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Determination of Process Parameters and Development of Al-GNPS Composites

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Abstract: Composites play very crucial role in replacing traditional materials due to their excellent mechanical properties combined with lesser weight attributable to composites. The present exploration deals with microstructural and mechanical properties of Pure Aluminum Graphene Nano platelets (GNP's) composites. The contents of GNP's varied from 0.5 to 2.0 wt. % in pure aluminium matrix. Using stir casting technique, the fabrication has been done by varying process parmeters such as stir speed and furnace temperatures. The speeds were varied from750-680 rpm and the furnace temperature ranging from 720^{o}c-660^{o}c .Mechanical properties such as Tensile strength, Impact Strength and micro hardness have been conducted as per ASTM E8 standard, SEM analysis was conducted to ascertain even distribution of graphene nano particles in the base matrix of pure aluminum and SEM, analysis revealed that there is a uniform distribution of GNPs in the pure aluminium matrix. Taguchi's response analysis and Analysis of Variance (ANOVA) have been employed to analyze the significance of process variables.
Keywords: Pure Aluminium– GNPs Composites; Stir Casting; Tensile Strength; Hardness; Taguchi Analysis: ANOVA.

I. INTRODUCTION

Use of metal matrix composites was increased day by day because of their characteristics of behavior with their high strength to weight ratio. Industries like automobile, sports, aerospace, construction, marine etc., utilizes the benefits of composites especially aluminium metal matrix composites. Due to its unique mechanical properties Graphene, only a single layer of carbon atoms hybridized sp2, has grabbed a great deal of attention to research [1-3]. Rashad et.al. [4], has demonstrated that the liquid state, the mixture of aluminium powder in the GNP has been effective in the manufacture of composites Al/GNP. One Author [5] has established that powder metallurgy, mixture of pure aluminium with graphene with 0.25 % results in improved tensile strength, hardness and corrosion resistance. There is no much literature associated with influence of the GNP on the mechanical properties of the Composites using stir casting technique. J.Habeeb Ghazi et .al,[6] prepared Al-Mg composites at fixed temperature of 750^{0}C, by maintaining 900rpm to improve homogeneity in molten material, resulted in enhanced mechanical properties with increased addition of reinforcements in the composites up to 20 percentage by weight. Alaneme et.al, [7] developed Al6063 with Borax mixed with silicon carbide composites at 750^{0}C. By operating the stir casting setup at 725^{0}C,with stir speed of 600rpm to 20 minutes for vortex formation and the reinforcements were preheated at 250^{0}C, Umanath et al. [8] developed Al6061-Silicon carbide and aluminium oxide composites. Bharath et.al [9] manufactured Al6061-Al_2O_3 composites at 800^{0}C, by maintaining stirrer at a speed 200 rpm for vortex, and preheating the reinforcements at 200^{0}C in an oven to remove gases and temperature drop when added in to molten metal, which results increased mechanical properties by decreasing ductility. In this work, Al matrix has been strengthened with 0.50, 1.0, 1.5, and 2.0% in weight Percentage using stir casting route. The mechanical properties such as tensile, impact strength and micro hardness of composites have been studied. The experimental results showed that the mechanical properties of fabricated composites have improved by the addition GNPs in the base matrix.

II. MATERIALS AND METHODS

A. Graphene Nano Platelets (GNPs)

Graphene is an allotrope of carbon in the structure of a plane of sp^{2} bonded atoms with a molecule bond length of 0.142 nanometers. Layers of Graphene stacked on top of each other form graphite, with an inter planar spacing of 0.335 nanometers. The following are the important properties of Graphene. Tensile strength: 5 GPA Electrical conductivity: 80000 S/m, Water content: < 0.5 wt. %, Carbon Content: > 99.5 %.True Density: 2.3 g/cc, Bulk Density: 0.10 g/ml, Specific surface area: 20-40 meter square / g.

As it was shown in Fig.1. It consist of platelets with the morphology of uneven shaped flakes with mean diameter of 5µm. The thickness of the Graphene is several nanometers ranging from 2-10nm.

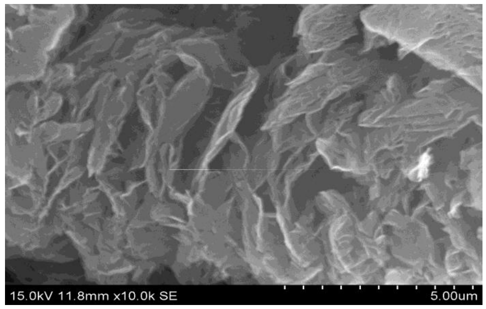

Fig.1. SEM image of Graphene

B. Fabrication of Al-GNPs Composites

Stir casting can be regarded as a popular process for manufacturing Aluminium metal matrix composites for research applications due to cost effectiveness. The process is usually carried out in a stir casting furnace with the matrix and reinforcements added to the furnace and then stirred continuously. The matrix material used for the present study is pure aluminium. Graphene nanoparticles with size of 30nm and with varying amounts of 0.5 wt. %, 1.0 wt. %, 1.5 wt. %, and 2.0 wt. % are used as reinforcing material in the preparation of composites. The stir casting with preheating furnace was shown in the Fig.2.

Fig.2. Preheating Furnace

Graphene Nano Particles are preheated at 250^{0}C to remove moisture, to avoid thermal mismatch and for proper dispersion in to the base matrix. The Stirring speed varying from 750 -680 rpm and furnace temperature ranging from 720-660 ^{0}c was maintained throughout work to prepare composites with different reinforcement combinations. The four blade Stirrer was designed in order to produce the adequate homogenous particle distribution throughout the matrix material. Stirring of the mixture is carried out for holding time 30 minutes to achieve homogeneity of particulates. The stainless steel stirrer blade was coated with zirconia to avoid the reaction between stainless steel and Al alloys at higher temperatures. Later the moulds which are preheated at 450^{0}C used for preparing casting. Radiography analysis exposes the fact that the prepared castings are free from pores, and voids.

C. Sem Analysis

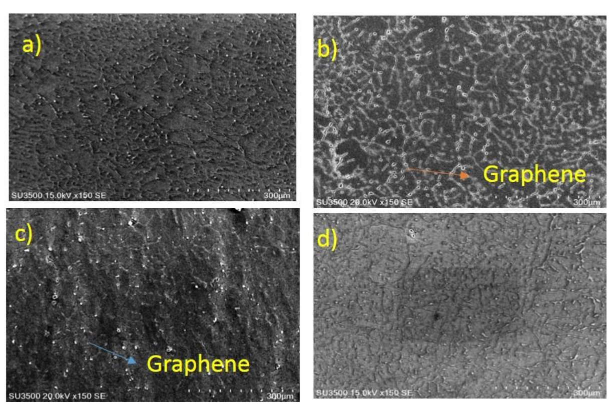

Fig. 3. SEM images of Al-GNP composites (a) Pure Al with 0.5 wt. % of GNP, (b) Pure Al with 1.0 wt. % of GNP, (c) Pure Al with 1.5 wt.% of GNP,

(d) Pure Al with 2.0 wt.% of GNPs

SEM analysis has been carried out for all samples as it was shown from Fig.3.a to 3.d show the microstructures of fabricated Pure Aluminium composites reinforced with Graphene Nanoparticles with varying weight Percentages ranging from 0.5 wt% to 2.0 wt%. In the microstructure clearly shown that the Graphene is dispersed uniformly in the matrix material. Graphene is irregularly in shape like lamellae phase. As the microstructure contains good amount of eutectic phases it should give a good range of mechanical properties with mechanical stirring during processing of stir casting process and Graphene weight fractions. Then the prepared sample is further utilized for assessing the mechanical properties such as tensile strength, micro hardness and impact strength. The results are depicted in Table 1.

Table.1: The Results of Tensile Test, Hardness and

S.no	GNPs (Wt. %)	Stir Speed	Furnace Temp	Tensile Strength (MPa)	Hardness	IS
1	0.5	750	720	94	128	92
2	1.0	750	700	84	116	87
3	1.5	750	680	74	89	82
4	2.0	750	660	66	83	78
5	0.5	720	720	92	124	92
6	1.0	720	700	83	114	85
7	1.5	720	680	72	87	80
8	2.0	720	660	64	82	75
9	0.5	700	720	90	124	92
10	1.0	700	700	81	112	85
11	1.5	700	680	70	87	80
12	2.0	700	660	62	82	75
13	0.5	680	720	84	120	88
14	1.0	680	700	80	107	86
15	1.5	680	680	70	87	81
16	2.0	680	660	61	80	69

D. Assessment Of Mechanical Properties

1) *Assessment of Tensile Test:* In tensile test the load is applied along only one axis, and the rate of loading is constant. This test is done on a Computerized Universal Testing Machine which is hydraulically powered. The specimen is 'I' shaped with Gauge length of 40 mm. Generally the tensile testing specimen has two main parts, the gauge section and the ends. The specimen dimensions are kept as per ASTM E8 standards shown in Fig.4a.&Fig.4.b.The specimens are fixed into the machine and load is applied at a constant rate. After the specimen is broken, the final width, final thickness, final gage length and final area values will be generated by the computer. The primary data generated are load (Kg) vs. displacement (mm) which is to be converted into stress (N/mm2) vs. strain data.

(a)

(b)

Fig.4. (a).Tensile Specimen (b).Tensile Specimen in CUTM

E. Influence of process parameters on Tensile Strength:

The response graph for tensile strenth is shown Fig. 5. It is conspicuous from the illustration, that the tensile strength of the prepared composite decreased with the increase of percentage GNP and it is increased with increase of stir speed and increase of furnace temperature.

Taguchi's analysis for impact strength during of Al-GNP composites are depicted in Table.2 and it is observed from the analysis that the optimum process variable for obtaining better impact strength is $A_1B_4C_2$ which means the GNP weight percentage at low level, stir speed at 680, furnace temperature at 680. GNP weight percentage is the most influencing parameter for impact strength and followed by stir speed and furnace temperature.

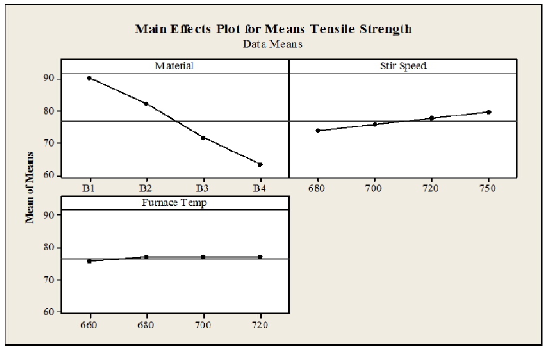

Fig. 5. Response Graph for Tensile Strength

Table 2: Response Table for Tensile Strength for Al-GNPs composites

Levels	Means			S/N Ratio		
	GNPs (Wt.%)	Stir Speed	Furnace Temp	GNPs (Wt.%)	Stir Speed	Furnace Temp
1	90	73.75	75.75	39.08	37.29	37.55
2	82	75.75	77	38.27	37.5	37.66
3	71.5	77.75	77	37.08	37.73	37.63
4	63.25	79.5	77	36.02	37.93	37.61
Delta	26.75	5.75	1.25	3.06	0.64	0.12
Rank	1	2	3	1	2	3

1) *Assessment of Micro Hardness Test:* To measure the hardness of prepared metal matrix composites, Vickers Micro hardness Tester was used. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not pressure. Dimensions of the Specimen for conducting hardness test was 55mm X 10mm X 10mm.The Vickers Micro hardness test results for all the specimens are shown in the Table.1.

F. Influence of process parameters on Micro Hardness:

The response graph for micro hardness is shown Fig.6. It is conspicuous from the illustration, that the micro hardness of the prepared composite decreased with the increase of percentage GNP and it is increased with increase of stir speed and increase of furnace temperature.

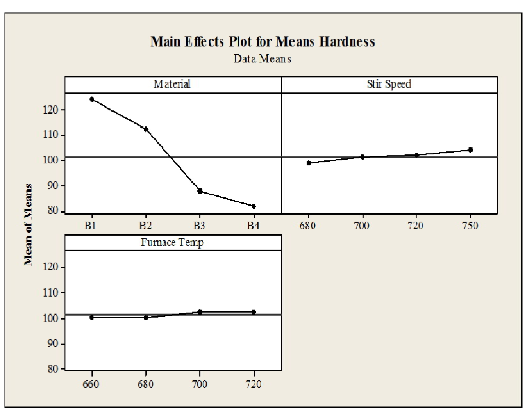

Fig. 6. Response Graph for Hardness

Taguchi's analysis for micro hardness during of Al-GNP composites are depicted in Table.3 and it is observed from the analysis that the optimum process variable for obtaining better impact strength is $A_1B_4C_2$ which means the GNP weight percentage at low level, stir speed at 680, furnace temperature at 680. GNP weight percentage is the most influencing parameter for impact strength and followed by stir speed and furnace temperature.

Table 3: Response Table for micro hardness for Al-GNP composites

Levels	Means			S/N Ratio		
	GNPs (Wt. %)	Stir Speed	Furnace Temp	GNPs (Wt. %)	Stir Speed	Furnace Temp
1	124	98.5	100.5	41.87	39.76	39.93
2	112.25	101.25	100.5	41	39.98	39.93
3	87.5	101.75	102.25	38.84	40.02	40.06
4	81.75	104	102.25	38.25	40.2	40.03
Delta	42.25	5.5	1.75	3.62	0.44	0.13
Rank	1	2	3	1	2	3

1) *Assessment of Impact Test:* Impact tests are designed to measure the resistance to failure of a material to a suddenly applied force. The test measures the impact energy, or the energy absorbed prior to fracture. The Charpy test involves striking a suitable test piece with a striker, mounted at the end of a pendulum. The test piece is fixed in place at both ends and the striker impacts the test piece immediately behind a notch. As per ASTM standard the specimen size for Charpy impact testing is 10 mm x 10mm x 55mm.

G. *Influence of process parameters on Impact Strength:*

The response graph for impact strength is shown Fig.7. It is conspicuous from the illustration, that the impact strength of the prepared composite decreased with the increase of percentage GNP and it is increased with increase of stir speed and increased first then it decreased for higher level of furnace temperature.

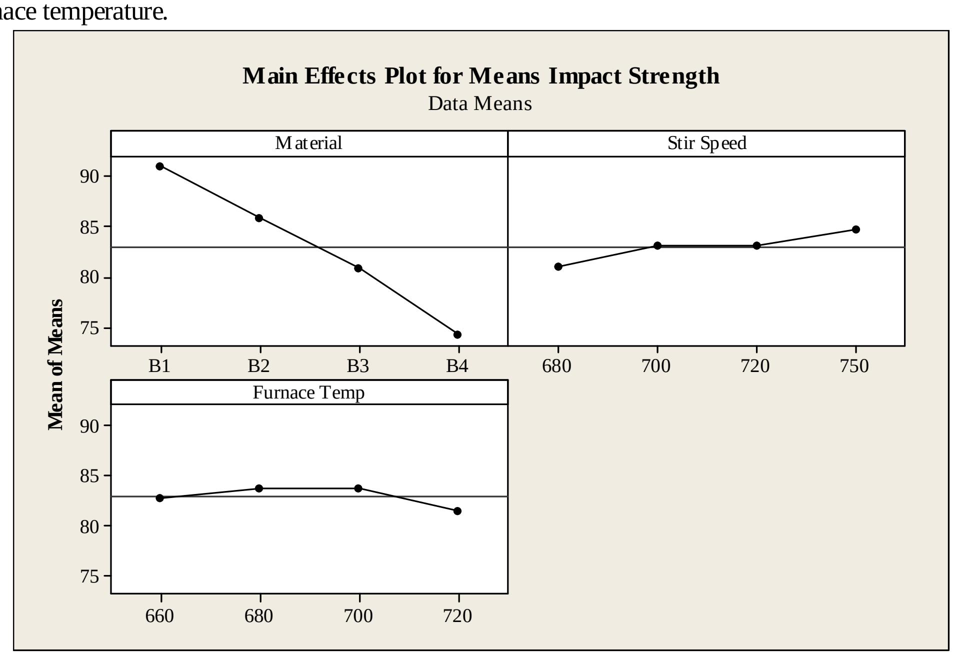

Fig .7. Response Graph for Impact Strength

Taguchi's analysis for micro hardness during of Al-GNP composites are depicted in Table.4 and it is observed from the analysis that the optimum process variable for obtaining better impact strength is $A_1B_4C_2$ which means the GNP weight percentage at low level, stir speed at 680, furnace temperature at 680. GNP weight percentage is the most influencing parameter for impact strength and followed by stir speed and furnace temperature.

Table 4: Response Table for Impact Strength for Al-GNP composites

Levels	Means			S/N Ratio		
	GNPs (Wt. %)	Stir Speed	Furnace Temp	GNPs (Wt. %)	Stir Speed	Furnace Temp
1	91	81	82.75	39.18	38.13	38.35
2	85.75	83	83.75	38.66	38.36	38.44
3	80.75	83	83.75	38.14	38.36	38.43
4	74.25	84.75	81.5	37.41	38.55	38.18
Delta	16.75	3.75	2.25	1.77	0.41	0.26
Rank	1	2	3	1	2	3

H. Analysis of Variance for Performance Measures

Analysis of variance (ANOVA) is a statistical analysis tool used to determine the significance of process parameters on the performance measures at 95% confidence level and it is computed using statistical software Minitab 16.0, and the results were shown in Table.5

Table 5: Analysis of Variance for fabrication of Al-GNP Composites

Analysis of variance – Inconel 625							
Source	DF	Seq SS	Adj SS	Adj MS	F	P	% C
Tensile Strength (MPa)							
Material	3	1651.69	1651.69	550.56	256.57	0	94.74
Stir Speed	3	74.19	74.19	24.73	11.52	0.007	4.26
Furnace Temp	3	4.69	4.69	1.56	0.73	0.572	0.27
Error	6	12.88	12.88	2.15	---	---	0.74
Total	15	1743.44	---	---	---	---	100.00
Micro hardness(HN)							
Material	3	4831.25	4831.25	1610.42	878.41	0	98.28
Stir Speed	3	61.25	61.25	20.42	11.14	0.007	1.25
Furnace Temp	3	12.25	12.25	4.08	2.23	0.186	0.25
Error	6	11	11	1.83	---	---	0.22
Total	15	4915.75	---	---	---	---	100.00
Impact Strength							
Material	3	612.688	612.688	204.229	66.69	0	94.43
Stir Speed	3	28.187	28.187	9.396	3.07	0.113	3.00
Furnace Temp	3	13.687	13.687	4.562	1.49	0.31	0.43
Error	6	18.375	18.375	3.062	---	---	2.14
Total	15	672.938	---	---	---	---	100.00

III. CONCLUSION

Aluminium metal matrix composites reinforced with Graphene were successfully fabricated by Stir casting technique and material characterization was carried out successfully. Microstructure analysis confirmed that homogenous dispersion of reinforcement particles in the aluminium matrix.

1) Defect free aluminium metal matrix reinforced with Graphene was produced by stir casting method. No porosity noticed in the prepared samples.
2) The influence of process parameters were determined by Taguchi's response analysis. The varying composition of material is the significance process variable for development of desired composite material.
3) ANOVA analysis determines the significance of the process variables and it is observed from the analysis GNP percentage is the predominant variable and then it is followed by stir speed, furnace temperature.
4) It is observed from the analysis the desired mechanical properties of the developed materials were decreased by increasing the percentage composition of graphene.

Finally there is an immense potential, scope and opportunities for the researchers, in the field of prediction of mechanical and tribological properties of Aluminium matrix composites by using aluminium casting methods, soft computing techniques, and process parameters.

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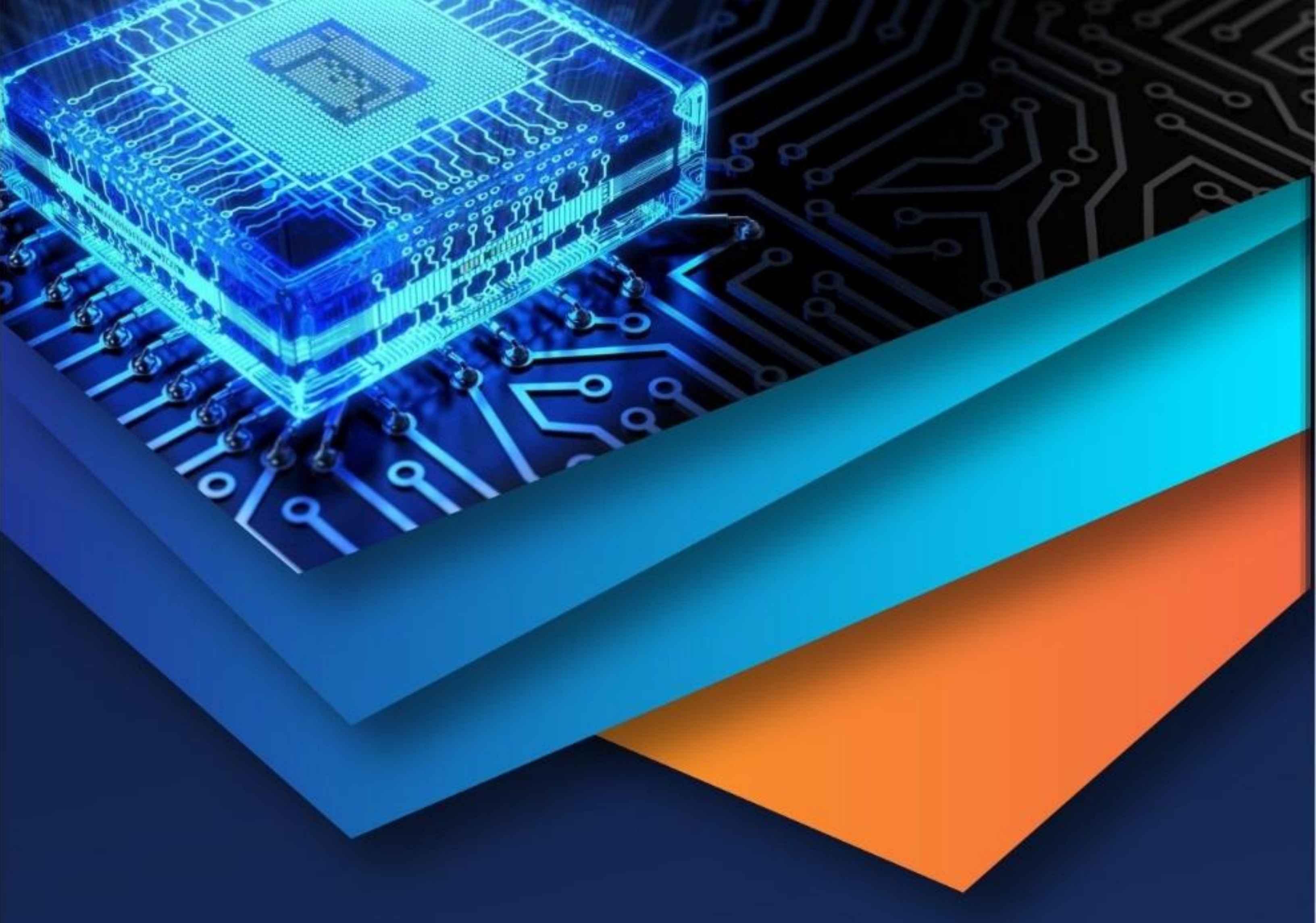

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