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Engineering Application of Natural Fibers and Its Properties: A Review

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Abstract: This paper is based on a study of natural fiber, its properties and its application in Today's world Natural fiber composite is the vastest field of research for engineers, professionals and scientists due to its countless properties like biodegradability, less-cost material, low weight, biodegradable, good mechanical properties, ease of availability and microstructural properties. A literature survey has been done on natural fibers (jute, sisal, kenaf, cotton, cotton straw, coir, abaca banana, hemp, neem, etc) and their utilization. This paper represents a review of various natural fibers (Sisal, Abaca and Hemp), their mechanical properties and their application.

Keywords: Natural fiber, Sisal, Abaca, Hemp, chemical properties, physical and mechanical properties, Application.

I. INTRODUCTION

The composite made through natural fiber and polymer is widely used in today's life due to its eco-friendly nature. As today pollution is an important aspect and lots of research is under progress to make an environmental friendly composite which is self-degradable in nature. Natural fiber has various advantages and due to its biodegradable properties, it attracts the attention of scientists and researchers over conventional epoxy and carbon fibers. The natural fiber composite applications are extensively growing in industrial and domestic human applications. The natural fiber consisted of various advantages over the polymers (epoxy resin polymers, petro based resins and carbon fibers) like biodegradable, low cost and good mechanical properties. Natural Fibers are widely used in aerospace application, leisure, building, sports, packaging and automobile industries. The behavioral properties of composite made from natural fiber are discussed in this paper.

Natural fibers are classified based on the place where they get extracted such as plant, animal fiber and minerals and their main components are protein and cellulose. The fiber from the plant is further divided based on its generated location like stems, leaf, seed, fruit, bark and xylem. The Natural fibers which are generated from the stem are Rice, Bamboo, Corn Stem, wheat, etc. example of leaf fiber is abaca, sisal, pineapple and agave while seed fibers include cotton, kapok and wider. Oil palm and coconut are part of the fruit fiber. Bark fibers consist of jute, abaca, soybean fiber, rosella and ramie. Animal fiber consists of wool, silk, hair and bird fibers. While mineral fiber includes asbestos, carbon and glass.

Fiber is a kind of substance that is lengthy, thin, complete and easy to turn to form an extended tissue. Fibers are characterized into 3 groups as per sources. Namely natural, synthetic sources and semisynthetic. Natural fiber exists in very large quantities, is more affordable and is easily available as compared with synthetic fiber. Natural fiber consists of lower density, greater strength to weight ratio, greater aspect ratio (length/Diameter ratio), great strength, etc. Due to such beneficiary properties: natural fibers are used as raw materials in paper, textiles, bio-composite industry etc.

II. NATURAL FIBER CLASSIFICATION

The natural fibers are categorized based on origin: plant, mineral and animal type. The plant fiber consists of a high quantity of cellulose and animal fiber contains a high percentage of protein. Whereas plant fiber has higher strength and stiffness as compared to different fibers like silk fiber which can have very high strength but low stiffness and it is expensive than plant fiber and it is not easily available. This makes plant-based fibers most useful as compared to other fibers and plant fibers are widely used for research and industrial applications. Many products are made with plant-based fiber composite with structural requirements and therefore natural fiber is the focus of the review. Due to this many countries cultivate those fiber plants which produce fiber over a shorter period (2-3 times in a year).

The properties of fibers mainly depend on their chemical configuration and its arrangement shown in figure -1.

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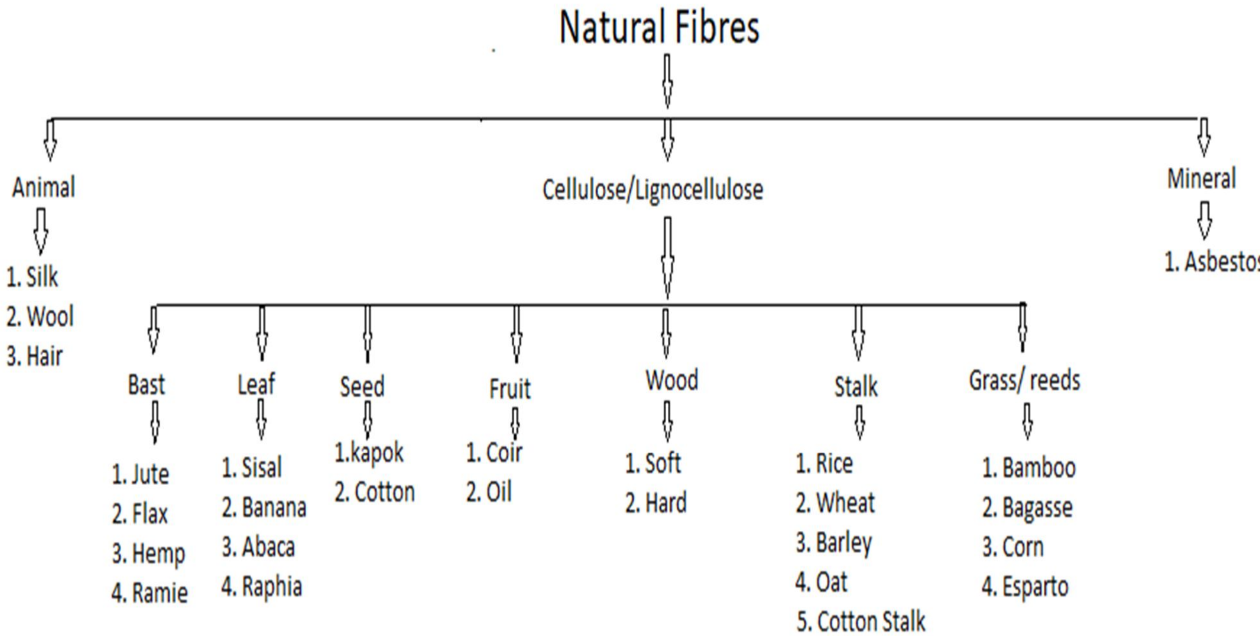

Figure-1

A. Sisal

Agave sisalana is the biological and botanical name of sisal fiber and it is mostly available material. It is easily cultivated. It is a hard fiber extracted from the leaves of the sisal plant (Agave sisalana). It is mainly cultivated in tropical and sub-tropical countries like West Indies, Africa and the far east. The estimated production of sisal fiber is 4.5 tons per annum throughout the world. Average leaves on each sisal plant are 200 – 250 leaves whereas each leaf has 1000 – 1200 fiber bundles. Each leaf of sisal fiber consists of 4 % fiber, 87.25% water, 0.75% cuticle and 8 % dry matter. A sisal leaf weighing 600 grams consists of 3 % of fiber by weight and each leaf contains 1000 fibers.

There are three types of fiber produced from sisal leaf: mechanical, xylem and ribbon. Mechanical fibers are extracted from the outside edge of the sisal leaf and it is the utmost commercially useful fiber. Such fibers occur in link with the conducting tissue in the middle line of the leaf. Xylem occurs opposite to the ribbon fiber and it has an irregular shape. The average sisal plant consists of 71% of cellulose, 12 % of hemicellulose, 10% of pectin and 9% of lignin content. The diameter of sisal fiber is 100-300 micrometers and the length of sisal fiber is 1.00- 1.5 m. The price of sisal fiber is very low as compared to manmade fibers. Tensile properties of sisal fiber are not uniform throughout its length, it is varied and the lower part has minimum tensile strength and the middle part has good tensile strength. It is found that the fiber becomes stiffer and stronger at the middle span. The sisal plant and its fiber show in figure-2.

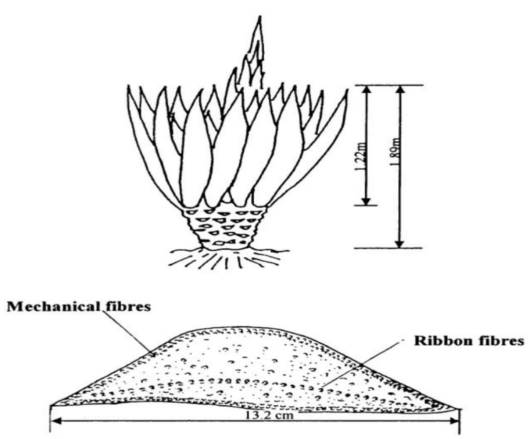

Figure-2 Sisal plant and its Fiber

B. Abaca

The Abaca plant and banana plant belongs to the Musaceae family. Its scientific name is Musa textilis and it is mainly cultivated in the Philippines. The fiber is concentrated in the abaca plant in vascular bundles and it is the most complex part of the plant and mainly fiber develops in that area. It gives resistance and good fibers because of high content of cellulose in plants. Main application of Abaca fiber is in the paper industry and spinning industry therefore it is called the queen of natural fibers. 90% of the world production of abaca is produced for the Philippines. Around 400 varieties of abaca are identified in the world in which twenty varieties have commercial value whereas 3 of them are greatest importance (Tangongon, Bongulanon and Maguindanao). Tanjong is a big and strong variety that is 4 to 5 m high. It easily grows in clay soil and its pseudostems produce strong fiber (2.5 % to 3% of total weight). Bongulanon variety has narrow leaves and medium-sized stems and it is an primary variety of abaca. It requires wet alluvial soil with a well-drained system. Maguindanao possesses large stems. After sowing its first harvest takes place 15 to 18 months and it has more than 15-year productive life. 1.75% of the strong and white fiber is extracted from pseudostems [11]. The fibers extracted from the leaf of the abaca plant are the strongest natural fibers because it exhibits special mechanical strength. It has high durability and resistance to saltwater damage. Abaca fibers are light brown in color and it has a length of up to 3 meters. It has lower elongation as compared to synthetic like nylon but has good tensile strength has thermal stability at 250 ° Celsius therefore it is suitable for the fabrication of thermoplastic matrix composite.

Figure-3: Abaca plant and its fiber

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C. Hemp

The scientific name of hemp or industrial hemp is Cannabis sativa. Hemp is widely used as natural fiber in the reinforced composite after sisal. Hemp is environment friendly and one of the oldest natural fiber. In hemp plants, fiber is contained in the tissue of stems and this tissue helps to hold the plant erect. Hemp fiber has high strength and high stiffness and that property makes them a useful material for reinforcement in composite materials. According to FAO hemp cultivation was 90,000 tons in 2005 and its production increased day by day. Out of total production of natural fiber, Hemp production is 0.5 %. Hemcore is the UK's first hemp fiber manufacturing company and its raw material is generally used in industries, for example, hemp door panels used in BMW 5 series cars and lots of companies are making clothes from hemp fiber. The main constituent of hemp fiber is lignin, cellulose, pectin and hemicellulose. Following components define the physical properties of hemp fiber. Cellulose is the strongest and stiffest organic constituent in natural fiber. Hemp fiber has a few drawbacks in that its physical properties and mechanical properties vary as per its source, age of the plant, rainfall during growth, geographic origin and separating techniques. Apart from its high stiffness and high tensile strength, it has a high aspect ratio (length/diameter ratio). The lower density of hemp fiber makes it good for reinforcements in the composite. The disadvantage of hemp fiber for use in the composite are non-uniform, non-smooth surface, variability of properties and low resistance to water absorption and decay. The hemp plant and its fiber are shown in figure-4.

Figure- 4: Hemp and its fiber

III. PROPERTIES AND APPLICATION OF SISAL FIBERS

A. Chemical Properties Of Sisal Fiber

The Chemical compositions of this fiber influenced by the source location and age of plants and so on. Because all-natural fibers contain cellulose, hemicellulose, moisture and lignin, therefore Sisal fiber also contains the same but it percentage varies as per source location and age of the plant.

The chemical composition of sisal fiber reported by different authors (Table:1)

Cellulose	Hemi-cellulose	Lignin	Ash	Wax	Moisture	Pentosan/ Pectin	Reference
78%	10%	8%	1%	2%	-		[1]
43-56%		7-9%	0.6-1.1%	-	-	21-24 % (Pentosan)	[2]
65-68%	10-22%	9.9 - 14%	-	-	10-22%		[3]
85-88%	-	-	-	-	-		[4]
49.62-60.95%	-	3.75 - 4.40%	-	-	-		[5]
66-78%	10-14%	10-11%		2%	10-22%	10% (Pectin)	[6]

B. Mechanical And Physical Properties Of Sisal Fiber

The physical properties of sisal plants vary as per their age. Its fiber size varies from 1.0 to 1.5 meters and diameter of fiber varies from 100 µm to 300 µm. Due to variation in physical properties of sisal fiber, its mechanical properties also vary throughout the fiber length. The lower and root section of fiber has high fracture strain but minimum tensile strength and minimum tensile modulus. The middle section fiber is stronger and stiffer than the lower section fiber and the tip has adequate properties. Different researchers reported different mechanical properties of this fiber as per source and age. Table-2 listed below

The Mechanical and Physical Properties of Sisal fiber as per various authors (Table-2)

Diametre (µm)	Density (g/cm^3)	Tensile Strength (N/mm^2)	Tensile Modulus (GPa)	Maximum Strain (%)	Reference
50-200	1.450	604	9.4-15.8	-	[7]
100-300	1.410	400-700	9-20	5-14	[8]
50-300	1.450	530-640	9.4-2.2	3-7	[9]
-	1.33-1.5	400-700	9.0-38.0	-	[3]

C. Application of Sisal Fiber

As per the content of cellulose and hemicellulose sisal fiber are graded under three categories and their application based on its grades like high-grade fiber used for carpet industries and wool industries, for making ropes, medium-grade fiber is used, also low grade fiber is used twine, bales and general industrial purpose and low-grade fiber is used by the paper industry and cordage industry. Sisal fiber has a wide range of applications in industries [29].

1) Automobile Industry: It is used in car doors, car ceilings, panels, wheel wells, etc.
2) Fabrication Industry: It is used in pulp construction material, sofa and wadding mat.
3) Paper Industry: Paper are made from low-quality sisal in the paper industry.
4) Agriculture Industry: It is used in the agro-textile industry as a material, its leaves are used as a fertilizer.
5) Cordage Industry: It is used to make ropes, binder's twine and baler.
6) Floor Covering Industry: It is used to make high-quality carpet, mattresses and wall covering.

IV. PROPERTIES AND APPLICATION OF ABACA FIBER

A. Chemical Properties of Abaca Fiber

The configuration of Abaca fiber is shaped by Cellulose, Hemi-cellulose and lignin and its structure is shaped by innumerable tubular structures called the lumen. A single cellulose molecule of abaca fiber is formed by a glucopyranose link between glucose units. A cellulose structure is formed by a 1500 glucose unit. The long-chain molecules are held together with hydrogen bonds and lie side by side in bundles and it has numerous neighboring hydroxyl groups. The rope-like structure is formed by hydrogen bonds and cellulose bundles. The structure is produced when a cellulose bundle is embedded in lignin and they cement each other [12]. Cellulose and hemicellulose are integral parts of the cementing process. Abaca fiber contains 56- 63 % of cellulose, 20 – 25 % of hemicellulose, 3 % of wax, 7-13 % of lignin and 0.5 % of ash.

B. Physical And Mechanical Properties Of Abaca Fiber

Strongest fiber among all the natural fiber is abaca fiber is the strongest natural fiber and obtained from the leaves of abaca plants. It exhibits high mechanical strength and opposition to saltwater and high durability. Abaca has a fiber length of up to 3 meters. As compared to synthetic material, it has lesser elongation and greater tensile strength. Abaca fiber has thermal stability at 250° C and that makes it suitable for thermoplastic composite. It has a density of 1.5 g/cm3. It has a higher tensile strength of 400-677 MPa and a high young's modulus of 34.4 to 41 GPa. Its total elongation varies from 3.4 % to 11.1 %. [10]

C. Application of Abaca fiber

Abaca fiber are used to make ship rigging in the 19th century. In today's era it is used to make fishing nets, coarse cloth for sacking, ropes and twines. It is also used to make clothes, curtains, etc. Abaca fiber has a wide range of applications in Industries [30].

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1) *Paper Industry:* Maximum abaca fiber is used to make paper and its paper is used for various purposes like coffee and tea bags, currency notes (Japan Yen bank currency note contain 30% of abaca fiber), filter paper of cigarette, medical and food packing paper, writing paper.
2) *Automotive Industry:* it is used in interior and exterior parts of automotive. Mercedes Benz has used abaca composite in automobile body parts.it is used to replace glass fiber in automotive.

V. PROPERTIES AND APPLICATION OF HEMP FIBER

A. *Chemical Properties Of Hemp Fiber*

Hemicellulose, Cellulose, lignin and pectin are the key constituents of hemp fiber. Cellulose is the stiffest and strongest constituent of fiber but various researchers reported variation in composition and that is the drawback of hemp fiber.

The variation in the chemical composition of hemp fiber is shown below given Table 3:

Cellulose (%)	Lignin (%)	Hemi-cellulose(%)	Pectin (%)	Other (%)	Reference
75.6	6.6	10.7	-	-	[13]
67.0	3.3	16.1	0.8	2.8	[14]
76.1	3.3	12.3	5.7	3.3	[15]
55.0	4.0	16.0	18.0	4.0	[16]
70-74	3.7-5.7	10.7	-	0.8	[17]
70-74	3.7-6	18-22	-	0.8	[11]

B. *Mechanical and Physical Properties of Hemp fiber*

Due to variation in the chemical composition of hemp fiber, its mechanical and physical properties also vary. Diameter, fiber length and properties differ significantly as per the age of the plant, source, retting, separating techniques, rainfall and geographic origin. The researcher shows that the diameter of the middle part of the hemp flax fiber bundle is more than the bottom and top part of the hemp flax fiber bundle and the cross-section of hemp straw is polygon [17]. The diameter and length of hemp fiber also vary during the developing stage of fiber and variability of diameter and length impart variation in mechanical properties. The length of fiber varies 8.3-14 mm, diameter varies from 17-23 µm and its density is 1500 kg/m3. Tables - 4 show various mechanical properties of hemp fiber which is reported by different researchers in their research papers are show in Table 4:

Tensile modulus (GPa)	Tensile Strength (MPa)	Elongation (%)	Reference
30- 60	310- 750	2-4	[19]
20-70	270-900	1.6	[20]
50	690-1000	1.0 – 1.6	[21]
-	1235	4.2	[22]
25	895	-	[23]

C. *Application of Hemp fibers*

The application of hemp fiber is based on fiber length. Shorter length fibers are used for manufacturing fiberboard, insulation products and erosion control mats and longer fiber is used in textiles industries. Hemp is used to making various textile products like bedspreads, towels, shirts, carpets, blankets, bags, shoes, hats, sheets and clothing etc.

It is also used in automotive industries to make a reinforced thermoplastic composite in interior parts of automotive. It is also used in the construction field to make strong and lightweight concrete. Long hemp fiber produces quality and fine fabric [31].

VI. CONCLUSION

As global warming affects the natural environment and ecology and today the total dependence of our life is on synthetic fiber products. So it is necessary to reduce application of synthetic product application from an environmental point of view and natural fiber or natural fiber-reinforced composite is the best replacement for synthetic fiber due to its biodegradable properties. Natural fiber has various limitations but through chemical cure, the properties of natural fiber will improve and its application area also increase.

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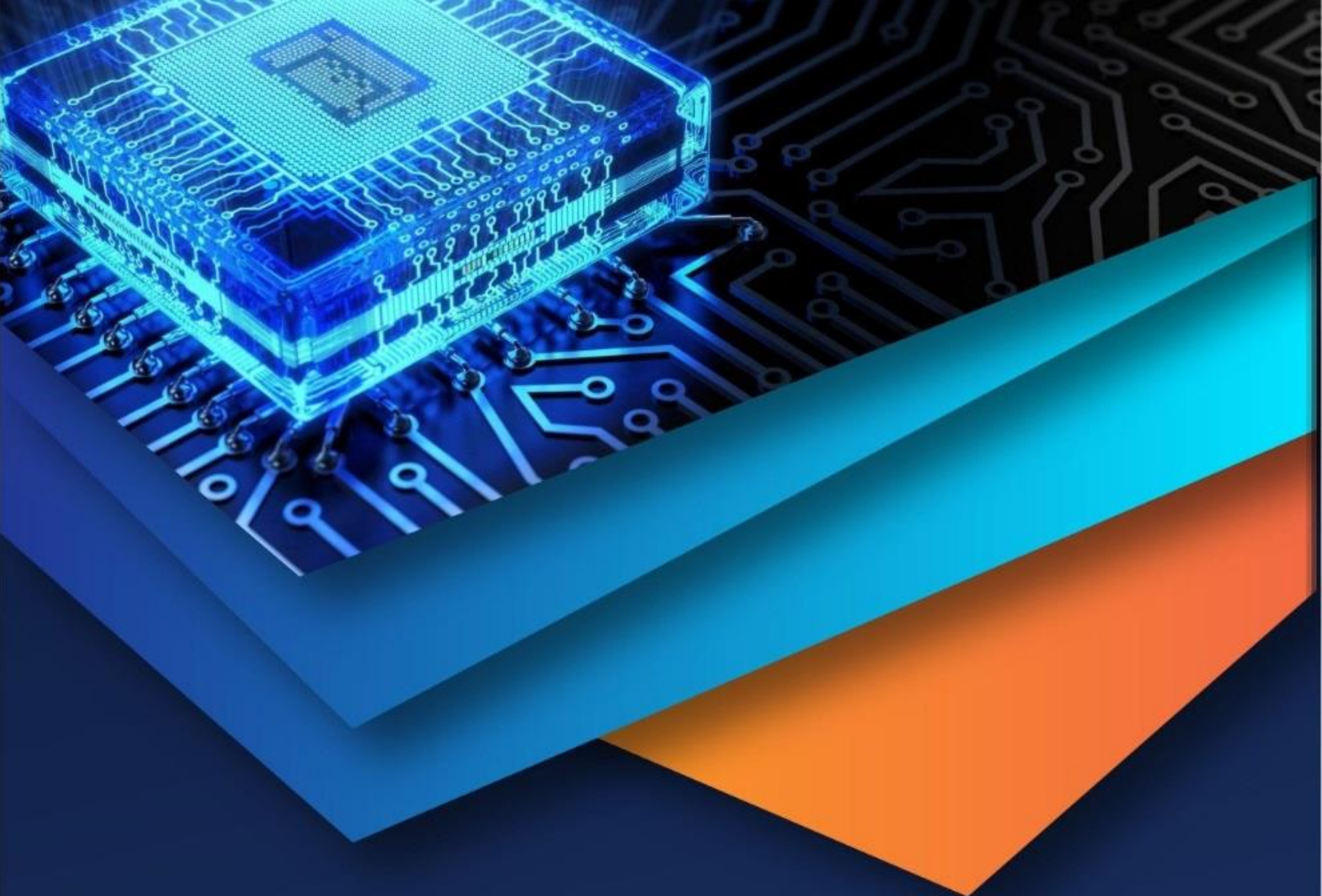

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