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# Fabrication and Study of Microstructure of Al 6061-$MnO_2$ Metal Matrix Composites

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***Abstract:** Aluminium metal matrix composites are gaining widespread acceptance for automobile, aerospace, agriculture farm machinery and many other industrial applications because of their essential properties such as high strength, low density, good wear resistance compared to any other metal. The present study deals with the addition of reinforcement $MnO_2$ particles with Al 6061 (Mg) alloy by melt stirring method. 0, 3, 6, 9 and 12 wt% of $MnO_2$ particles are added to Al 6061 (Mg) alloy to make aluminium based composite. Microstructural and composition studies like optical microscope, scanning electron microscopy (SEM) and EDAX, XRD have been investigated. A comprehensive knowledge of the properties is provided in order to have an overall study of the composites and the best results can be employed for the further development of the Aluminium reinforced composed. The investigation shows that Al 6061 metal matrix composites can be replaced with other conventional metals for better performance and longer life.*
***Keywords:** Aluminium 6061 (Al 6061), Magnesium (Mg), Manganese dioxide ($MnO_2$), Scanning electron microscopy (SEM)*

## I. INTRODUCTION

Metal matrix composites (MMC) nowadays gaining huge consideration because of their superior mechanical properties and finding applications in aerospace and automobiles [1]. In light weight MMCs a sturdy reinforcement is introduced into metal matrix to improve its mechanical properties. Presently, there are several techniques available to fabricate MMCs like casting techniques, powder metallurgy, chemical synthesis, in situ routes etc [2]. In comparison with other techniques, liquid state processing route like casting techniques have some vital advantages such as wide selection of materials, better matrix-particle bonding, easier control of matrix structures [3]. Several techniques have been employed to prepare the composites including powder metallurgy, melt techniques and squeeze casting. Stir casting route is the most promising one for synthesizing discontinuous reinforcement aluminium matrix composites because of its relative simplicity and easy adaptability with all shape casting processes used in metal casting industry [4]. Stir casting of MMCs involves producing a melt of the selected matrix material, followed by the introduction of a reinforcing material into the melt and obtaining a suitable dispersion through stirring [5]. However, due to poor wetting of the ceramic particles by molten alloy, obtaining a uniform dispersion of the reinforcement into the liquid matrix is difficult [6]. Furthermore, structural defects, such as interfacial reactions, formation of porosity and non-homogeneous particle distributions, arise from the unsatisfactory casting techniques [7].

The present study involves synthesis of cast composites by adding $MnO_2$ particles to molten alloy during stir-casting [8]. There is an effort to understand the microstructure of the composites including particle distribution and defects like porosity [9].

## II. EXPERIMENTAL DETAILS

### *A. Materials Used*

In this investigation, an alloy of Al 6061 and 3 wt% of magnesium was used as the matrix for the synthesis of particle reinforced metal matrix composites. The molten Al 6061 was alloyed with magnesium since it promotes wetting between the molten alloy and the oxide particles, in order to retain these particles inside the melt. The chemical compositions of the commercial Al 6061 and magnesium ingots, in weight percent, are shown in the Table 2.1. Manganese dioxide ($MnO_2$) of particle size between 10 μm to 120 μm was used for reinforcement

Table 2.1 Chemical Composition of Al 6061 and magnesium

| Element | Si | Fe | Cu | Mn | Mg | Zn | Al |
|---|---|---|---|---|---|---|---|
| Al 6061 | 0.62 | 0.7 | 0.22 | 0.15 | 0.84 | 0.25 | Bal |
| Magnesium | 0.006 | 0.020 | 0.016 | 0.002 | Bal | 0.002 | 0.023 |

### *B. Reinforcing Material*

In the present investigation Manganese dioxide is used as reinforcing elements. Manganese dioxide or ($MnO_2$) (Bulk Modulus = 34.4 GPa, poison ratio = 0.28, density = 4.55 g/cm$^{3,}$ molar mass = 86.93 g/mol, boiling point = 535°C) is easily available, cost effective ceramic reinforcement, having good thermal properties so that it could be used as refractory material. The strong ionic inter-atomic bonding imparts excellent dielectric properties and higher hardness, higher strength and higher stiffness.

### *C. Methodology*

In this investigation, an alloy of Al 6061 and 3 wt% of magnesium (to promotes wetting) was used as the matrix, $MnO_2$ particles (size 10 μm to 120 μm) was added as reinforcements in amounts of 3, 6, 9 and 12 wt%. Stir casting is a type of casting process in which a mechanical stirrer is introduced to form vortex to mix reinforcement in the matrix material. It is a suitable process for production of metal matrix composites due to its cost effectiveness, applicability to mass production, simplicity, almost net shaping and easier control of composite structure. Stir casting setup as shown in Fig: 2.1 consist of a furnace, reinforcement feeder and mechanical stirrer. The furnace is used to heating and melting of the materials. The melting unit consists of an electrical resistance heating vertical furnace designed for a temperature of 1200°C.

Al 6061 was used as the matrix material and it was alloyed with 3 wt% magnesium to impart wetting to the $MnO_2$ particles, added as reinforcements in amount of 3, 6, 9 and 12 wt%. About 1800 g of pure Al 6061 ingots as shown in Fig.1 were melted and superheated to a desired processing temperature in a clay-graphite crusible inside the muffle furnance. The weighted amount of powder was added into molten Al 6061 at a processing temperature of 900°C and the rate of addition of oxide particles was controlled at an approximate rate 8-10 g/min. An alumina coated stirrer was kept constant at disperse the $MnO_2$ particles in the melt. The speed of the stirrer was kept constant at 300 rpm. A magnesium lump of 3% was wrapped with aluminium foil and plunged into the melt-particle slurry after the addition of $MnO_2$ particles. A power supply unit was connected to supply voltage of 240 V.

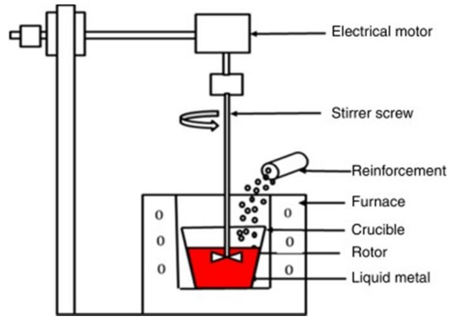


Fig.2.1: Stir casting apparatus

Table.2.2 shows the nominal composition of the composites synthesized and these composites have been designated by using the letters AM to indicate Al 6061-Mg alloy followed by a letter P indicates the percentage of $MnO_2$ powder of 3, 6, 9 and 12 wt% respectively. The composite designated as AMP3, A and M indicating base metal Al 6061 and the alloying element of Magnesium followed by P3 indicating addition of 3wt% of $MnO_2$

Table 2.2: Nominal Composition of the composites

| Designation of composites/Alloy | Al 6061 (wt%) | Magnesium (wt%) | Particle (wt%) |
|---|---|---|---|
| AM | 97 | 3 | 0 |
| AMP3 | 94 | 3 | 3 |
| AMP6 | 91 | 3 | 6 |
| AMP9 | 88 | 3 | 9 |
| AMP12 | 85 | 3 | 12 |

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## III. RESULTS AND DISCUSSION

### *A. Morphology of $MnO_2$ Particles*

The size and shape of the $MnO_2$ particles in the powder have been observed under SEM and the results are shown in Fig 3.1. The size of particles is in the range between 10 µm and 120 µm and the shape of the particles are irregular in shape. The $MnO_2$ particles in the powder have been observed under SEM (scanning electron microscope) and the result are shown in the Fig 3.2 along with the EDAX analysis.

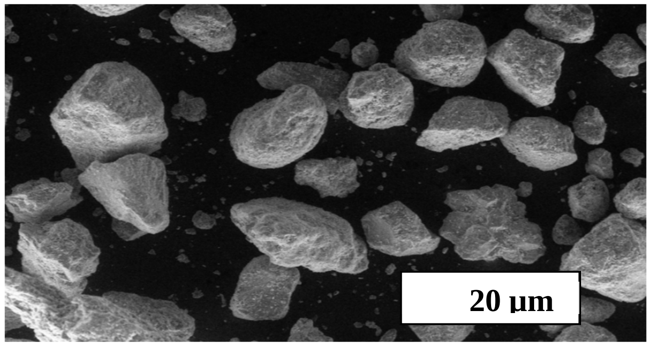
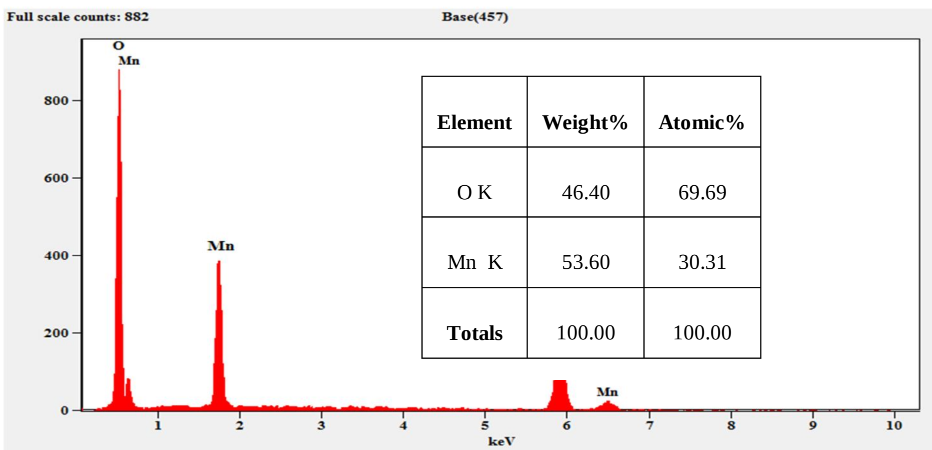



Fig 3.1: SEM micrographs showing size and shape of the $MnO_2$ powder

The powder has been examined for their X-ray diffraction (XRD) pattern using X-ray diffractometer in the two theta range of 10-80$^o$ using Cu as a target material, $K_\alpha$ radiation and nickel filter. The step size and the dwell time were suitably adjusted, which was used for identification of various phases with the help of inorganic JCPDS (Joint Committee on Powder Diffraction Standards) X-ray diffraction data card available from the International Centre for Diffraction Data as the Powder Diffraction File (PDF), which shows the $MnO_2$ particles are fairly pure. XRD pattern of $MnO_2$ particles used in the synthesis of Al 6061 (Mg) - $MnO_2$ composites is shown in Fig 3.3.




| Element | Weight% | Atomic% |
|---|---|---|
| O K | 46.40 | 69.69 |
| Mn K | 53.60 | 30.31 |
| **Totals** | 100.00 | 100.00 |

Fig.3.2: EDAX Spectrum of $MnO_2$ used in the synthesis of Al 6061(Mg) - $MnO_2$ composites

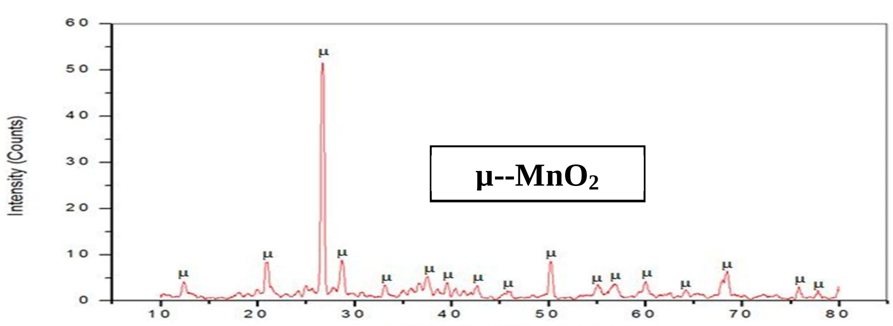



Fig.3.3: XRD pattern of Manganese dioxide particles used in casting of Al 6061 (Mg)-$MnO_2$

Samples from cast ingots of the alloy were prepared by standard metallographic procedure for metallographic examination on FESEM with EDAX model ULTRA-55, Carl-Zeiss. The SEM studies were carried out with an electron beam accelerating potential of 10 kV.

In the present investigation cast composites have been developed by addition of $MnO_2$ powder into molten aluminium. Aluminium matrix composites have been synthesized by the addition of $MnO_2$ powder into aluminium melt followed by 3 wt% addition of magnesium to promote wetting. Fabrication of metal matrix composites with $MnO_2$ particles by casting processes is usually difficult because the wettability of $MnO_2$ particles by molten matrix was poor, a uniform distribution of particles could not be observed in the composites fabricated by stir casting. In addition, other factors like stirring speed, pouring conditions, solidification rate etc had noticeable influence on the distribution of particles.

### *B. Optical Microscope*

Optical microstructure is analyed under the OLYMPUS Microscope BX51M with Clemex Image Analyser for better contrast of the images and to detect easily, firstly samples are prepared. Samples are of circular shape and grind on the different grit size emery papers. The emery papers used are of 400, 600, 800, 1000, 1200, 1500 and 2000 grit size. After grinding on the emery papers samples are polished on polishing machine with use of Alumina paste and water. Then, samples were analyzed under the optical microscope to study the microstructure and the distribution of the particles. The specimens are visualized under different magnification of 200X and 500X is as shown in Fig.3.4 and 3.5 respectively.

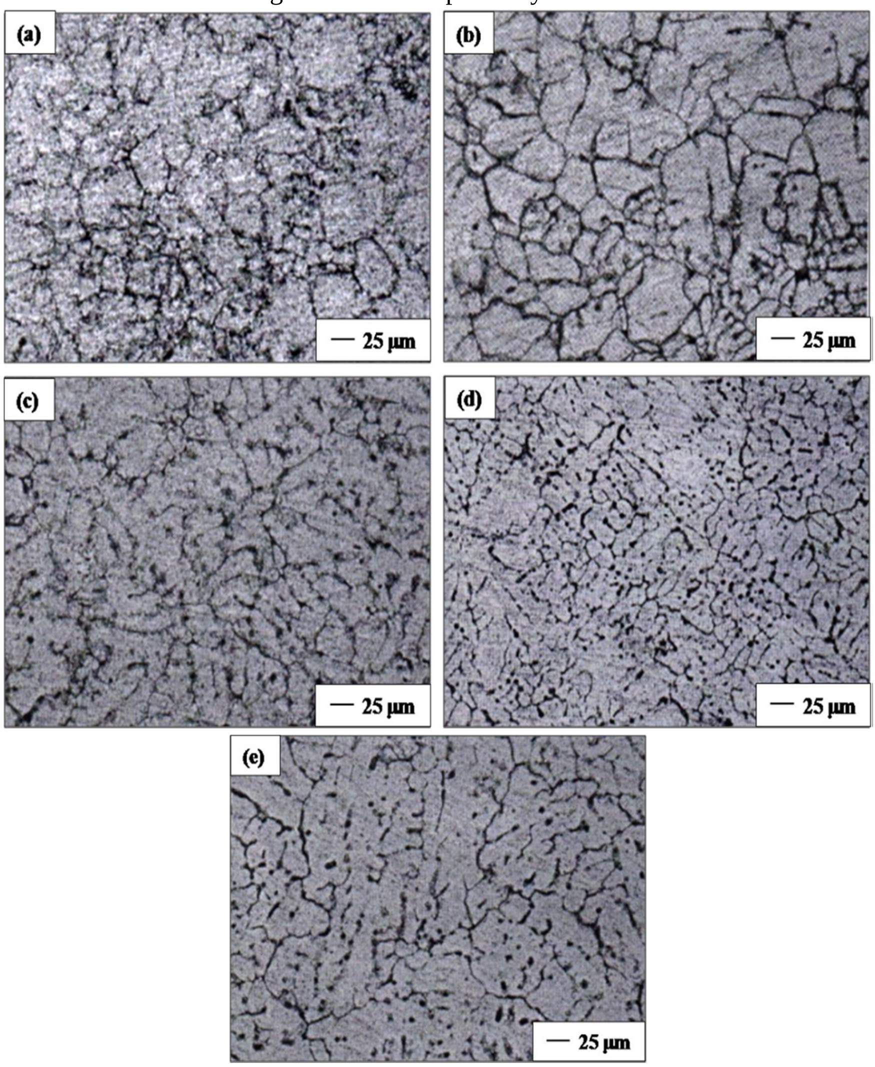



Fig.3.4: Optical micrographs of different cast composites developed by addition of 0, 3, 6, 9 and 12 wt% designated as (a) AM, (b) AMP3, (c) AMP6, (d) AMP9 and (e) AMP12 respectively at magnification of 200X

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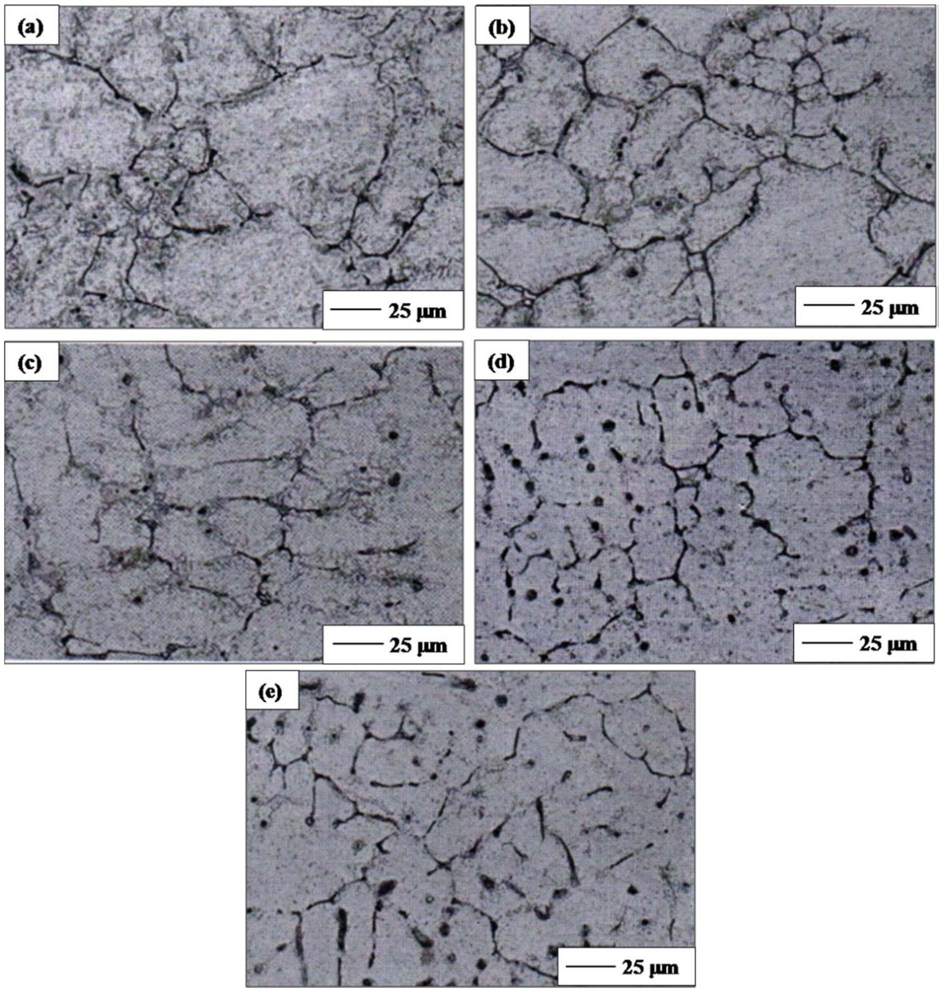


Fig.3.5: Optical micrographs of different cast composites developed by addition of 0, 3, 6, 9 and 12 wt% designated as (a) AM, (b) AMP3, (c) AMP6, (d) AMP9 and (e) AMP12 respectively at magnification of 500X

It is clear from the figure 3.5 that the black particles of the $MnO_2$ are present in the aluminium matrix alloy. From the above figures it was found that the particle size of the $MnO_2$ is very fine. Microstructure consists of fine particles dispersed in the inter dendritic region (fine dendrites) visible in the microstructure of all the composites shown in Fig 3.4 and at higher magnification shown in Fig 3.5 and fine precipitates of alloying elements in the matrix of aluminium solid solution from above figures it can be easily detected that the distribution of the particles is almost uniform.

Manganese has a strengthening effect but causes reduction in ductility. The oxide particles are inside the dendrites as well as along the boundaries as shown at lower and higher magnification in Fig 3.4 and 3.5 respectively. The amount of oxide particles increases with increasing addition of $MnO_2$ particles as observed in the microstructure. The grain size of the matrix alloy in the composite is lower than those observed in corresponding alloy as shown in Fig 3.4 and 3.5, and it is an indication that the oxide particles ($MnO_2$), which is possibly wettable due to reactive wetting, as been able to nucleate primary solid solution during solidification resulting in smaller grain size in the composites

### *C. Scanning Electron Microscopy (SEM)*

The schemes of sectioning the cast alloy were used to prepare specimens for metallographic studies. Samples from cast ingots of the alloy were prepared by standard metallographic procedure for metallographic examination on FESEM with EDAX model ULTRA-55, Carl-Zeiss. The SEM studies were carried out with an electron beam accelerating potential of 10 kV.

All the four SEM microstructures in Fig.3.6 (a) AMP3, (b) AMP6, (c) AMP9 and (d) AMP12 respectively contain similar phases but their weight fractions varies depending upon the amount of $MnO_2$ additions. The composite AMP12 has more distributed phases than that in the composite AMP3.

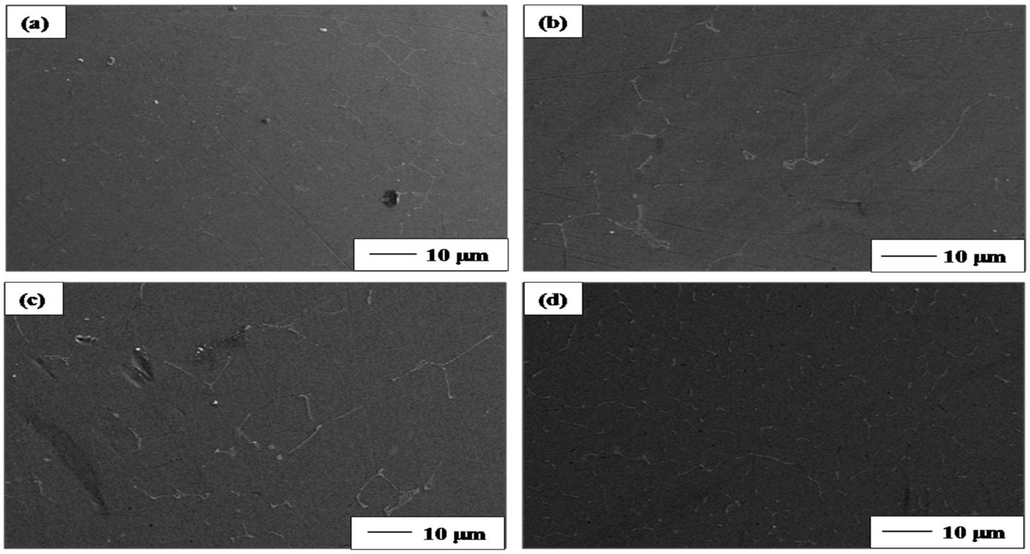


Fig.3.6: SEM micrographs of different composites developed by increasing amounts of Manganese dioxide ($MnO_2$) powder designated as (a) AM3 (b) AMP6 (c) AMP9 and (d) AMP12 respectively at Magnification of 1000X

## IV. CONCLUSION

The aluminium metal matrix composites have been produced successfully by the addition of 0, 3, 6, 9 and 12 wt% of Manganese dioxide ($MnO_2$) powder to molten Al 6061 alloy by liquid stir casting method followed by casting in permanent mould. The influence of increasing amount of $MnO_2$ powder addition on evolution of cast microstructure has been investigated. The conclusions of the present study are outlined below.

*A.* Stir casting technique (Liquid Metallurgy) was successfully adopted in the preparation of Al 6061 (Mg) - $MnO_2$ alloy and composites containing 0, 3, 6, 9 and 12 wt% of $MnO_2$ powder reinforcement.

*B.* XRD analysis shows the $MnO_2$ particles are fairly pure and SEM metallographic study revealed the presence of $MnO_2$ particles in the composites with fairly homogeneous dispersion.

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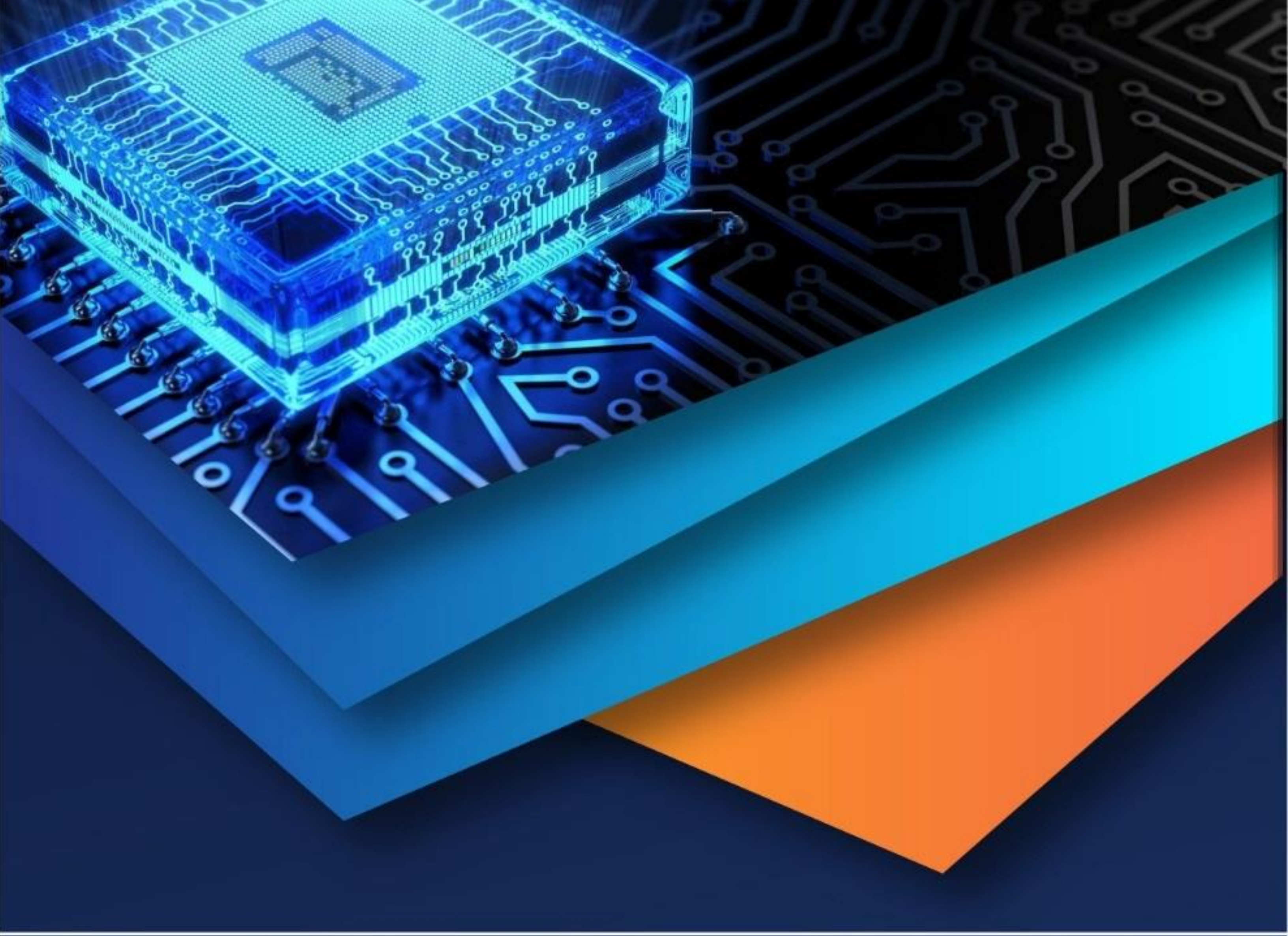


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