The use of aluminium in vehicles reducing the energy consumption while increasing load capacity. Its strength can be adapted to the application required by modifying the composition of its alloys. The alloy is used in automobiles, aircraft, truck, railway cars, spacecraft etc. Aluminium based metal matrix composites have been one of the key research areas in materials processing field in the last few decades. 6XXX series contains a mixture of magnesium and silicon. And this Alloys series has moderate in strength. Al (6063) alloy is processing in larger quantities and due to low cost used in aircraft applications, architectural applications, extrusions, window frames, doors, shop fittings, irrigation tubing. Al6063 alloy has high corrosion resistance; however, its hardness is relatively less which limits it's their applications. The addition of the ceramic particles like Zirconium and charcoal to the Aluminium alloys improves the mechanical properties. The present study is conducted to increase the mechanical properties of Al6063 using zirconium dioxide and charcoal as reinforced particles to enhance the hardness and wear resistance. A large number of fabrication techniques are used for production of Metal Matrix complex, in that stir casting processes is considered the one of the widely used fabrication process of aluminum based composite. So in this study Al-ZrO_2-charcoal Metal matrix composite produced by the stir casting method. Compocasting process involves the agitation of particulate reinforcement and semisolid metal.

A. Material Selection And Their Property

The material used in the present investigation consists of Aluminium alloy (Al6063) as the base matrix alloy. Its chemical composition (%) is Mg = 0.45-0.9, Si=0.2-0.6,Fe=0.35max, Cu=0.1max, Mn=0.1max, Zn=0.1max, Ti=0.1max,Cr=0.1max, Al=balance. It possesses high heat dissipation capacity and is suitable for high strength and high-temperature applications. The mechanical property of the Al 6063 of the material is listed in the Table 1.

Zirconium dioxide is taken as the reinforcement phase because ZrO_2 it has good wettability with Al, high hardness, and high-temperature stability. ZrO2 has following property Viz., density = 5.68g/cm3; colour = white; Thermal conductivity = 1.7-2.7 W/mK. Charcoal is the lightweight black carbon and ash residue hydrocarbon produced by removing water and other volatile constituents from animal and vegetation substances. The properties of graphite, density = 0.18-0.22 g/cm³; Specific gravity= 2.6; Mean grain size =21 µm; colour = black; Melting point = 1.200-1550 ^{o}c

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Table 1- Al 6063 properties

Density	2.69 g/cm^3
Elastic Modulus	68.3 Gpa
Melting Point	615 °C
Specific Heat Capacity	900 J/Kg-K
Tensile Strength: Ultimate (UTS)	145 - 186 Mpa
Vickers Hardness	118 HV
Thermal Conductivity	201-218 W/Mk
Elongation	18 -33%

II. PROCESSING METHOD

Table 2- Experimental plan

Experiment No.	Sample No.	Melting temperature (°C)	Reinforcement preheat Temperature (°C)	Reinforcement (%)	
				ZrO_2	Charcoal
1.	1.	700	450	0	1
2.	2.	700	500	2	1
3.	3.	650	450	4	1
4	4	650	500	6	1

Samples are to be prepared using Al 6063 reinforced with zirconium dioxide ZrO_2 (2%, 4% and 6%) and charcoal (1%) by volume at various melting temperatures of 675°C, 700°C and reinforcement pre-heat temperatures as 450°C and 500°C. Experiments were conducted using Taguchi L_4 orthogonal design of experiments is shown in Table 2.

A. Stir Casting

The aluminium alloy Al 6063 ingots were cut in small rods with the dimensions of 50 mm thickness and 25 mm diameter into feed crucible. The required proportion of the rods as per experimental plan is fed in to crucible and melted by heating in the induction furnace at 650 - 700 °C for 1 to 2 hours and melt the rod above its liquids temperature to make it in the form of semi liquid state (around 700°C). The ZrO_2 and charcoal particles are preheated at 450 - 500°C to make their surface oxidized. Preheated die is heated at temperature of 200°C for proper solidification. During the reheating process of aluminium alloy at 800°C stirring at a speed of 650 rpm.

Then the reinforcement powders are added to semi liquid aluminium alloy in the furnace. Argon gas is passed in to the molten metal to remove the soluble gases present in the liquid state metal. Stirring of molten metal is carried for 3 minutes duration. The aluminium composite material reaches completely liquid state at the temperature of about 850°C and the completely melted aluminium hybrid composite is poured in to the permanent metal die and subjected to solidification to produce the required specimen. The casted samples are shown in Fig.1.

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III. TESTING

A. Testing Of Samples

The samples were casted as per the experimental plan to prepare specimens for various testing and investigating the properties of these hybrid composite samples.

Fig 1- Casted sample

B. Tensile Test

The Casting were made according to the parameters (squeeze pressure, melting temperature, squeeze time) selected in the Taguchi L4 orthogonal Array. The required dimensions to prepare tensile specimen as shown in Fig. 2, these specimen is machined according to the ASTM - E8 standard. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area. The tensile testing specimen was presented in Fig 3 .

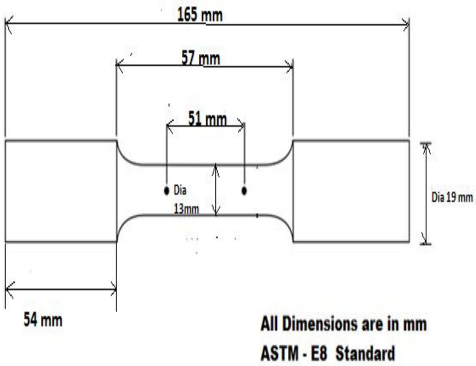

Fig. 2- Dimension of Test Specimen

The specimen is loaded and specimen undergoes deformation. The specimens has the Gauge Length – 51 mm and Rod Diameter 19 ± 0.25 mm. Universal testing machine used for testing the specimen is a make of FSA and its model is M100. Loading accuracy well within ±1%, conform to IS:1828 / BS:1610.

Fig 3- Tensile Test Test Specimen

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C. Hardness Testing

Hardness is the property of the metal that resists to deformation usually by penetration or indentation and scratching. Hardness of the material mainly depends on strain, ductility, elastic stiffness, strength, plasticity, viscoelasticity, toughness and viscosity. Hardness is measured by Vickers techniques and the results presented by Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). Hardness test samples are shown in Fig 4.

Fig 4- Hardness test samples

The HV number is determined by the ratio *F/A*, where *F* is the force applied to the diamond in kilograms-force and *A* is the surface area of the resulting indentation in square millimeters. *A* can be determined by the formula.

$$A = \frac{d^2}{2\sin(136^\circ/2)},$$

Which can be approximated by evaluating the sine term to give,

$$A \approx \frac{d^2}{1.8544},$$

Where *d* is the average length of the diagonal left by the indenter in millimeters. Hence,

$$HV = \frac{F}{A} \approx \frac{1.8544F}{d^2} \quad [\mathrm{kgf/mm^2}]$$

Where *F* is in kgf and *d* is in millimeters.

D. Corrosion Test

Pitting is one of the most damaging forms of corrosion. Pitting factor is the ratio of the depth of the deepest pit resulting from corrosion divided by the average penetration as calculated from weight loss. The corrosion test conducted by Al6063 composite after exposure to 3.5% NaCl solution

mpy = 534 x (W / D soAT)

Where,

W = weight loss in milligrams

D = metal density in g /cm3

A = area of sample in cm2

T = time of exposure of the metal sample in hours

E. Scanning Electron Microscope Images

Rough surface (unpolished) of the test pieces were used to see the distribution pattern of the ZrO_2 and Charcol in the metal matrix complex. Initally, charcol and ZrO2 was imaged seperatly. Charcol, ZrO2 and metal surfaces were coated with the gold as thin layer before imaging to get proper images. After gold coating, samples were placed in the sample holder and analysed in the JEOL scanning electron microscope using the standard settting with high vacum and 10KV power in various magnifications.

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IV. RESULTS AND DISCUSSION

Scanning electron microscope images of sample material (rough surface) shows that the the ZrO_2 and Charcol was evenly distributed in the complex matrix (Fig 5). ZrO_2 is embedded in the material well and looks bright smalle spheres in the SEM image.

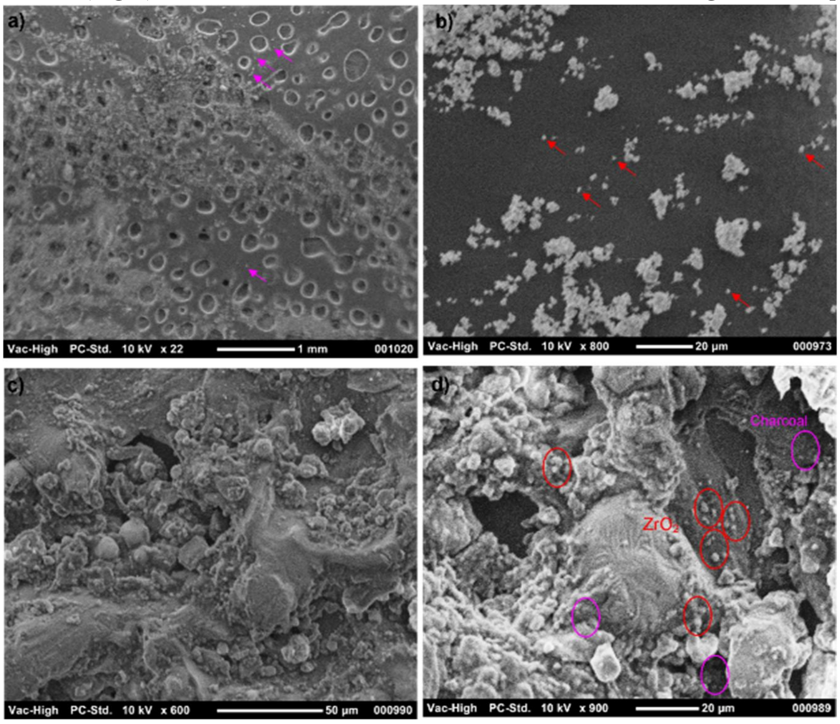

Fig 5 – SEM microscope images of the a) Charcol, b) ZrO_2 and c and d) Al-ZrO_2-Charcoal Metal Matrix composite rough surface in various magnifications. In higher magnification composite image shows that even the distribution of the Zro_2 (relatively bigger spheres with brightness – samples are circles in red) and Charcol (spheres with dull - pointed in pink circles) in the metal matrix. In picture Vac-high represents the high vacuum; PC-Std - JEOL Scanning electron microscope standard settings; 10KV- Voltage power; x100, x600 and x900 – Magnification; scale bar – reference size.

A. Tensile Test

The speciemens after the tensile test was presented in the Fig 6. The detailed results of the tensile test was preented in the Table 3. Tensile strength of the Al6063 is -136.79 N/mm^2 and it gradually increased 2% ZrO_2 + 1% charcoal reinforced composite, however found the maximum tensile found in the 6% ZrO_2 + 1% charcoal reinforced metal composite. The results shows that the resistance capability of the Al6063 increased against the tensile force in addition Zro2 and Charcoal.

Fig 6- Tensile test specimen after testing

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Table 3 -Tensile test result

S.No	Stir Speed	Melting Temperature	Stiring Time	Tensile Test	SNRA
	Rpm	˚C	Minutes	N/mm^2	
1	250	700	10	127.86	42.1347
2	250	650	5	130.37	42.3036
3	250	700	5	136.795	42.7214
4	250	650	10	142.38	43.0690

The optimization of process parameter of tensile test is carried with minitab software the optimal values was shown in Fig 7.

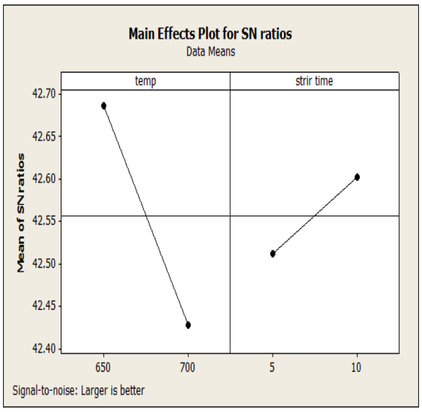

Fig 7: Optimized SN ratios of tensile test

Table 4 Response table for signal to noise ratios for tensile test

Level	Temperature (°c)	Stir time (Mins)
1	136.4	133.6
2	132.3	135.1
Delta	4.1	1.5
Rank	1	2

B. Hardness Test

Micro hardness test at various locations was carried out to know the effect of reinforced particulates on the alloy matrix. Vickers hardness measurement has been carried out on the embedded reinforcement particles as well as in the locality of particles and matrix. The results of the hardness test was presented in the Fig 8. Results visualised that the hardness increased in reinforcement. Hardness of the Al6063 alloy was 95 and it increased to 100.7 in 6% ZrO_2 + 1% charcoal reinforced metal composite. This indicates the resistance behavior of the composite against the indentation has been drastically increased with the addition of the ZrO_2 + 1 charcoal particle.

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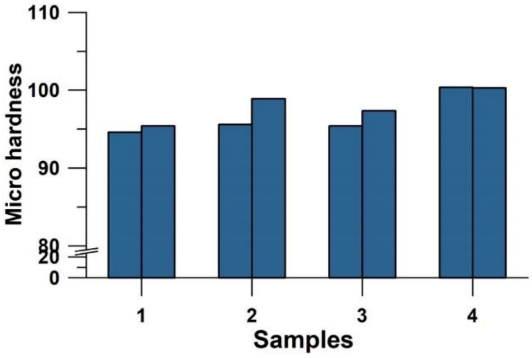

Fig 8-result of the hardness test

The optimization of process parameter of hardness test is carried with minitab software the optimal values was shown in Figure 9.

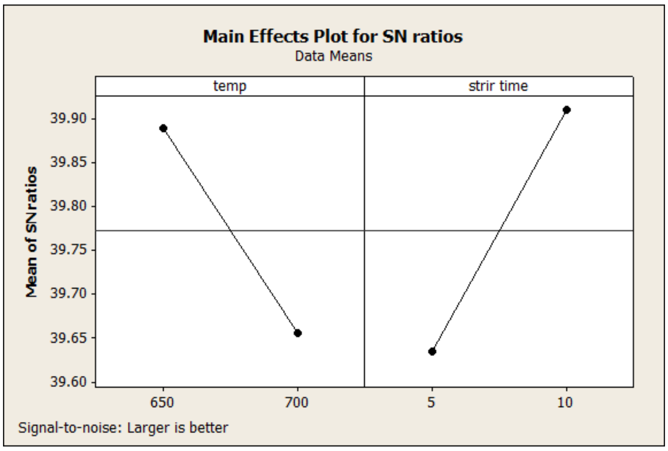

Fig 9 Optimized SN ratios of Hardness test

Table 5 Response table for signal to noise ratios for Hardness test

Level	Temperature °c	Stir Time Minutes
1	98.74	95.89
2	96.13	98.97
Delta	2.62	3.08
Rank	2	1

C. Corrosion Rate

The corrosion test is carried out in the casting samples. The corrosion rate was calculated by weight loss method. The samples were weighted and immersed in 3.5% of NaCl solution for 10 days. After 10 days sample were collected and then weighted. The corrosion test samples were presented in the Fig 9. The corrosion test results are presented in the fig 9. In general corrosion rate was less in the reinforced samples compared to Al6063 alloy. The overall better corrosion resistance was found in 4% ZrO_2 + 1% charcoal reinforced composite compared to other combinations.

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Fig 9 - Corrosion test samples (after 10days)

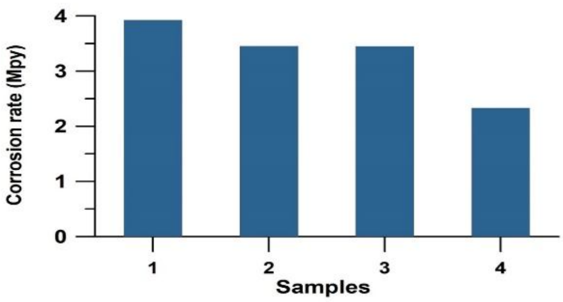

Fig 10 – Results of the corrosion test

The optimization of process parameter of hardness test is carried with minitab software the optimal values was shown in figure 4.8

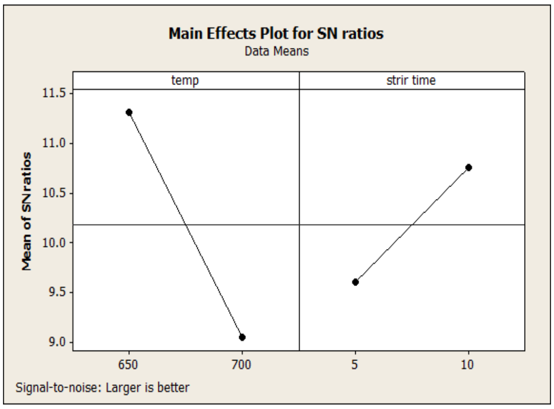

Fig 11 optimized SN ratio curve for Corrosion test

Table 6 Response table for signal to noise ratios for Corrosion test

Level	Temperature °c	Stir Time Minutes
1	11.315	9.611
2	9.054	10.759
Delta	2.261	1.148
Rank	1	2

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D. ANOVA for Tensile and Hardness Test

The inferences made from the above said graphs can be arrived at mathematically with the help of ANOVA. The confidence limits are taken as 95% for all the factors. Factors with P-value less than 0.05 are considered to be significant. The table 7 and 8 shows the values obtained for ANOVA test. It is clear from the table that all the inferences made from the figures 5.3 are statistically true.

Table 7 ANOVA table for tensile

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Temperature	1	6.84	55.5%	6.84	6.84	9.81	0.197
Stir time	1	9.52	35.5%	9.52	9.52	13.65	0.168
Error	1	0.70	8.8%	0.70	0.70		
Total	3	17.05	100%				

Table 8 ANOVA table for hardness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Temperature	1	16.4	74.52%	16.4	16.4	0.15	0.765
Stir time	1	2.4	15.67%	2.4	2.4	0.02	0.907
Error	1	109.7	9.81%	109.7	109.7		
Total	3	128.4	100%				

Based on the analysis of these experimental results with the help of signal to noise ratio, the optimum condition resulting in tensile test are shown. The figure clearly indicate that the third level of stir casting, melting temperature and stirring time.

E. Confirmation Experiments

For commercial utilization, samples were prepared by optimum parametric setting. The values of tensile and hardness and the corrosion rate shows in tables

Table 8 Optimized values for tensile test

Sample NO	Stir speed	Melting temperature	Stir time	Tensile test
	RPM	˚C	Mins	N/mm^2
4	250	650	10	142.38

Table 9 Optimized values for hardness test

Sample NO	Stir speed	Melting temperature	Stir time	Hardness test
	RPM	˚C	Min	HV
4	250	750	10	100.7

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Table 10 Optimized values for correstion test

Sample NO	Stir speed	Temperature	Stir time	Corrosion rate
	RPM	° c	min	Mpy
4	650	650	5	2.33

V. SUMMARY AND CONCLUSION

The hybrid composite samples of Al 6063 as matrix, ZrO_2 and charcoal particulates as reinforcements were produced using stir casting process. Based on the synthesis and results of the mechanical property tests such as tensile strength, hardness and corrosion rate the following conclusion may drawn

Composite having 6% ZrO_2 ,1% charcoal, stir time 10 mins and 93% Al 6063 combination, fabricated at melting temperature 650°C and reinforcement pre-heat temperature 500°C has higher tensile strength (142.38N/mm^2), hardness (101 HV) and better corrosion resistance (2.330mpy) compared to Al 6063 and other combinations.

This hybrid composite can be explored for use in applications where higher strength and corrosion resistance is required.

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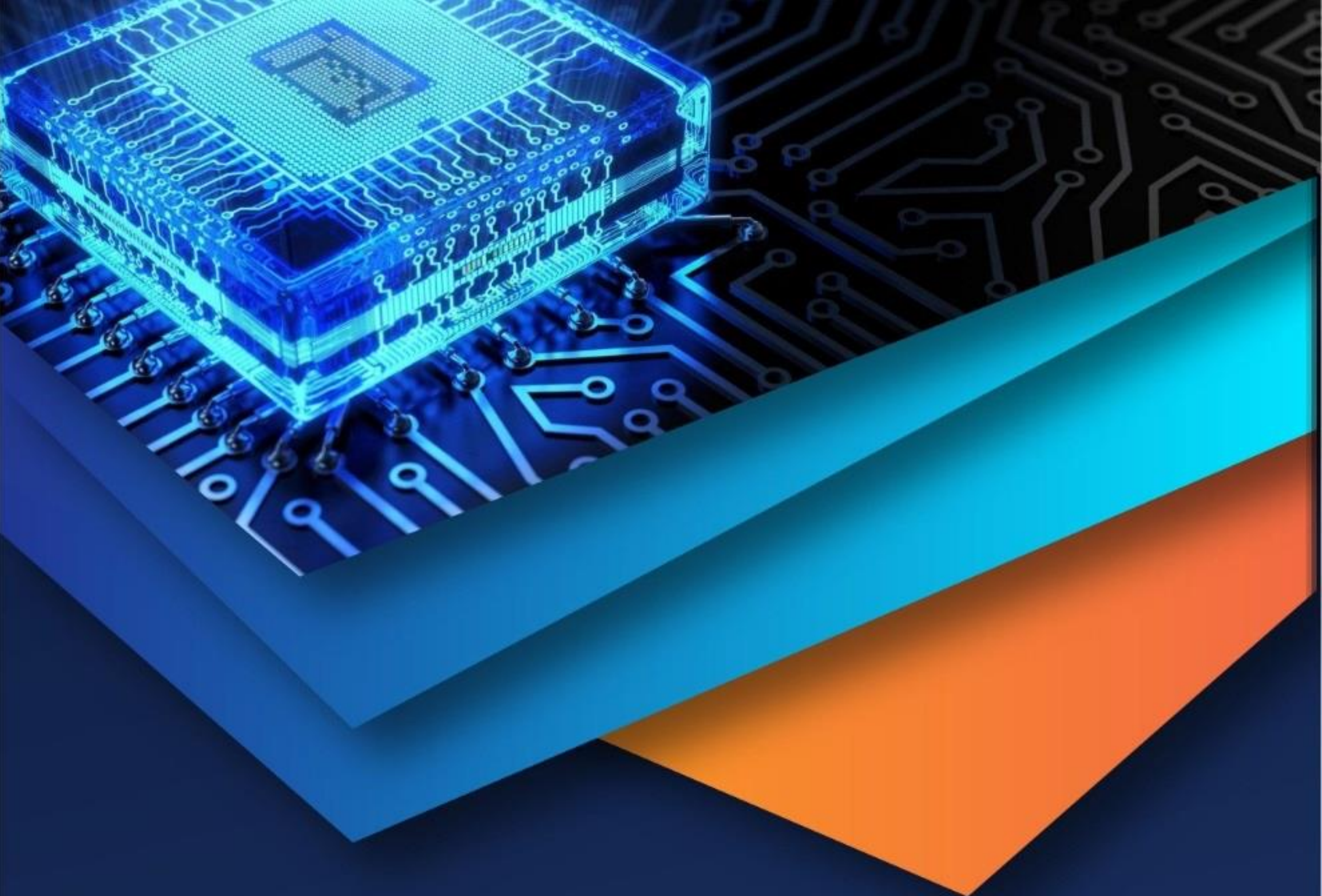

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