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Evaluation of Mechanical Properties of Aluminum-Silicon Carbide Metal Matrix Composite

Anjali Vardai[1], Giridhar Agadi[2], Abhay Devamore[3], Bhimappa Hanji[4], Karthik Ramdurg[5]
[1, 2, 3, 4]*Student of Mechanical Engineering Department At Jain College of Engineering and Research, Visvesvaraya Technological University*
[5]*Assistant Professor of Mechanical Engineering Department At Jain College of Engineering and Research, Visvesvaraya Technological University*

Abstract: ***A composite is a fusion of two or more different material chemically and unsolvable phases, its properties and structural concert are greater the ingredients performing homogeneous phases. Ceramics and Metals as well, can be implanted with particles, to advances their Property of these mixtures are known as MMCs. The mutual reinforcement's effect on Aluminium Metal Matrix material with individual and multiple particulate reinforcements like Hybrid Metal matrix composites are finding better applications in field such as aerospace, marine, automotive, structural, underwater, and transportation and various other fields. It s fairly observed that the density of composite was decreased and the hardness was increased. Due to its versatile properties it is preferred for fabricating different types of metal matrix composites. Metal matrix composites exhibit better and improved strength, toughness, formability, corrosion resistance, machinability, stiffness, wear, creep, fatigue and numerous other mechanical properties as compared to metals The present investigation has been focused on the different combinations of the usage of reinforced materials as a reinforcing agent in different Aluminium matrix alloys in the processing of aluminium metal matrix composites by stir casting method.***
Keywords: AMMC's, Silicon Carbide, Stir casting, Reinforcement, Mechanical and Wear properties.

I. INTRODUCTION

A composite material is a combination of two or more chemically distinct materials to form a stronger material. The term "composite" broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix), and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents, and from the properties of the boundaries (interfaces) between different constituents. Composites are a blend of materials with different composition. These materials even possess their identities in their composite, i.e. it does not fuse or conjugate completely into each other. They are gaining significant acceptance because of higher specific strength, specific modulus and good wear resistance as compared to ordinary reinforced alloys. Reinforcing particle used in this evaluation is silicon carbide is added externally. There are different types of composites based on their matrix constituents, they are

1) Metal Matrix Composite (MMCs)
2) Ceramic Matrix Composite (CMCs)
3) Polymer Matrix Composite (PMCs)

The various reinforcements used are Silicon Carbide, Aluminium Oxide, Titanium carbide, Boron Carbide, SiC reinforcement increases the tensile strength, hardness, density and wear resistance of Al and its alloys. Metal matrix composites consisting of discontinuous fibers or else continuous fibers in a molten metal get mixture of specific modulus and very high strength. From the last few decades in much industrial application concentrate on MMCs due to their specific properties like ratio of strength to weight and also cost effectiveness. The applications of MMCs are rapidly increasing in various sectors due to its improved properties when compared to monolithic metals.

Aluminium alloy is used as matrix material for the fabrication of Al-SiC as hybrid composite material. Ultrasonic assisted casting comes under the liquid state process. Powder blending followed by consolidation (PM processing), high energy ball milling, friction Stir Process, diffusion bonding and vapour deposition technique comes under Solid state process. Powder metallurgy, spray deposition, liquid metal infiltration, Squeeze casting, Stir casting. Hence stir casting method is used in this study. Most of the studies on casting analyze the mechanical properties like hardness, tensile, wear and similar other properties and evaluate the microstructure of the resulting specimens. Whereas Finite Element Analysis (FEA), Response Surface Methodology (RSM) and Artificial Neural Networking (ANN) methods are used for analyzing the performance of welded specimens.

A. Effect of SiC on AMC

1) Rajesh Kumar Bhushan used stir casting method and provided 5, 10 and 15 wt% SiC with size of the particle from 10 to 40 µm to AA 7075 to produce AMC. Scanning electron microscopy (SEM) and energy – dispersive X-ray analysis (EDAX) tests were conducted for examining the samples and studied the interaction and distribution of SiC particles with of matrix. Hardness of samples increased with increasing SiC reinforcement from 5% to 15%. Composite sample with 10% SiC exhibited maximum tensile properties.

2) Abhijit et al evaluated wear behavior of Al7075 composite reinforced with SiC particles. 20 µm grain sized SiC particles at 0, 3, 6 and 9% are used for fabricating components by stir casting route. Uniform particulate mixing was observed using X-Ray Diffraction method. Wear tests were performed on all samples with a constant load of 30 N, stable sliding distance of 2000 m and varying sliding velocity as1, 2, 3 and 4 m/s. Friction between disc and pin resulted in decrease in COF and increase in wear rate. Minimum material removal was achieved in worn out surface Al7075 composite pin having 9% of SiC.

3) Anshuman et al used ultrasonic stir casting method for fabricating Al-SiC composites with 0, 3, 5, 8 and 10 weight % of SiC particles. Probe was used for 5 minutes in order to disperse the reinforcement properly in the melt. Tensile, compressive, hardness and density tests were conducted. All the properties were found to be increasing with increasing wt% of SiC.

II. OBJECTIVES

The objectives of the end were developing good metal matrix composite properties. The factors to include in the investigation should be the ones thought relevant to the objective of producing good metal matrix composite. To investigate the strength of composite material on percentage variation of reinforcement in aluminium MMC's. To determine the strength characteristics like compressive, hardness, wear and impact strength of composite material.

III. MATERIALS

1) *Materials:* The matrix material used in the present evaluation is pure aluminium. Aluminium is purchased from shrinivas metal works, industrial estate, hubbali, Karnataka, India. Silicon carbide in the powdered form is commercially available.

2) *Matrix Material:* Matrix is the base material in the composite. Among the various matrix materials available, aluminium and its alloys are widely used in the production of metal matrix composites. Reinforcement of aluminium alloy is hard and soft reinforcements such as SiC, MgO_2, graphite, Si-rice husk etc. Generally, Aluminium 6061 alloy, Aluminium 356 alloys, Aluminium 6063 alloy are used. Al-2024 alloy is the basic material and is taken as matrix material.

Table.1- Composition of Al-**2024** alloy material

Materials	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	others	remainder	Al
Wt %	0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	0.05	0.15	remainder

3) *Reinforcement Selection:* Many materials can be used as reinforcements with Aluminum alloys which provide strength, hardness, very high resistance to crack propagation, high fracture toughness to the design structure. In this evaluation Silicon Carbide (SiC) in powdered form is taken as the reinforcement for AMMC.

Fig.1- Silicon Carbide (SiC)

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IV. METHODOLOGY

A. *Materials Selection and Experimental Procedure*

The material selection criteria involves the requirement of high strength and good corrosion resistance aluminum alloys for the matrix materials, and the inexpensive reinforcement particles which can result in increased yield strength and elastic modulus at little expense of ductility.

The matrix alloys and composites were prepared by stir casting process.

1) *Stir Casting Process:* Stir casting is a liquid state method for composite materials fabrication, in which a dispersed phase (SiC particles) is mixed with a molten matrix metal by means of mechanical stirring (Figure 2). The liquid composite material is then cast by conventional die casting method.

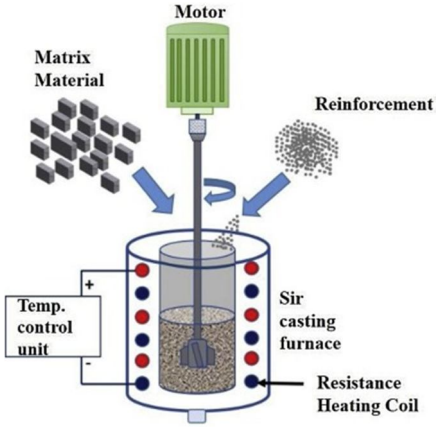


Fig. 2- Stir Casting Process

- The Stir casting method (also called liquid state method) is used for the hybrid composite materials fabrication, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods. The Aluminium-SiC, metal matrix hybrid composite is prepared by stir casting. For this we have chosen 100gm of Aluminum 2024-alloy and desired amount (0%,5%,10%) of SiC in powder form.
- Segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes is one of the major concerns associated with the stir casting process. The distribution of the particles in the final solid depends on strength of mixing, wetting condition of the particles with the melt, rate of solidification and relative density. Geometry of the mechanical stirrer, position of stirrer in the melt, melt temperature, and the properties of the particles added determines the distribution of particles in molten matrix.
- The melt temperature is raised up to 720°C and then the melt is stirred with the help of a mild steel turbine stirrer. The stirring is maintained between 5 to 7 min at an impeller speed of 200 rpm, to increase the wet ability. The melt temperature is maintained 700°C during addition of SiC. The melt is poured into the preheated permanent metallic mold. The pouring temperature is maintained at 680°C. The melt is then allowed to solidify in the mould. The metal matrix hybrid composites are obtained.
- The recent development in the stir casting process is the double stir casting process or two step process. In this process, initially the metal matrix composite is heated to above its liquid temperature and then cooled then cooled down to a temperature between the liquid and solid points to a semi-solid state. The reinforcement material which is preheated is then added and mixed to the semi-solid state matrix material. Again the slurry is heated to a fully liquid state and mixed thoroughly.

2) *Selection the Quality Characteristics:* The selection of quality characteristics to measure as experimental output greatly influences the number of tests that will have to be done to be statistically meaningful. The quality characters, which were selected to influence the mechanical properties of the metal matrix composites, are: yield strength, ultimate tensile strength and tensile ductility (%elongation), hardness and bending force.

3) *Selection of Process Parameters:* This is the important phase of investigation. If important parameters unknowingly left out of the experiment, then the information gained from the experiment will not be in a positive sense. The parameters which influence the performance of the metal matrix composites.

4) Conduction of Tests

The following tests were conducted on the metal matrix composites:

- Compression test for strength and % area reduction
- Rockwell hardness test
- Izod impact test
- Wear test

V. TEST SPECIMENS

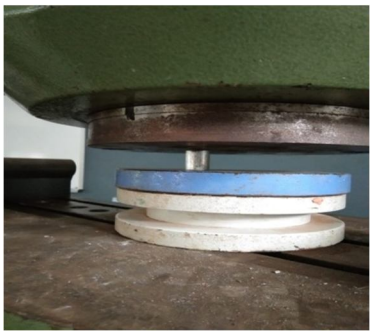


Fig. 3- Specimens for compression test

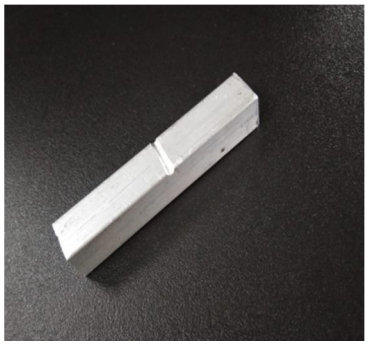


Fig. 4-Specimen for Izod impact test

Fig. 5- Specimens for hardness test

Fig. 6- Specimen for wear test

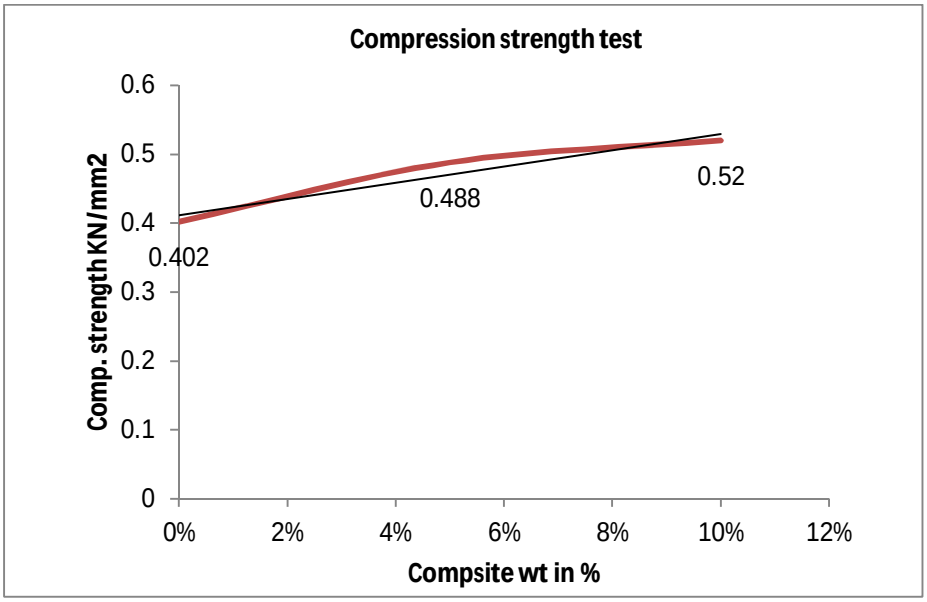
VI. RESULTS

1) *Compression Test:* Compression test is used to assess the mechanical behavior of the composites and matrix alloy. The composite rod were machined to get compression test specimens with a diameter of 25mm, gauge length of 25mm. Compression testing machine used for the Compressive Strength measurement. The aluminium composites which has 0%, 5%, 10 wt % SiC reinforced shows better compressive strength than aluminium composites having 5wt % SiC and pure base aluminium alloy whenever the load is applied 120KN, 150KN and 190KN respectively. The compressive strength can be calculated as follows.

$$\textbf{Compressive strength} = \frac{\textbf{Applied force } (F)}{\textbf{Area of the specimen } (A)} \quad \text{.....KN/mm}^2$$

Table. 2- Compressive strength of Al-SiC Composite

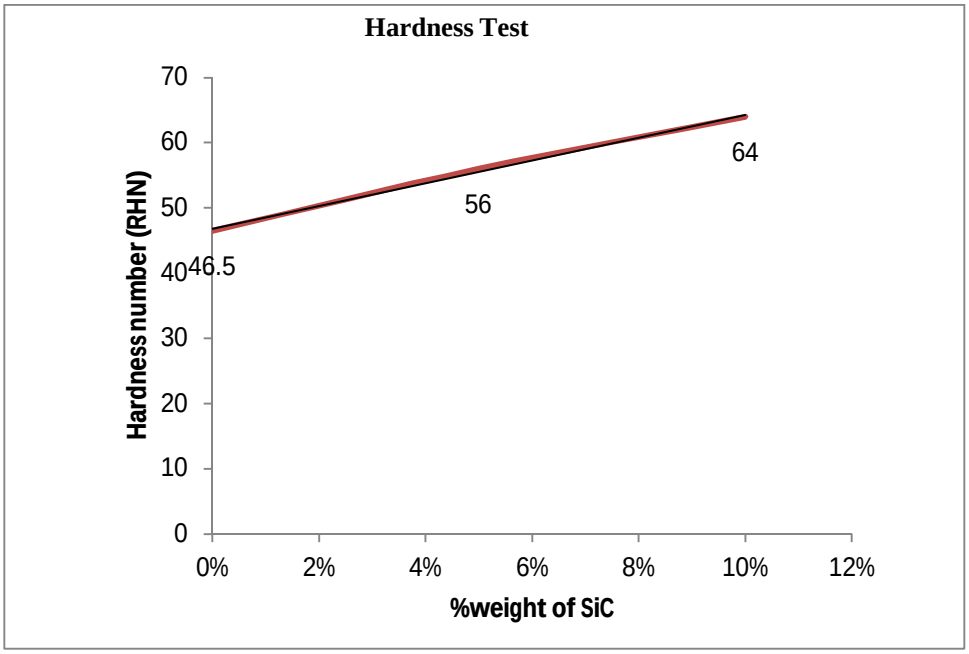
Sample no	Al (gm)	Composite wt in %	Compressive Strength(KN/mm^2)
1.	100	0%	0.402
2.	100	5%	0.488
3.	100	10%	0.52



2) Hardness Test: A Rockwell hardness tester machine is used for the hardness measurement. The surface being tested generally requires a metallographic finish and it was done with the help of 100, 220, 400, 600 and 1000 grit size emery paper. Load used on Rockwell's hardness tester was 60kg at dwell time 30 seconds for each sample. For hardness testing samples were prepared as per specification required for Rockwell hardness Test (25mm × 25mm).

Table. 3- Hardness strength test

Sample no	Al (gm)	Composite wt in %	Hardness (HRN)
1.	100	0%	46.5
2.	100	5%	56
3.	100	10%	64



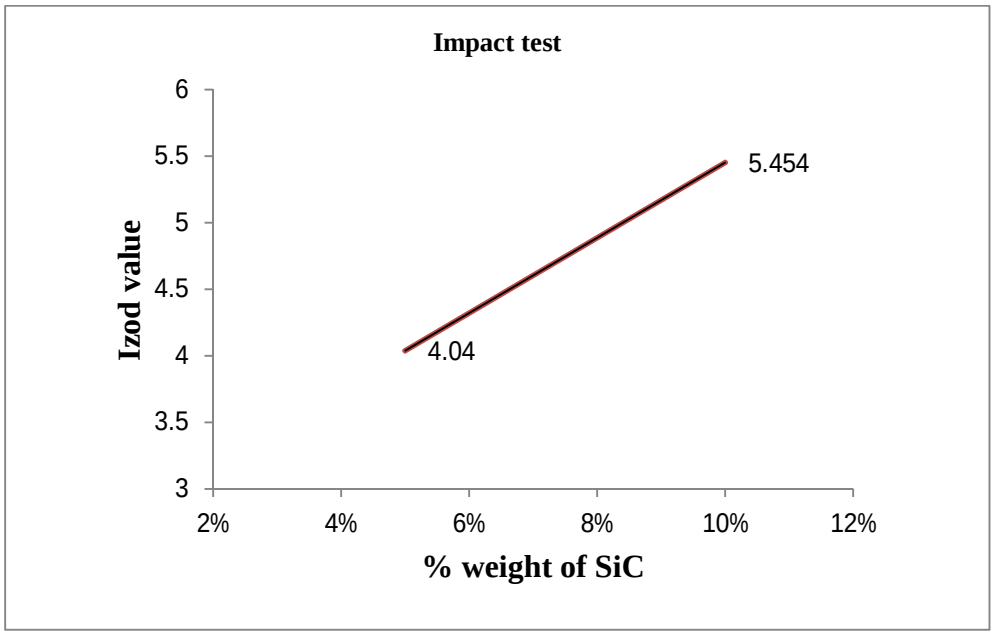
3) Impact Test: The toughness is the energy requires breaking the material. The energy is calculated in joules. The energy consumed is calculated by the difference between total energy supplied to the energy available at the end. The measure of toughness can be found with the help of Charpy and Izod impact tests. The standard specimen size for Charpy impact testing is 10mm×10mm×55mm. and for Izod impact testing 10mm×10mm×75mm.

The impact strength can be calculated as follows.

$$\textit{Impact strength } I = \frac{\textit{Actual energy absorbed } (Ea)}{\textit{Area of the specimen } (A)} \quad \ldots\ldots\ldots\ldots \text{ J/mm}^2$$

Table. 4- Izod impact testing

Sample no	Al (gm)	Composite wt in %	Impact strength (J/mm^2)
1.	100	5%	4.040×10^{-3}
2.	100	10%	5.454×10^{-3}

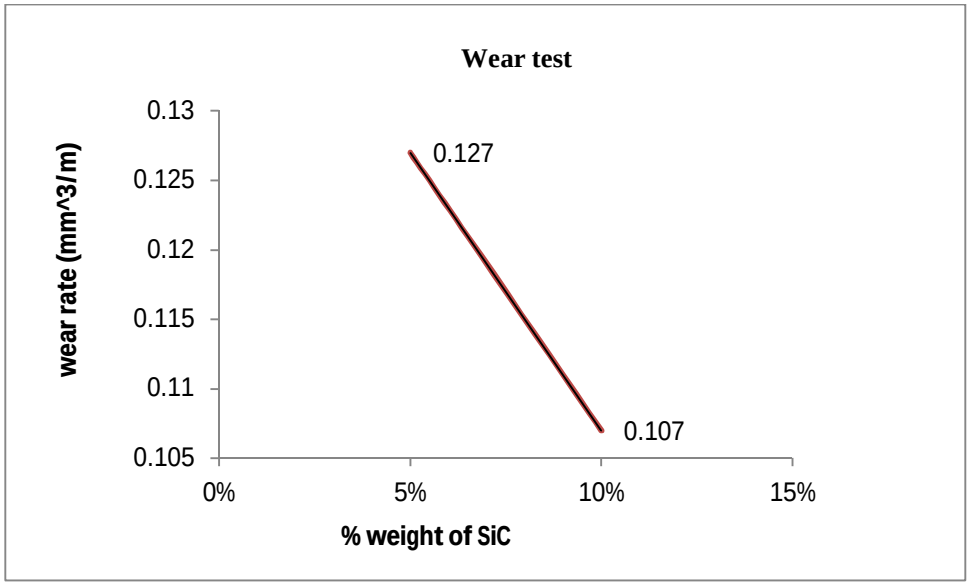


4) Wear Test: Aluminium alloys have been widely used as a matrix material and reinforced with various materials like SiC, Al2O3, TiC, alumina and Tib2 etc., in the form of particles or fibers for the fabrication of metal matrix composites. Along with this the addition of the metals like Cu, Zn and Nickel will further improve the properties because they have developed strong bonding between matrix material and reinforced material. The wear rates of hybrid composite materials are influenced by three factors: load, speed, and reinforcement.

$$Wear\ rate = \frac{wear\ volume}{wear\ velocity \times applied\ load \times time} \quad \ldots\ldots\ldots\ldots \text{ mm}^2\text{/Kg}$$

Table. 5- Wear rate of Al-SiC composites at 300rpm grinding speed.

Sample Composition	Mass Loss (g)	Density (g/mm3)	Wear Rate (mm2/Kg)
Al with 5% SiC	0.33	0.002466	0.127
Al with 10% SiC	0.28	0.0023125	0.107



VII. DISCUSSION

In the present work, the compositions (Al-100%, SiC-0%), (Al-95%, SiC-5%), (Al-90%, SiC-10%) it is fairly observed that the density of composites is decreases with the addition of wt% of reinforcement material. In compressive strength test the strength is increased by 5-6% than the pure aluminium. The aluminium composites which has 10wt % SiC reinforced composite shows better compressive strength than aluminium composites having 0,5wt % SiC. Correspondingly, the hardness of material is increased by 12-14%. In the wear test, it is observed that the material wears 1g for 300sec at a speed of 2000rpm of disc, so the material is wear resistant as compared with the pure aluminium. The wear rate improves with increase in % of SiC reinforcement. In the impact test, the impact strength is increased with increase in wt percentage of SiC

VIII. FUTURE SCOPE

The evaluation can be extended by adding of other materials with aluminium alloy. Tensile, coefficient of thermal expansion and corrosion experiments can be carried out. Microstructure analysis can be done for the measurement of particle size using Scanning electron microscopy.

Taguchi's techniques and ANOVA (analysis of variance) can be applied for the measurement of ultimate tensile strength (UTS). Matrix alloy composition contributes 9.95% of variation parameter, % volume fraction of SiC aids 50.44% of variation parameter and particle size of SiC influences 28.08% of variation in the yield strength.

IX. CONCLUSION

Based on the experimentation the following conclusions are as follows:

1) The hardness of the material is determined and found to be, the composition (90%, SiC-10%) shows the better result as compared to the 0% and 5 wt %of SiC in Al-SiC composite material.

2) Impact strength of the composites is determined by using Izod test. As we increase the amount of SiC the toughness value gradually increases.

3) The compressive strength is increases with the amount of increase in the reinforcement content, the specimen containing 10% of SiC shows good strength as compared to the 0% and 5% of SiC specimens of Al-SiC material.

4) The wear rate of composite is decreased with percentage amount of increase in the SiC. Wear rate decresed by about five times compare to that of the wear rate of commercially pure aluminium. From the above investigations, we observed that the wear rate mostly depends on applied load, sliding distance and sliding speed and the most influence parameter is sliding distance.

5) Al with 10% SiC shows great improvement in the mechanical properties such as Hardness, wear resistant. Aluminium composites are finding applications in aerospace and automobile fields and are capable of replacing the conventional materials.

From the above results we find that the composition (Al-90%, SiC-10%) exhibits good toughness, hardness, compressive strength and also having the low wear rate comparatively alloys without reinforcement.

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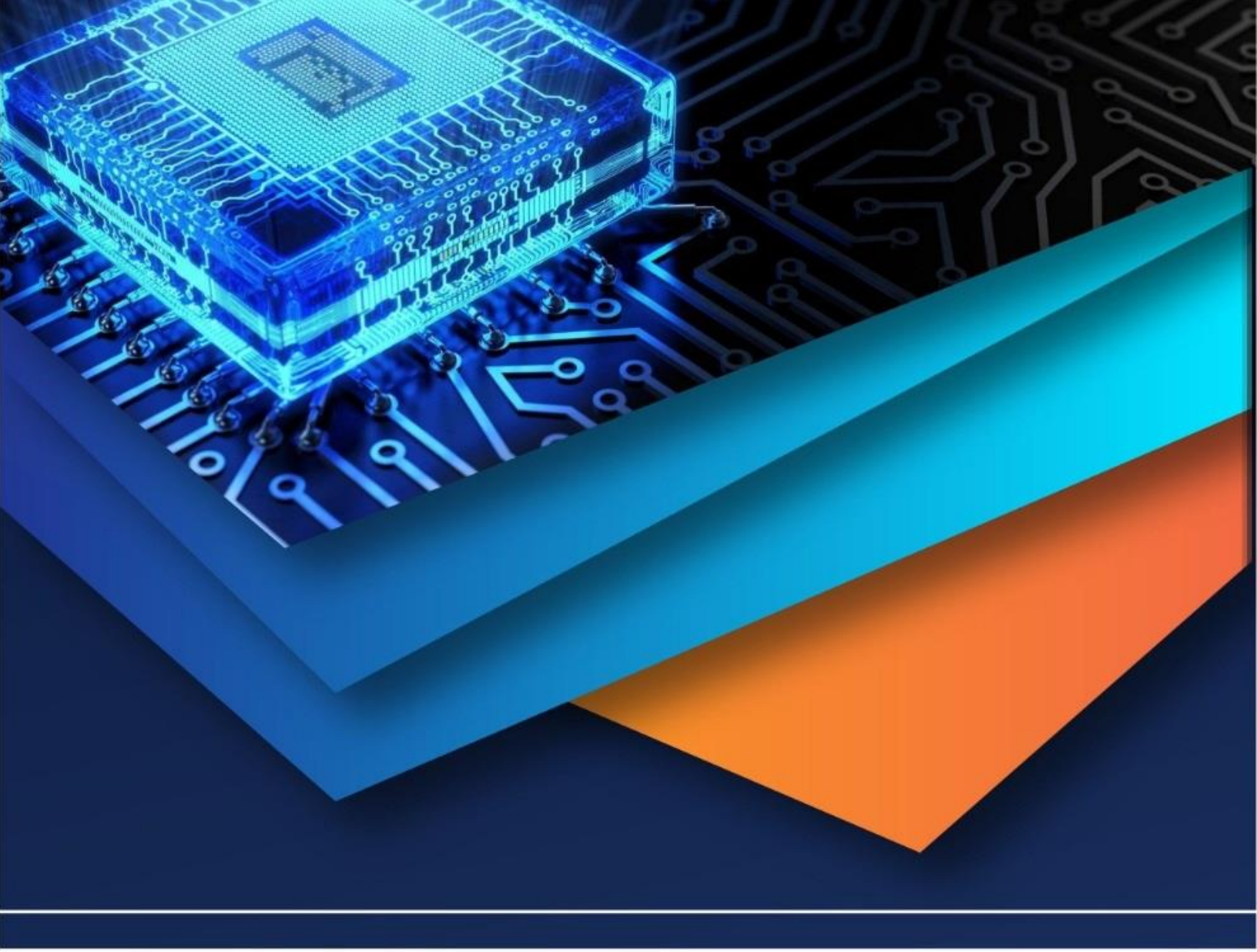

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