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Experimental Investigation of Thermal properties of sisal fiber reinforced composite and effect of SiC filler material

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Abstract: ***With a view of exploring the potential use of natural recourses, we made an attempt to fabricate sisal fiber polymer composites by hand lay-up method. Natural fiber composites are renewable, cheap and biodegradable. Their easy availability, lower density, higher specific properties, lower cost, satisfactory mechanical and thermal properties, non-corrosive nature, makes them an attractive ecological alternative to glass, carbon or other man-made synthetic fibers. The main objective of this work is to investigate effect of silicon carbide (SiC) on thermal properties of sisal natural fiber reinforced polyester composites. The composites with and without silicon carbide (SiC) have been made by incorporating 100% biodegradable sisal fibers as reinforcement in the polyester matrix. Three different samples with 0%, 5%, 10%, 20%, 30% SiC powder are considered. With the addition of SiC filler powder, thermal conductivity increases, specific heat capacity gradually increases then decreases, thermal diffusivity decreases and thermal stability improves with SiC powder.***
Keywords –Silicon carbide filler, polyester, Natural fiber composites, Sisal fiber, Thermal properties

I. INTRODUCTION

Natural fibers have played a significant role in human civilization since prehistoric times. The human beings depend on them for garments and other simple domestic uses as well as complex applications such as land dwellings and reed-built sailing craft etc. The natural fiber reinforced composite had the advantage of being light, strong, cheap, nonabrasive, high specific mechanical and thermal properties and are more environmental friendly. However these have some drawbacks such as brittleness, moisture absorption and low processing temperatures. Thermoplastic polymers especially polypropylene are produced and used today in vast quantities. However, they are seldom used as pure polymers and are usually combined with mineral fillers like fly ash, graphite, silicon carbide etc. Fillers find application in the polymer industry almost exclusively to improve thermal and mechanical properties. The properties of composites mainly depend on the matrix, fibers, and other interfacial bonding. Several investigators have used natural fibers as reinforcement in the development of green composites. The adhesion between the reinforcing fibers and the matrix in composite material plays an important role in final thermal properties of the composites.

More recently, fiber reinforced resin composites that have high strength to weight and stiffness to weight ratios have become important in weight sensitive applications such as aircraft and space vehicles, energy saving in connection with automobile air conditioning has become more important thus the study of effect of temperature on thermal properties of fiber reinforced composites used in the automotive industry is important.The use of thermal insulation materials has increased significantly in recent years so this is a new insulation material for low temperature thermal systems. Currently various researchers and material scientists all over the world are focusing their attention on thermo physical properties of natural fiber –reinforced polymer composites. Vegetable fibers can be extracted from different parts of the plants such as stems, leaves, roots, Fruits and seeds. Material characteristics play an important role in manufacturing and design engineering. Knowledge of the response of the work material during manufacturing is essential for adopting more efficient, effective and economical processing methods. Proper understanding of the response of the work material under different situations is possible only if the characteristics of a material are known. Composites with natural fibers are gaining increasing attention for a variety of applications. Available natural fibers such as jute, coir, sisal, and Palmyra belong to this category [1]. Glass, carbon, boron and Kevlar fibers are being used as reinforcing materials in Fiber Reinforced Plastics [FRP] which have been widely accepted as materials for structural and non-structural applications. Synthetic fibers are not eco-friendly. Hence attention has been focused on the utilization of natural fibers for the production of fiber-reinforced materials. One of the natural fiber-polymer composites are investigated by Paramasivan and Abdulkalam, A.P.J. [2] using sisal fibers and epoxy matrix. The fabrication process followed by winding and laminating technique, that which is of easy and low cost technique.

According to this technique, to improve the tensile strength of sisal epoxy composites is up to 250-350 MPa which is near to strength of glass-epoxy composite with same volume fraction. As sisal fiber is of low density, that the specific strength of glass fiber composites can be compared with specific strength of sisal fiber composites. This work denotes the easiness of developing new composites by reinforcing easily available natural fibers, to be used in areas like construction and consumer goods. It also reports the use of electron probe microanalysis for calculating the filler scattering in sisal-polymer composites. Chopped sisal fibre polyester composites are prepared by the press mold technique. Mechanical properties of the composites are evaluated through accelerated weathering tests conducted pertaining to ASTM D-520 specification. It is found that the specific modulus of the composite is 1.90 compared with 2.71 for glass fibre reinforced plastics, while the specific strength is of the same order as that of polyester and 30% less than glass fiber reinforced plastics. Accelerated testing revealed little change in initial modulus, reductions of 5% in ultimate tensile strength, 16% in flexural strength and 5.4% in water absorption. Lakkad.S.C. et al [6] in this work, evaluate the mechanical properties like tensile, compressive strength and young's modules of elasticity of bamboo specimens and these results are compared with same properties of mild steel and glass fiber reinforced plastics. Jindal.U.C. [7] compared the ultimate tensile strength of dendrocalamus stricutus specie of bamboos with mild steel. The bamboo composites have nearly six times more than that of mild steel. Also compared the properties of different orientations of fiber placing in composite like parallel and transverse orientations of bamboo fibers. Fiber incorporated plastics have been very popular due to their flexibility, their lightness and the ease of fabrication of complicated shapes with economic savings in contrast to fiber reinforced metals/alloys. In addition, these composites can be easily substituted for conventional materials in several areas such as the building industry, transportation and consumer goods. Some of these attempts made in recent times for the utilization of natural fibres through composite material technology have indicated their potential as substitute for the conventional materials such as wood and glass fibre reinforced plastics (GFRP) in many applications. There are, however, a number of limitations, including cost factor and their performance over a long time duration, which need further research. Extensive literature is available on the production and mechanical behavior of composites obtained by reinforcing epoxy with fibre of glass, boron, carbon silicon carbide etc. Many researchers in the past have developed composites with natural fibres such as sisal hene, quen, jute, banana, cotton, etc. [3, 4, 5, 8].Many researchers reports about the enhancement of thermal conductivity of polymer by thermal conduction mechanisms and other techniques [9,10,11]. Progelhof et al. [15] have predict the thermal conductivity of composites and demonstrated various theoretical and empherical models with brief description that focusing the relative merits. Maewal et al. [16] evaluated the heat transfer in fibrous composites by using binary mixture with a periodic hexagonal micro structure primarily in fiber direction. Chamis [17] summarized the expressions for the thermal conductivity of different orientations of composites like longitudinal and transverse isotropic composites. G. Kalaprasad compared the thermal diffusivity, thermal conductivity and specific heat of synthetic and natural fiber composites.

II. EXPERIMENTAL

A. Materials

Unsaturated polyester resin of grade ECMALON 4411, methyl ethyl ketone peroxide and cobalt naphthanate were purchased from Ecmass resin (Pvt) Ltd., Hyderabad, India. SiC fine particles (size of 10 microns) were collected from local construction industry. Sisal natural fibers were extracted from Sisal plant.

B. Fiber extraction and Processing

The sisal leafs are cut from Sisal Plant. These leafs are tied in to bundles and retted in water for about two weeks. The retted leafs were washed in running water and then fiber was cleaned and dried in sunlight for 12hours and cut to the desired length. Fibers were soaked in 2% NaOH solution in a water bath where the temperature was maintained throughout at 22±2°C for 24 h, then washed with distilled water and left to dry at room temperature.

Figure1.A) Sisal Plant B) Processed Fiber

C. Polyester Bonding Material

Polyester resin is durable, comparatively inexpensive, has superior corrosion resistance, has good range of mechanical properties, 4413, which is a general purpose polyester resin is used as matrix material. Resin ECMALON 4413 is of pale yellow Colour of 500-600 CPS Viscosity (BrokfieldViscometer) 1.13 grams/c.c. of Specific Gravity.

D. Catalyst and Accelerator

Curing or cross-linking of polyester is achieved by adding a catalyst (initiator) plus an accelerator (promoter) at room temperature. The function of catalyst is to speed up a chemical reaction by providing an alternate reaction pathway with lower activation energy. The function of accelerator is to alter chemical bonds and speed up the chemical process. In this work, cobalt accelerator along with Methyl Ethyl Ketone Peroxide (MEKP) catalyst is used.

Optimum quantity of catalyst and accelerator must be used. If more quantity is used, the specimen cures faster but will be of lesser strength and poor appearance. If lesser quantity is used, then the sample takes very long time (more than 8 hours) to cure. In this work approximately 2ml catalyst and 2 ml accelerator is used, which gave a curing time of around 4 hours.

E. Fabrication of composite

Hand lay-up technique was adopted in the preparation of unidirectional composites. Clean the mold with shellac NC thinner solution. Apply a thin coating of poly-vinyl alcohol on the interior tile surface and along the edges of the rubber sheet. Dry it for a day. Fill the mold with required mass of fibers by spreading them as homogenously as possible. Take the required mass of silicon carbide powder in a measuring jar. Pour small amounts of liquid polyester in the silicon carbide powder jar and stir it thoroughly. Add catalyst to this paste using a syringe and stir it fast. Add accelerator to this mix and stir it fast. Extreme caution should be taken in ensuring that the catalyst and accelerator does not get into direct contact with each other. Else they both react chemically extremely rapidly with issuing out fire. Immediately apply this paste on top of the fibers which are filled in the mold, otherwise it would solidify rapidly in the measuring jar itself. To ensure that no air bubbles are trapped inside, take a transparency sheet and cover it over the mold immediately by using rolling operation. Place a tile on top covering the entire mold and its contents. Place sufficient weight (roughly 50 kg) on top of the mold and leave it undisturbed in a closed room for 1 day until the composite cures. The specimens were also post cured at 70 °C for 8 h after removing from the mold. In the same above process composites are also prepared by adding SiC (5%,10%, 20%, 30%) to resin and proper mixing were done before poured on fibers.

Table 1. Material composition of specimens

Sample code	Polyester	Sisal fiber	silicon carbide (SiC)
A	70	30	0
B	65	30	5
C	60	30	10
D	50	30	20
E	40	30	30

III. RESULTS AND DISCUSSION

A. Thermal Conductivity

Thermal conductivity is the property of a material to conduct heat. It can be defined as ‘the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions’. Thermal conductivity of the samples is measured at 500C using guarded heat flow test method as per ASTM E1530 specifications. Unitherm Model 2022 manufactured by ANTER Corp., Pittsburgh, PA is used for this test.

Table 2. Thermal conductivity of samples

Sample	Thermal conductivity
A	0.25
B	0.31
C	0.38
D	0.43
E	0.45

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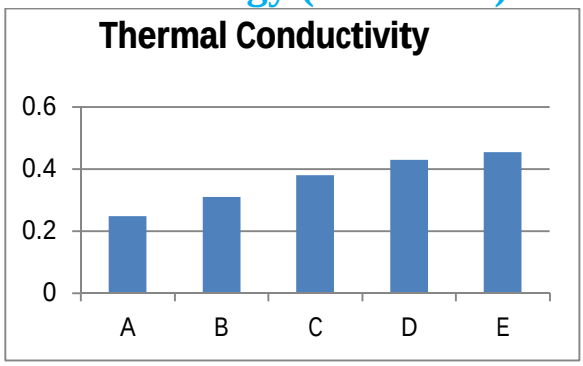

Figure 2. variation of thermal conductivity of 0%, 5%, 10% SiC in sisal fiber composite

Thermal Conductivity of samples is increase with increase of SiC % in composite. It shows a maximum thermal conductivity at 30% Sic sample. It gives the better cooling and heating of composite for the samples.

B. Specific Heat Capacity

Differential Scanning Calorimeter (DSC) technique using Double Furnace setup is used for measuring specific heat capacity. DSC is a thermo- analytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature. Compared to Single Furnace setup, Double Furnace DSC gives more accurate readings over larger temperature range, with more rapid response time as it measures the heat flow change of the sample directly.

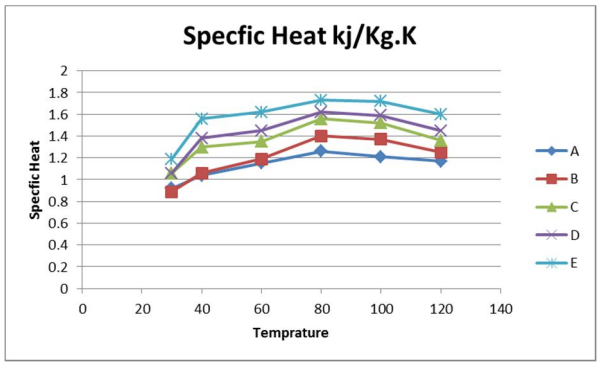

Figure 3. variation of specific heat of 0%, 5%, 10% SiC in sisal fiber composite with temperature

Temperature dependence of specific heat capacity at constant pressure was determined as a function of temperature using differential scanning calorimeter from ambient temperature to 120^0C.For filler fraction 30% of SiC has highest specific heat than other fractions of SiC, this is due the reason that heat captured by the SiC powder. This results the storage of heat with in composite increases with the increase of filler fraction.

C. Thermal Degradation

Thermal Degradation by TGA Thermo-Gravimetric Analysis (TGA) is a technique in which the mass of a substance is monitored as a function of temperature or time as the sample specimen is subjected to a controlled temperature program in a controlled atmosphere. TGA measures a sample's weight as it is heated or cooled in a furnace. The loss in weight over specific temperature ranges provides an indication of the composition of the sample, including volatiles and inert filler, as well as indications of thermal stability.

All the measurements were performed as per ASTM E1131 standard using high resolution Perkin Elmer TGA7 Thermo-gravimetric Analyzer. The samples weighing between 10 and 20mg are placed in a platinum pan and tests are performed within the temperature range of 20–700oC at a heating rate of 5oC/min under nitrogen atmosphere at flow rate of50 ml/min. TG and DTG curves were analyzed to study the high temperature degradation behavior. TGA curves of specimens provide three distinct temperature regions, wherein the samples experience major weight loss. A small weight loss was observed during Phase-1 attributed to the evaporation of moisture. Actual degradation happens in second region attributed to the thermal degradation of hemicelluloses, cellulose and lignin

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together with polymeric matrix and thereafter the rate of decomposition was slow. From DTA curves most decomposition also occurs at the temperature of 380-386°C .Quantitative data in Phase-2 including onset thermal degradation temperature, end of degradation temperature, corresponding weight loss , and are plotted. The end of degradation point is taken as the point where the steep drop of weight% finishes and the curve flattens out relatively Subtracting end of degradation weight% from onset weight% gives weight loss% during the Phase-2.

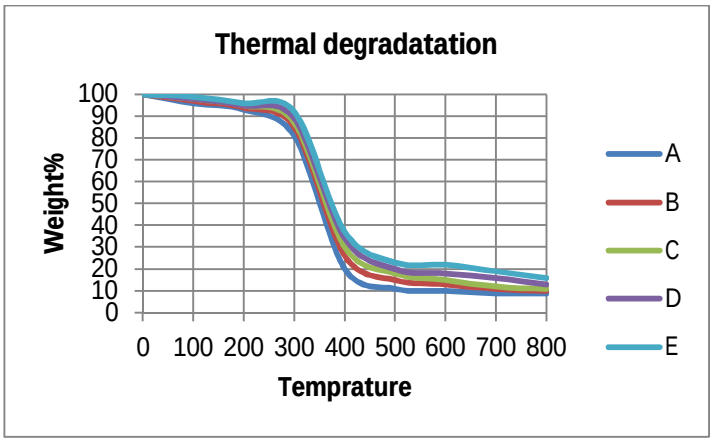

Figure.4 variation of thermal degradation with temperature

D. Thermal Diffusivity

Although thermal diffusivity can be experimentally measured by flash method, in this work it is calculated after knowing thermal conductivity, specific heat capacity and density.The results of temperature dependence of thermal diffusivity for A,B,C are presented. Thermal diffusivity of samples A,B,C decreases with increase of temperature, which is compared to thermal conductivity in opposite manner from 150K to 260K. it is due to the reduction of mean free path phonons.

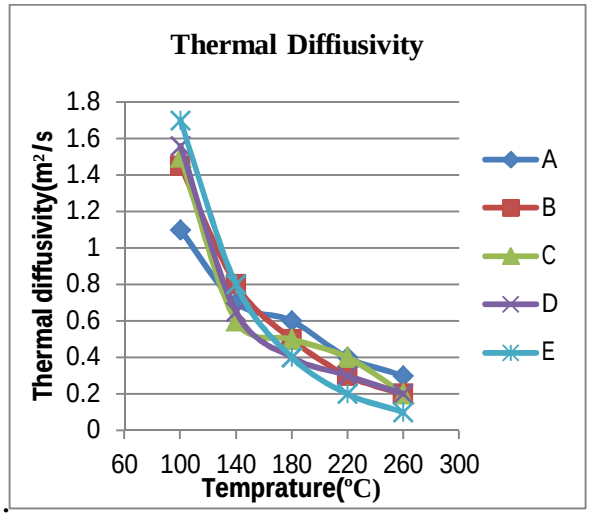

Figure 5. Variation of thermal diffusivity of 0%, 5%, 10% SiC in sisal fiber composite with temperature

Thermal diffusivity is describes the equilibrium of a temperature imbalance. It is a function of thermal conductivity, density and specific heat capacity at a constant pressure. The diffusivity decreases with temperature, while specific heat increases with temperature. Diffusivity decreases higher in temperature range of 100^0C to 180^0c, later on decrement steadily. Sample with 30% SiC has higher decrease of diffusivity compared to other fractions.

IV. CONCLUSIONS

We find that Thermal conductivity of the composite increases with increase in the SiC filler content that 30% SiC fraction sample has highest thermal conductivity. Specific heat capacity increases with increase in temperature at any SiC filler content. As 30% SiC sample has highest specific heat that gives the high storage of energy. Thermal diffusivity of composite decreases with increase of

temperature. The 30% SiC filler content has highest degradation at onset temperature and also least amount of weight loss. Thus, it has highest thermal stability. Temperature at maximum weight loss is nearly constant (350^0C-380^0C) for all SiC content.
This study indicates the hand lay process might be a good choice for preparation of polymers with filler materials.

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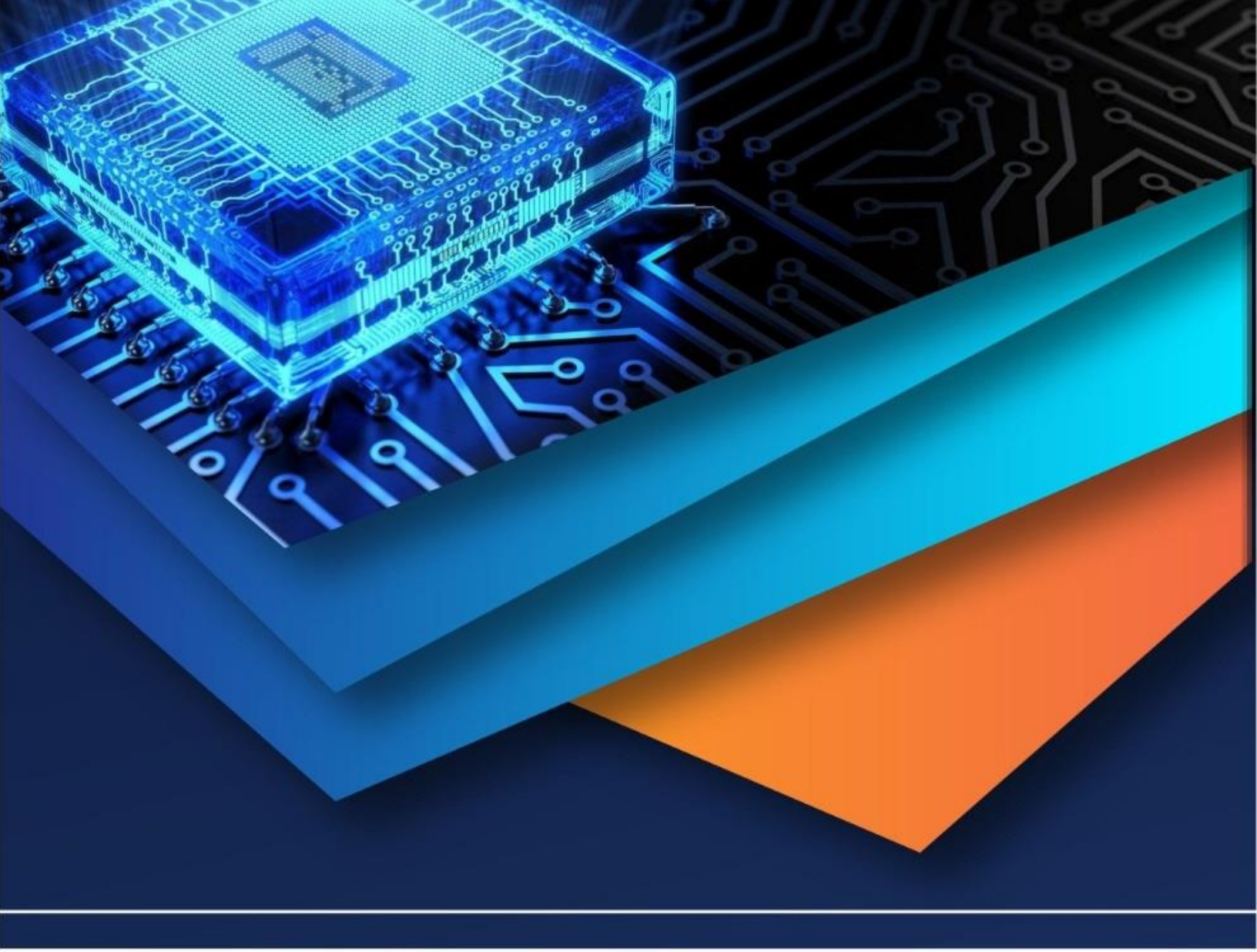

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