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Development of Biodegradable and Sustainable Composites from Agricultural Waste for Tableware Applications

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Abstract: In order to provide a sustainable alternative to single-use plastics, this study explores the development of biodegradable tableware using agricultural waste materials such as rice husk, wheat bran, sugarcane bagasse, and wheat starch. The raw materials were converted into composite tableware products using processes drying, pulverizing, mixing, and compression moulding. The final products were assessed through physicochemical, microbial, and water absorption tests. The results showed that although the tableware showed high biodegradability and compliance with food safety standards, it also had limitations in terms of moisture resistance and microbial stability under humid conditions. Microbiological tests confirmed minimal leaching of substances, and microbial tests demonstrated good hygiene under dry storage.These results imply that the product is appropriate for short-term use, particularly when combined with dry or semi-moist foods, and that coatings or natural antimicrobial agents could be used to increase the product's water resistance and shelf life. All things considered, the project shows how agro-waste can be transformed into useful, environmentally friendly consumer goods, supporting the ideas of the circular economy and providing a workable way to lessen plastic pollution.
Keywords: biodegradable, sustainable, pulverizing, migration, resistance, antimicrobial, eco-friendly.

I. INTRODUCTION

The rising international interest in environmental sustainability has created the popularity of biodegradable tableware produced from organic materials.

Compared to plastic tableware, which create major environmental issues because of their long decomposition periods and poisonous chemical characteristics, biodegradable tableware provide a more environmentally friendly option. They are made from plant residues like wheat husk, sugarcane bagasse ,rice husk and wheat starch that are not only renewable but also degradable at a faster rate in landfills, limiting pollution. With growing consciousness among consumers and tighter regulations on single-use plastics across the world, biodegradable tableware have been increasingly adopted in domestic use, restaurants, and mass gatherings. Their compostability, heat resistance, and durability also play their part in making them popular, encouraging proper consumption and waste disposal. [1]

Still, even with their obvious environmental advantages, biodegradable tableware encounter some challenges that limit their popularity. One of the main is the uneven supply of raw materials. The supply of agricultural residues such as wheat bran, sugarcane bagasse and rice husk depends greatly on seasonal variations, weather conditions, and crop yields. This volatility can result in supply chain disruptions and price fluctuations, and it is hard to have a consistent production process. In contrast to plastic tableware, which are produced from available and inexpensive petrochemical raw materials, biodegradable tableware are subject to agricultural cycles and weather patterns, which might not always be favorable to market demand. [2]

In addition, the processing techniques needed to produce biodegradable tableware are resource-intensive. The manufacturing process usually entails certain steps that may take a lot of energy and time, further increasing the cost of production. In contrast to plastic tableware, which are manufactured in bulk using efficient, low-cost production processes, biodegradable tableware tend to need specialized machinery and longer production times. This added expense and energy use might render biodegradable tableware uncompetitive in price, especially in the developing world where plastic products are widely used because of their cheapness and availability. [3]

Market awareness is another important hurdle to the use of biodegradable tableware. Though biodegradable tableware have several advantages environmentally, most consumers and companies are not aware of these benefits or lack knowledge of such products. In addition, the additional expense of biodegradable tableware over plastic options can be a major disincentive. In nations where plastic tableware are more affordable and available, the higher price of biodegradable tableware might not be worth it unless there is a definite awareness of their environmental benefits. [4]

Lastly, the ecological impact of the processes employed in manufacturing biodegradable tableware cannot be ignored. While such plates are generally thought to be eco-friendly, the total sustainability of biodegradable items is a function of their complete life cycle, including raw material procurement and production. If raw materials are procured in an unsustainable manner or production involves large energy or water requirements, the environmental advantages of biodegradable tableware may be effectively negated. Hence, it is important that the process of production itself does not degrade the environment. [5]

Overall, although biodegradable tableware represent a promising avenue for plastic reduction and sustainability, they are challenged by various setbacks such as the irregular supply of raw materials, energy-intensive manufacturing processes, unawareness in the market, and possible environmental hazards from production. Overcoming these challenges is imperative to making biodegradable tableware a sustainable, widely used option compared to plastic, hence facilitating a more sustainable future. [6]

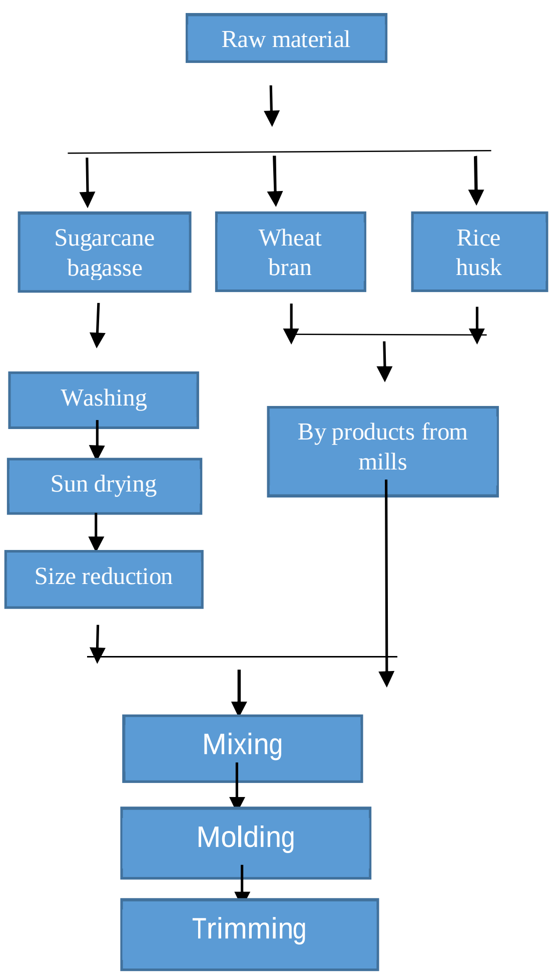
II. LITERATURE SURVEY

1) Agne Katileviciute et al., 2019. "A sight to wheat bran: high value-added products." Wheat bran is a low-cost agricultural by-product that includes valuable bioactive ingredients such nonstarch carbs, proteins, and minerals. It provides a promising substrate for the production of enzymes, biochemicals, and biofuels, hence promoting environmentally benign and long-term biotechnology applications. It was a renewable feedstock that helps to reduce waste and environmental effect in a variety of industries, such as medicines, food, and bio plastics.[7]
2) Carlos T. Hiranobe, Andressa S. Gomes et al., 2024. Sugarcane, which is mainly utilized for sugar and ethanol production, produces huge quantities of biomass such as bagasse, leaves, tops, and vinasse, which can be reused for bio refinery applications. Current studies investigate the utilization of sugarcane for energy production, biofuels, and biochar, although issues such as high energy expenditure and mass production are still issues. Pellet manufacturing may increase energy production, but quality control must be implemented for storage and transportation. Sugarcane-based materials must undergo additional testing for application over extended periods in civil construction. Sugarcane bagasse is an environmentally friendly and inexpensive adsorbent, but cellulose extraction and modification are still challenging to improve. Scaling up the synthesis of nanostructures and enhancing fiber dispersion within composites are also persisting challenges. Sugarcane's versatility makes it important for industry and the global economy. [8]
3) N. Visavarungroj, J. Herman, J.P. Remone et al., 2022, 'crosslinked starch as binding agent: i. Conventional wet granulation'. In wet granulation, several starches are used as binding agents, including pregelatinized-crosslinked waxy-corn starches providing friable granules with better characteristics. Granules made from dry starch were more friable than those made using starch paste. Crosslinked starches demonstrated no appreciable advantage over native waxy-corn starch.[16]
4) Rizwan Shoukat, Marta Cappai et al., 2025,Starch functions as a thickening, shelf life extender, fat replacement, texture modifier, gelling agent, and stabilizer. In non-food uses, it serves as a sizing agent, binder, disintegrant, absorbent, and adhesive, as well as a sealer and to improve material bonding strength in construction. The demand for modified starch has surpassed that for its native counterpart, indicating its increasing market worth and the industry's interest in products with innovative functional qualities and added value. This study focuses on rice starch, namely its structure and content, as well as their effects on physicochemical qualities and usefulness.[17]
5) Zuzanna Sydow, Mateusz Sydow et al., 2021.The reuse of waste for the creation of tribological materials provides not only environmental benefits due to the transformation of waste into raw materials, but it may also improve the mechanical and tribological qualities of these materials. Furthermore, the use of trash saves production costs due to cheaper filler material prices and longer product service life. The current review aims to evaluate the reuse of agricultural, industrial, and postconsumer wastes as reinforcements in composites used in tribological applications. Tribological performance (wear rate, coefficient of friction) of monolithic and hybrid composites supplemented with waste materials.[19]
6) Liu, Y., et al. (2018) The generation of lignocellulosic agriculture waste and the residue is unavoidable, and disposal of the same with burning or burying creates environmental issues. In recent years the scientific community is continuously looking for sustainable development using natural resources for development. Rice husk (RH) and straw (RS) are already proposed as natural fiber reinforcing materials for natural fiber reinforced polymer composite (NFRPC). In this article, an attempt has been

made to obtain the optimized proportion of rice husk and straw reinforcement in bio epoxy resin for the development of rice husk and straw fiber-reinforced hybrid composite with improved mechanical properties. The grey relational analysis (GRA) methodology is implemented to obtain the optimized proportion of RH and RS for maximization of tensile and flexural strength of polymer composite simultaneously. The experimental and grey relational analysis result presents the addition of 05 and 08 wt % of RS and RH fiber respectively in bio epoxy resin presents rice straw and husk reinforced polymer composite with improved tensile and flexural strength simultaneous. [20]

7) Abbass, O. A., Salih, A. I., & Al Hurmuzy, O. M., 2020.Study of the Mechanical and Physical Properties of Bio-Composite Material Based on Wheat Starch and Wheat Straw Fibers.This study investigates the development of biodegradable bio-composite materials using wheat starch as a natural binder and wheat straw fibers as reinforcement. Various composite formulations with different fiber content were prepared and evaluated for their mechanical strength, density, water absorption, and surface characteristics. The results indicated that increasing fiber content enhanced the tensile strength and structural integrity of the composites while maintaining biodegradability. The wheat starch matrix exhibited effective bonding with straw fibers, validating its role as a natural adhesive. The study confirms that wheat-based composites are viable for applications like disposable tableware, offering a sustainable and eco-friendly alternative to conventional plastics. The use of agro-waste not only supports waste valorization but also contributes to circular economy goals and green material development.

III. PROPOSED METHODOLOGY



IV. MATERIALREQUIRED:

A. Paddy Husk

Nature-Based Reinforcements for Structural Stability Paddy husk are cellulose, hemicellulose, and lignin-rich, making them structurally hard and long-lasting. The lignocellulosic parts of these form a network of fibres, acting as reinforcement in biodegradable composites. High cellulose content (35–45%) increases tensile strength, whereas lignin (20–30%) is a natural binder, increasing water resistance and durability [4]. In addition to that, rice husk is rich in silica (15–20%), which provides thermal stability and qualifies the material for high-temperature-resistant tableware applications [9]. Rice husk has been shown in research to improve the mechanical strength of biodegradable materials so that it competes with traditional plastics [10].

Fig: 1 Paddy husk

B. Sugarcane Bagasse

Strength and Biodegradability Improvement Sugarcane bagasse, which is a waste lignocellulosic biomass containing high cellulose (40–50%) and hemicellulose (25–35%) content and thus a good reinforcement material for biodegradable composites [11].Its fibrous characteristics enhance the rigidity of molded products with minimal weight composition. In addition, its inherent hydrophobic nature reduces water absorbency, further enhancing the resistance of disposable tableware [12]. Studies confirm that sugarcane bagasse-based products undergo degradation within 90–120 days when undergoing composting processes, with notable environmental reduction when compared to petrochemical-based plastics [13].

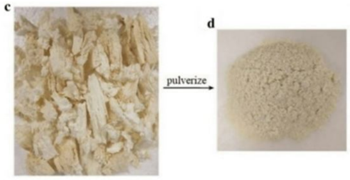


Fig: 2 Sugarcane bagasse

C. Wheat Bran

Providing Rigidity and Moisture Resistance Wheat bran, a byproduct of wheat milling, contains high levels of proteins, dietary fibers, and natural waxes, which contribute to its unique properties as a reinforcement material. The protein content (~15%) in wheat bran acts as a natural adhesive, improving the cohesion of composite materials. Additionally, wheat bran's wax layer provides inherent water resistance, reducing moisture absorption and preventing degradation in humid conditions [14]. Its inclusion in biodegradable materials has been shown to enhance stiffness, making the tableware more resistant to bending and deformation underweight [15].

Fig:3 Wheat bran

D. Wheat Starch

A Versatile and Biodegradable Binder for Improved Moldability

Wheat starch excels in film formation, biodegradability, and adhesive strength, serving as an eco-friendly binder for uniform fiber dispersion in composites. Gelatinization forms a tough, flexible matrix with lignocellulosic materials, enhancing its binding ability. Bioplastics from wheat degrade fully in 60–90 days in soil, while plasticizers like glycerol boost flexibility and adaptability for diverse applications, including food packaging.

Its sustainable nature offers a greener alternative to petroleum plastics, blending functionality with environmental consciousness. However, without additives, wheat starch composites may lack the durability or mechanical strength needed for certain long-term or high-load applications, suggesting room for further refinement.

Fig:4 wheat starch

V. PREPARATION AND PROCESSING

A. Material Collection

Rice husk, wheat bran, sugarcane bagasse, and wheat starch were the main agricultural by-products utilized in this investigation. Their abundance, biodegradability, and demonstrated potential for use in bio-composite applications led to their selection.

- Rice Husk (Oryza sativa): Procured from rice mills in Tamil Nadu, dried, and pulverized.
- Wheat Bran (Triticum aestivum): Collected post-milling, providing fibrous reinforcement.
- Sugarcane Bagasse (Saccharum officinarum): A fibrous by-product collected from local sugar mills.
- Wheat Starch: Used as a natural binder, enhancing inter-particle cohesion.

To guarantee purity and uniformity, all raw materials were obtained locally and thoroughly cleaned before use.

B. Drying

In order to prevent microbial contamination, increase pulverization efficiency, and increase moldability, collected raw materials were sun-dried for 48 to 72 hours in a dust-free environment to lower their moisture content to less than 10%.

C. Pulverization

For homogeneous mixing and the best moulding behavior, the dried materials were ground into a fine, consistent powder using a mechanical pulverizer. The particle size ranged from 200 to 500 µm.

D. Ratio Preparation for Moulding

By varying the proportion of each raw material while keeping wheat starch as a constant binder, various composite blends were created. Three compositions were chosen for testing:

Composition	Sugarcane Bagasse	Rice Husk	Wheat Bran
Trial 1	2	1	1
Trial 2	1	2	1
Trial 3	1	1	2

E. Mixing

To create a semi-solid dough, the powdered ingredients were thoroughly combined with water and starch binder. A rotary mixer was used for mixing in order to guarantee that the fibres and binders were distributed evenly. Consistent molding results were ensured by controlling the moisture content to prevent over-hydration.

F. Molding

Compression molding was applied to the composite dough in preheated stainless steel moulds at 200°C for 5–6 minutes at 3–5 MPa Pressure. This thermal-pressing process activated the starch binder, resulting in proper fusion and shaping.

G. Trimming

The bio-composite products frequently showed excess material or uneven edges along their borders after the molding process. A trimming procedure was carried out to guarantee consistency, secure handling, and visual appeal. A rotary cutter was used for the trimming.

VI. EXPERIMENTAL TESTING

A. Moisture Absorption

A moisture absorption test measures the water absorption property of a biodegradable table ware. In this test, the BDtableware is kept in an electric oven at a temperature of 90 ºC and plate weight is determined at a particular interval until the concurrent state occurs. The moisture absorption of BD plate is calculated using the following. [23]

Moisture Absorption (%) = $((M0 - M1) / M0) \times 100$

B. Migration Test

The migration test evaluated biodegradable tableware for performance and safety. Cups filled with distilled water showed no migration of harmful substances, color, or odor in 30 minutes. Structural softening and penetration of moisture were noted upon prolonged use, reflecting suitability for short-term use but highlighting the requirement for more durability for long-term use.

Overall Migration (mg/dm²) = $(Wf - Wi) / A$

C. Microbial Contamination Test

The microbial contamination test evaluates the hygiene and safety of biodegradable tableware. Samples are exposed to controlled environments, examining microbial growth on surfaces over time. Results assess susceptibility to contamination, ensuring compliance with food safety standards. Effective antimicrobial properties confirm suitability for safe use in food applications and eco-conscious settings

D. Physicochemical Properties

Biodegradable tableware exhibits balanced physicochemical traits for practicality and sustainability. A neutral to slightly acidic pH ensures safe food contact without altering taste. Lightweight bulk density provides ease of use while maintaining durability. Controlled specific gravity enhances strength and biodegradability, combining functionality with eco-friendliness to meet consumer demands and environmental goals.

IV. RESULT AND DISCUSSION

A. Moisture Absorption

This water absorption value falls within the High Water Absorption range (50-100%) for biodegradable cups. This may be suitable for cups designed to hold liquid foods.

Trail	Dry weight(w1)	Final weight(w2)	Water absorption(W)
1	21	41	100
2	23	42	82.61
3	22	43	91.1

Table 1: Moisture absorption

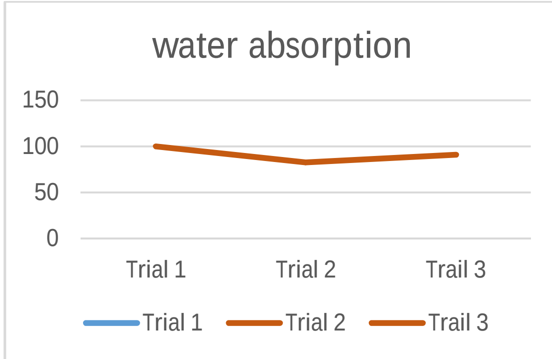


Fig: 5 Moisture absorption

B. Migration Test

Wf =105mg

Wi =100mg

A=1dm^2

Overall migration=$\frac{105-100}{1}$

Overall migration rate =5mg/dm^2

Simulant Used	Initial Color	Final Color	Color Change Grade	Remarks
Distilled Water	Clear	Yellowish	1	Mild pigment leaching

Table 2: Migration test

The result was compared against the permissible overall migration limit of **10 mg/dm^2** as specified in EU Regulation No. 10/2011

C. Microbial Contamination Test

MICROORGANISMS	COLONY FORMING UNITS[CFU/g]
Total Bacteria	1.7×10^3
Fungi	2.8×10^4
E.coli	0.6×10^3
Coli Forms Bacteria	Not detected
Bacillus & Clostridium	Not detected

Table 4.6 Microbial contamination test

D. Physicochemical Properties

PARAMETER	RESULT
pH	7.8
Specific Gravity	2.1
Bulk Density	0.9 g/cm^3

Table 4.7 Physicochemical property

The biodegradable tableware demonstrated high water absorption (50-100%), suitable for short-term liquid food use. Migration tests confirmed compliance with EU limits (5 mg/dm²). Microbial contamination was minimal, showing safe hygiene standards. Physicochemical properties, including neutral pH (7.8), specific gravity (2.1), and bulk density (0.9 g/cm³), ensured durability and environmental sustainability.

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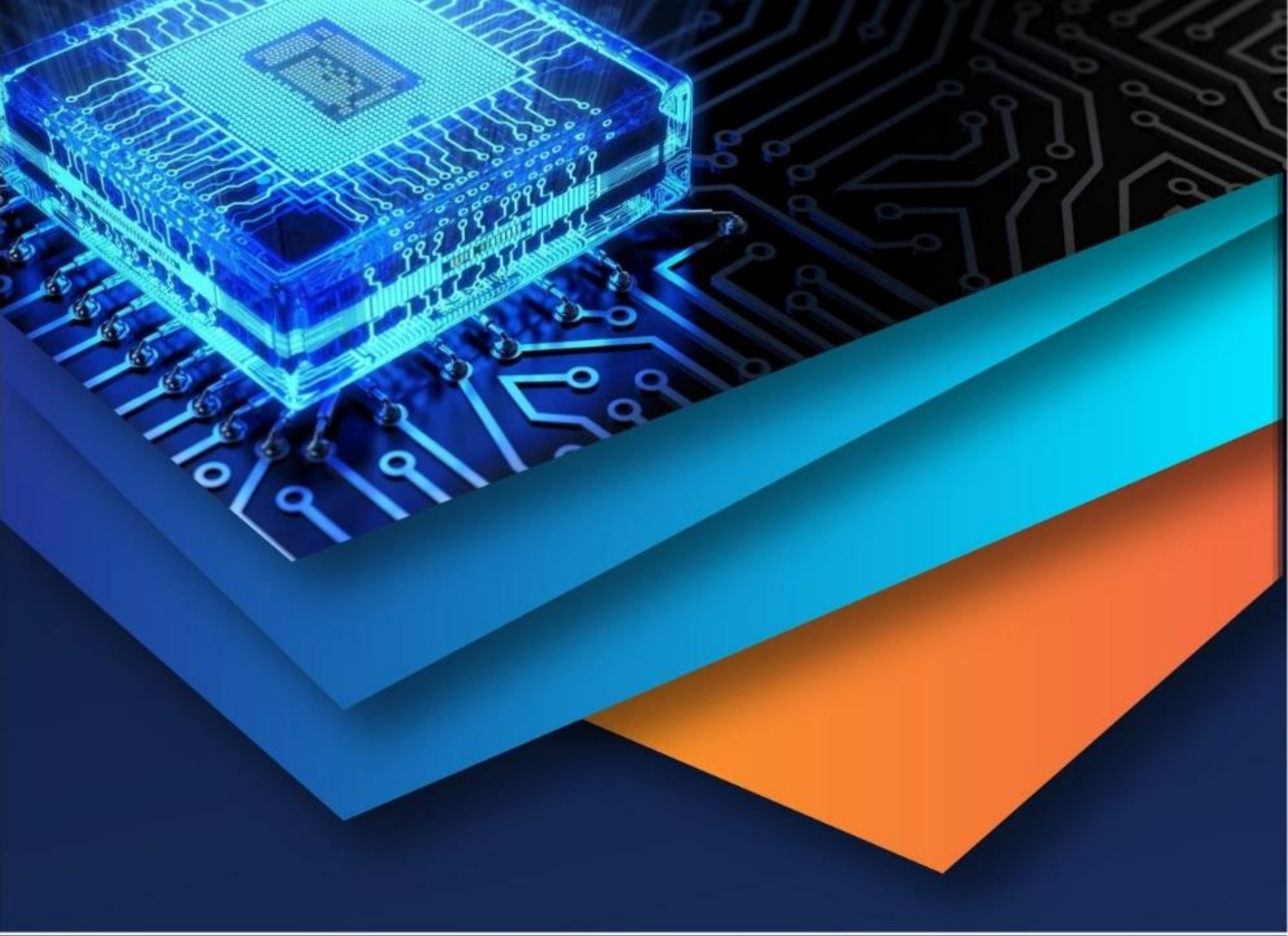

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