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Preparation of Bio-Based Packaging Using Waste Paper Composites, Sugarcane Bagasse and Coconut Fibre

Swathi K.[1], K. Gowri[2], S. Vanitha[3], Dr. Kalanidhi[4], Ms. S. Iswarya[5], Dr. Chandran Massi[6]
[1, 2, 3]*Department of Food Technology, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur621212*
[4, 5]*Assistant Professor, Department of Food Technology, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur-621212*
[6]*HOD, Department of Food Technology, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur-621212*

Abstract: The increasing environmental impact of plastic packaging has led to a growing need for sustainable alternatives. This study focuses on developing bio-based packaging materials using sugarcane bagasse, coconut fiber, and waste paper composites. Sugarcane bagasse (Saccharum officinarum) and coconut fiber (Cocos nucifera) are lignocellulosic residues rich in cellulose, hemicellulose, and lignin. The raw materials were dried, ground, soaked, and blended to form pulp, which was processed into packaging films with or without binders and dried through oven curing. The films were evaluated for water absorption, FTIR and SEM characteristics, physical properties, and antibacterial activity. A slight increase in water absorption was observed, while FTIR and SEM confirmed good structural interaction among components. The films exhibited favorable thickness, flexibility, and water-resistance properties, along with antibacterial activity against E. coli. These results indicate that the developed bio-packaging materials are suitable for food packaging applications. Future studies will further explore their classification and potential uses.

Keywords: Bio-package, waste paper, sugarcane bagasse, coconut fibre, antibacterial activity.

I. INTRODUCTION

The increasing environmental problems caused by plastic waste have pushed the world to look for safer and more eco-friendly packaging options. Most conventional plastics come from non-renewable synthetic polymers, and they do not break down easily. As a result, they accumulate in landfills and oceans, contributing to long-term pollution [1]. Their slow degradation also leads to the formation of microplastics (<5 mm), which spread through soil, water, and marine ecosystems, creating serious ecological risks [2]. Because of these concerns, it has become important to explore biodegradable and renewable packaging materials.

Bioplastics and other bio-based materials have gained attention as potential alternatives to petroleum-based plastics. These materials are mainly produced from renewable resources and can reduce fossil fuel use, greenhouse gas emissions, and the overall environmental impact [5, 8]. Agricultural residues such as lignocellulosic wastes are especially promising since they are easily available, inexpensive, and help in converting waste into useful products [17].

The food industry uses a large amount of single-use plastics because of the need for safe and affordable packaging. However, these plastics usually have a very short life span and are not biodegradable, which results in massive waste generation [9,11]. The rise in ready-to-eat foods and takeaway services has increased the use of small condiment sachets made from PE, PP, PET, and PS. These plastics contribute around 7–12% of global plastic waste, yet their recycling rate remains very low—only about 35% [6]. Since they persist in the environment and may release harmful chemicals, there is a strong need to replace them with safer, biodegradable options. Many researchers have tried blending conventional plastics with biodegradable polymers or creating bio-derived polymers. However, these approaches often have drawbacks like incomplete degradation or the need for specific composting conditions [12,10,20]. This highlights the need for packaging made entirely from natural, biodegradable materials.

Lignocellulosic agricultural wastes such as waste paper, sugarcane bagasse, and coconut fiber are eco-friendly for developing bio-based packaging. Waste paper makes up more than 30% of global solid waste and contains a high amount of cellulose, which can be reused effectively [13,14]. Sugarcane bagasse is widely available and rich in cellulose, making it suitable for strengthening biodegradable composites [16,15]. Coconut fiber also has high mechanical strength and cellulose content and is abundant in India [3,18]. Together, these materials can form strong, eco-friendly, and biodegradable packaging.

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Natural binders such as gelatin, starch, and lignin are often added to improve the strength and flexibility of bio-based composites. Gelatin, for example, forms good films and is safe for food-contact, although it sometimes needs reinforcement to improve water vapor resistance [4,19].

In this study, packaging sheets were prepared using varying combinations of waste paper, sugarcane bagasse, and coconut fiber, with and without natural binders. The sheets were tested for physical properties, water absorption, and antibacterial activity to evaluate their potential for food packaging applications. The results aim to support the development of sustainable, biodegradable packaging that can replace conventional plastic materials.

II. MATERIALS AND METHOD

A. Materials

The main materials that are used in this bio-based packaging project are sugarcane bagasse, coconut fibre and waste paper composites. Sugarcane bagasse and coconut fibre are collected from street vendors around Vallam, Thanjavur. Waste paper was sourced from discarded notebook sheets.

Flowchart:

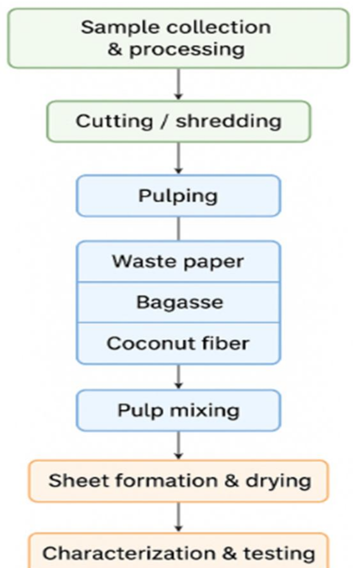


Figure 1-Flowchart of Bio-based Packaging sheet preparation

B. Sample Collection and Processing

Waste paper, sugarcane bagasse, and coconut fibers were collected and dried at 60–80 °C in an oven for 4–6 hours or under sunlight for 1–2 days. Coconut fibers were cut into 1–2 cm pieces, and waste paper was shredded using a paper shredder.

C. Pulping

1) Waste paper pulp preparation: Shredded waste paper was soaked in water for 24 hours, then blended until a smooth pulp was obtained.
2) Bagasse and coconut fibre pulp preparation: Dried sugarcane bagasse and coconut fiber were soaked in hot water (60–70 °C) for 2–3 hours and blended using a high-speed blender.
3) Pulp mixing: The pulps of waste paper, bagasse, and coconut fiber were combined in a beaker and stirred for 30–60 minutes to achieve uniform dispersion. Gelatin (binder) was added gently at a ratio of 1:3 or 1:4 (binder: mixture).

D. Sheet Formation and Drying

The mixture was poured into trays lined with aluminum foil and spread evenly to form thin sheets. The sheets were dried in an oven at 50–80 °C for 4–6 hours. The resulting bio-based sheets were stored for characterization.

E. Characterization & Testing

1) Water Absorption

Water absorption (Wa) was measured following Yun et al. (2008). Dried sheets were immersed in distilled water at 25 °C for 24 hours. Excess surface moisture was removed, and the sheets were weighed. Water absorption was calculated as:

$$Wa(\%) = \frac{W_e - W_o}{W_o} \times 100$$

Where W_e is the weight at absorption equilibrium and W_o is the initial dry weight.

2) FT-IR Analysis

FT-IR spectra were recorded using an ATR-FTIR spectrophotometer (Perkin Elmer) in the range 4000–400 cm^{-1} at 4 cm^{-1} resolution. Films were oven-dried prior to testing (Uppasen et al., 2023).

3) SEM analysis

Surface morphology and fiber distribution were observed using SEM (LEO 1450 VP) at 15 kV. Samples were gold-coated using a Polaron Range Model SC 7620 sputter coater (Uppasen et al., 2023).

4) Physical Tests

- Thickness: Measured using a digital micrometer (0.01 mm sensitivity) at five random locations; mean values reported (Susmitha et al., 2021).
- Flexibility: Sheets were bent over rods of varying diameters. The smallest diameter at which the sheet did not break was recorded as the flexibility value.
- Water Resistance: Samples (100 × 20 × 0.5 mm) were immersed in distilled water, and the time until film damage was recorded to assess water resistance (Ansori et al., 2023).

III. RESULT

A. Sample Collection and Processing

In this study, waste paper, sugarcane bagasse, and coconut fibers were collected, cleaned, and processed for further use. All samples were first washed with tap water to remove dust and then air-dried for 1–2 hours. After that, they were dried completely in a hot-air oven. Once dried, the coconut fibers and bagasse were cut into small pieces using scissors, and the waste paper was shredded into tiny pieces, as shown in Figure 1

Fig 3.1: Processed waste paper, sugarcane bagasse and coconut

B. Pulping

The shredded waste paper, coconut fiber, and sugarcane bagasse were soaked in water for 24 hours to soften the fibers. After soaking, each material was blended separately using a high-speed blender to form pulp (Figure 3.2). All the pulps were then combined and stirred for 1 hour. The mixture was prepared both with gelatin and without gelatin to compare the difference.

Figure 3.2-Soaked samples (sugarcane bagasse, waste paper and coconut fibre)

C. Drying

The mixed pulp was poured into Petri dishes and aluminum foil trays and dried in a hot-air oven at 50°C for 5 hours. Thin sheets were formed after drying (Figure 3). From the comparison, the sheet prepared **without gelatin** showed better texture and biodegradability.

Figure 3.3(a)Packaging material formed as a thin layer in petridishes

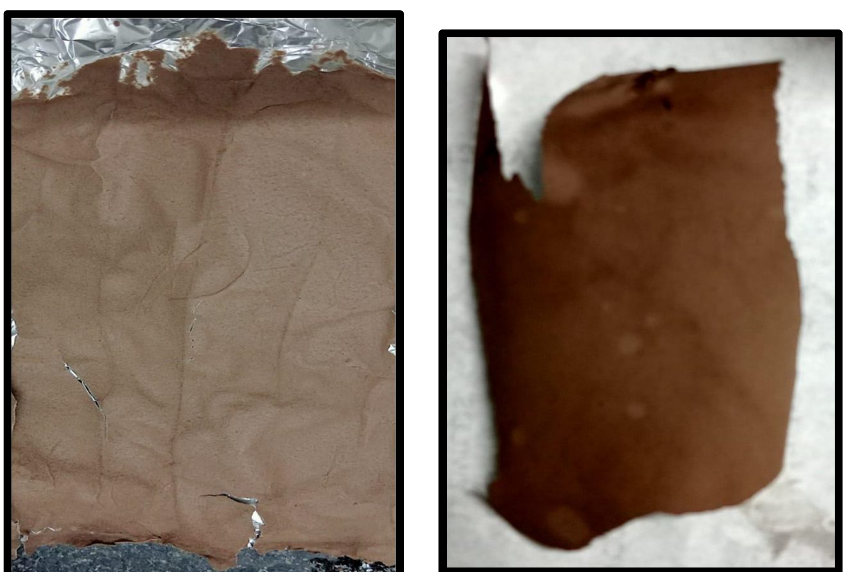


Fig 3.3(b): Packaging material formed as a sheet in an aluminium foil

D. Characterization and Testing

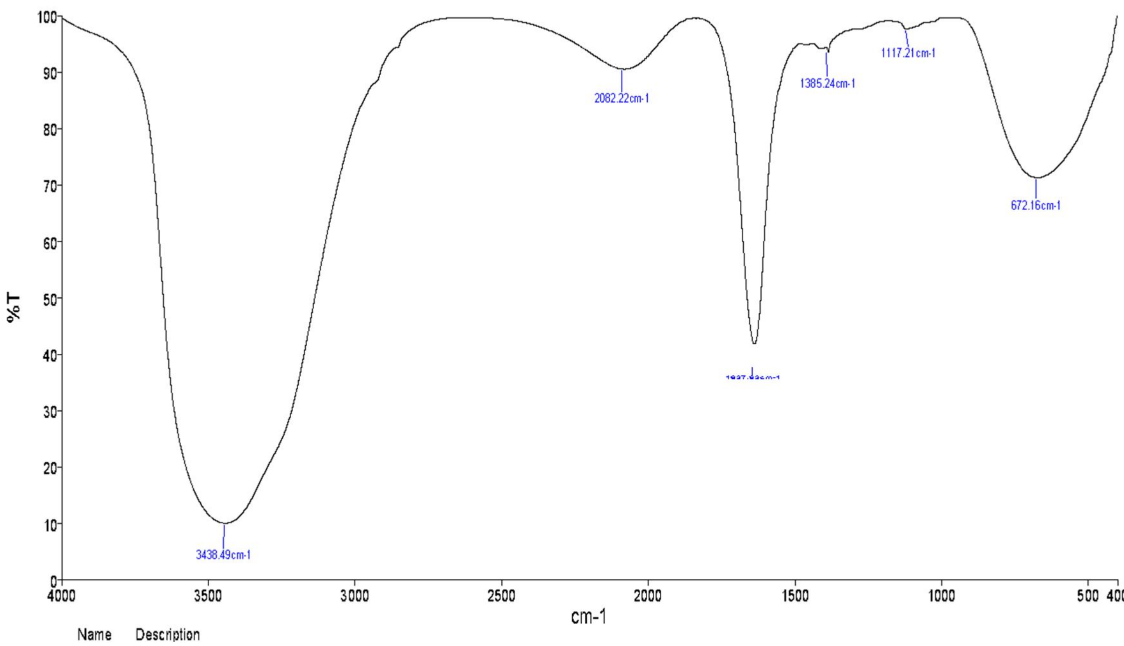
1) Water Absorption Test

Sample ID	Initial Weight (g)	Final Weight (g)	Water Absorption (%)
Sample 1	0.352	0.416	18.18%
Sample 2	0.348	0.410	17.81%
Sample 3	0.358	0.425	18.71%
Sample 4	0.355	0.418	17.73%
Sample 5	0.347	0.410	18.16%
Average			17.92% ± 0.33%

The results show that the developed film absorbed around **17–18% water**, with an average of **17.92%**. This indicates a moderate level of water absorption, which is expected because all three materials—bagasse, coconut fiber, and waste paper—contain cellulose that naturally absorbs moisture.

Even though the film absorbs water, it still maintains its structure. However, for applications that require high waterproofing, the material may need surface coating or the addition of hydrophobic agents in the future. For short-term use, especially in dry or semi-dry food packaging, the film is suitable.

2) FT-IR Analysis



S. No	Peak intensity
1	3438.49
2	2082.22
3	1385.24
4	1117.21
5	672.16
6	1637.93

The FTIR results showed peaks from **672.16 cm⁻¹ to 3438.49 cm⁻¹**, indicating the presence of functional groups commonly found in natural fibers.

- The broad peak at 3438.49 cm^{-1} corresponds to O–H stretching, which shows the presence of cellulose.
- The peak at 1385.24 cm^{-1} represents C–H bending, found in lignocellulosic materials like bagasse and coconut fiber.
- Peaks at 1117.21 cm^{-1} and 1637.93 cm^{-1} indicate C–O and C=O stretching, confirming the presence of cellulose and lignin.
- The peak at 2082.22 cm^{-1} shows the presence of unsaturated or aromatic components.

Overall, the FTIR spectrum confirms good blending of all three natural fibers and indicates that the chemical structure of the material is intact.

3) *SEM Analysis*

SEM images (*Figure 4*)of the developed film showed a rough and uneven surface with visible natural fibers embedded in the matrix. Coconut fiber and bagasse were clearly seen within the waste-paper base. The fibers appeared to be well-integrated, with no major gaps or cracks.

Although the surface looked porous and irregular, the structure appeared stable. This roughness may help in moisture interaction, while the strong fiber network supports mechanical strength. The SEM results confirm that the sheet was successfully formed using natural fibers without synthetic additives.

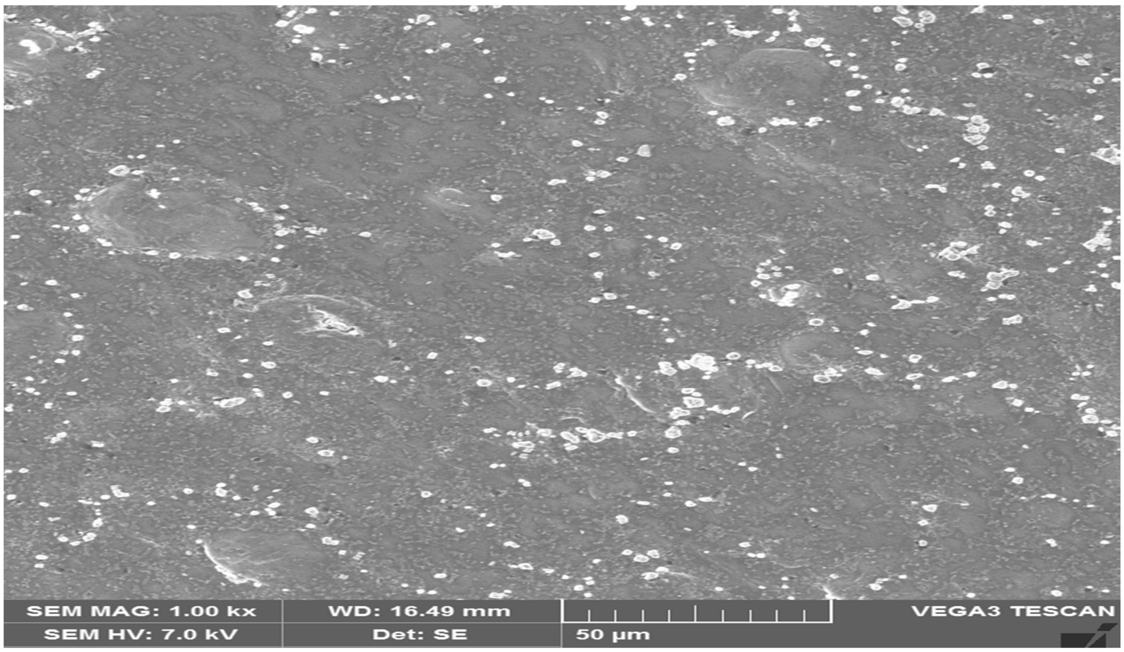


Figure 4 Sem Image

4) *Physical Tests*

a) *Thickness*

The thickness of the film averaged **0.36 mm ± 0.02 mm**, showing good uniformity across the sheet. Consistent thickness is important for maintaining strength and appearance in packaging.

b) *Flexibility*

The film was bent repeatedly up to **50 cycles**, and there were no cracks or visible damage. This shows that the film has good flexibility and can withstand normal handling during packaging.

c) *Water Resistance*

After 48 hours of immersion in water, the film showed only **4.2%** weight increase. It swelled slightly but did not lose its shape. This shows that the film has moderate water resistance and is suitable for short-term applications with light moisture exposure.

Test Parameter	Result	Remarks
Thickness	0.36 mm (±0.02 mm)	Uniform thickness ensuring consistent mechanical properties.
Flexibility	No visible cracks or permanent deformation after 50 cycles of bending	Excellent flexibility, suitable for handling and packaging.
Water Resistance	4.2% weight increase after 48 hours immersion	Moderate water resistance, suitable for short-term exposure to moisture.

In this study, we successfully created biodegradable sheets from waste paper, sugarcane bagasse, and coconut fibers. The results showed that the sheets formed without gelatin had better properties compared to those with gelatin. This suggests that the natural binding properties of the fibers were sufficient to hold the sheet together, eliminating the need for additional binders.

The sheets formed after drying the pulp mixture in the oven at 50°C for 5 hours (Fig 3.3). The absence of gelatin in the mixture seemed to improve the sheet's quality, indicating that the fibers were able to bond well on their own. These findings are promising for the development of sustainable packaging materials

IV. CONCLUSION

This study demonstrates that waste paper, sugarcane bagasse, and coconut fiber can be effectively upcycled into biodegradable packaging films with promising functional properties. The films showed moderate hydrophilicity, intact chemical structures (FT-IR), uniform morphology with good fiber bonding (SEM), and desirable physical characteristics, including consistent thickness, flexibility, and moderate water resistance. These results indicate that the developed films are suitable for dry and semi-dry food packaging. Given their low cost, biodegradability, and use of readily available waste materials, these composites offer a sustainable alternative to conventional plastics. Further optimization—particularly of moisture barrier properties—will support broader application and potential commercialization**.** Overall, our findings suggest that bio-based packaging films could play a significant role in promoting sustainable packaging practices and reducing environmental impact.

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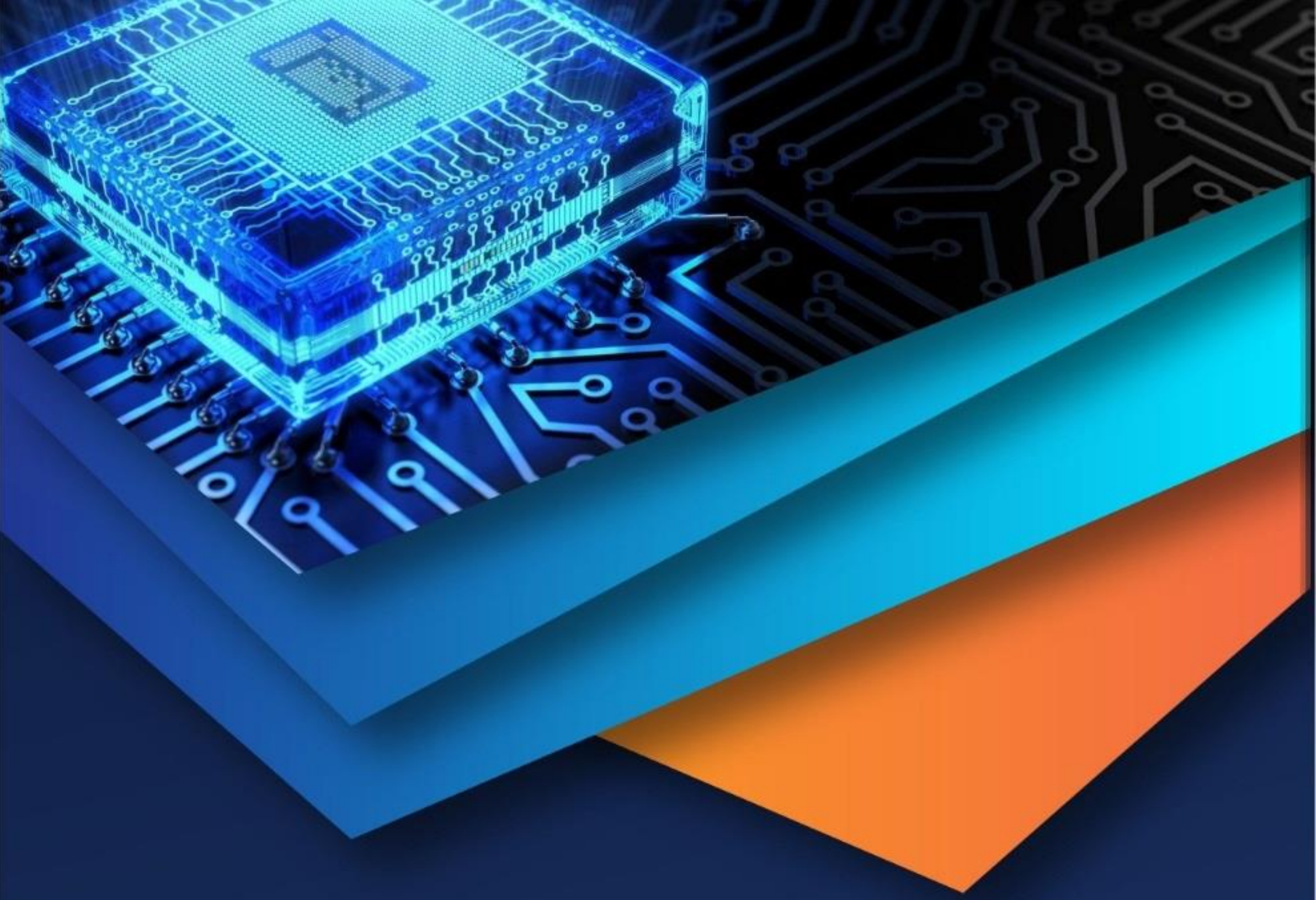

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