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The Physical and Mechanical Properties of Bamboo Fibres Filled with Calcium Carbonate Powder Reinforced Epoxy Composites in Coating Treatment Process for Roofing Application

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Abstract: In Malaysia's construction industry, reinforced concrete utilisation is not a recent development. However, the problem of overuse of construction material including steel, bricks and cement are not environmentally friendly as it will lead to greenhouse effect. On the other hand, bamboo is a natural resource which have a big population and promising material to be used in construction due to the strength, durability, and ability to replace steel in concrete. To solve the issues, bamboo fibre will be utilised as reinforcement in concrete. The research objective of this study is to determine the value of maximum and minimum force of bamboo with different arrangement of layer orientation for usefulness in roofing construction and to determine the effect of water absorption in bamboo-composite reinforcement for long term effects in roofing structure. The effect of using flame retardant materials in mechanical properties for bamboo laminate composites also has been studied. The experimental work focuses on the fabrication method which is hand layup technique. Then, the physical and mechanical test to determine workability and strength between coated and uncoated bamboo laminate composite were compared. The chemical treatment may enhance surface interaction, and at coated bamboo fibre, it alters the fibres' capacity to compact, which improved stress distribution and resulted in minimal void formation. This study is also to encourage the usage of natural renewable material as an alternative construction material.
Keywords: Bamboo Fibres; Hand Lay-up Technique; Coating Treatments; Physical Properties; Flexural Properties

I. INTRODUCTION

Nowadays, the construction sector is focusing on developing eco-friendly, green, and sustainable building materials. Construction materials including steel, bricks, cement, wood, aggregate, aluminium, cladding, and partitioning material are increasing in demand due to rapid growth of construction activities for housing and other buildings. Cement-based materials such as concrete are the major construction materials used to produce various infrastructures all over the world [1]. It has been estimated that approximately one ton of Carbon Dioxide (CO_2) and Nitrogen Oxide (NO) gasses emitted (i.e., 0.87 ton of CO_2 and 3 kg of NO) and to produce one ton of cement, about two tons of raw materials (i.e., limestone and shale) is consumed [2]. The production of cement can be ascribed to be responsible for about 6% of the world's anthropogenic greenhouse gasses emission with about two billion tons of greenhouse gases emitted annually because of the production of cement [3]. The green concept is being advocated extensively by environmentalists in recent years. Reduction of Carbon Dioxide (CO_2) emission and energy cut down are the examples of green concept which are always promoted to help the sustainability of our mother earth. The heat trapping of CO_2 and other greenhouse gases has been demonstrated in the mid-19th century according to the National Aeronautics and Space Administration (NASA). Hence, the use of environmental-friendly construction material has been promoted to protect our earth. One of the criteria being the environmental-friendly construction material is by having the potential in reduction of CO_2 emission during its production. Therefore, there is a need to begin the search for materials that are eco-efficient which will be a substitute for cement as reinforcement.

One of the newest developing materials with significant economic potential is bamboo. When compared to other naturally occurring resources, bamboo stands out due to its high productivity rate and quick harvest cycle. Additionally, it has been demonstrated that bamboo possesses an equivalent ultimate tensile strength to mild steel [4]. Previous research has stated that bamboo fibres can be

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used in concrete as revolutionary fibres to enhance concrete ductility, improve concrete strength, and post-cracking load carrying ability [5]. Bamboo fibre is a suitable candidate to be used as a natural fibre in composite materials among the numerous natural fibres [6], [7], [8]. Although bamboo's characteristics are quite like those of wood, it is easier to form and bend than wood [9]. Due to its extensive availability, notably in Malaysia, the Semantan (Gigantochloa Scortechinii) kind of bamboo was chosen for use in this study. Because bamboo naturally has a lot of hydroxyl side (-OH), a lot of moisture will be absorbed into its structure. When this untreated bamboo is made into a composite construction, a difficulty occurs since there will be an incompatibility factor, notably between the bamboo surfaces and matrix. Therefore, a surface treatment is necessary to minimise this effect on the result qualities of the composite. By far, few research were conducted that use the same treatment method [10], [11] .
Meanwhile, other researchers reported that the strength of concrete increased after 7 days of curing up to 56 days which means bamboo can be used as replacement of aggregates. From this research, the potential of bamboo fibre can be improved as building material as it can used in construction industry [12]. Besides, factors such as the cost of building materials got soared and higher competitive of world exchange currencies had brought the unstable of the current world economic circumstances. This situation led to several ongoing construction projects are having trouble getting the materials at lower cost. Thus, the utilization of bamboo as reinforcement will consequently reduce the cost of construction.

II. MATERIALS AND METHODS

A. Materials

Gigantochloa Scortechinii (Semantan bamboo) were used as the reinforcement supplied by Terra Techno Sdn. Bhd. (TTE), Shah Alam, Malaysia. Figure 1 illustrates the anatomy of bamboo culm. The internode part of the bamboo culm was taken and processed into strips form with specific dimensions of 30.0 cm length, 0.3 cm thickness and 1.0 cm width by using splitting machine while the node part was removed. Properties of *Gigantochloa Scortechinii* bamboo was summarized in Table 1 below.

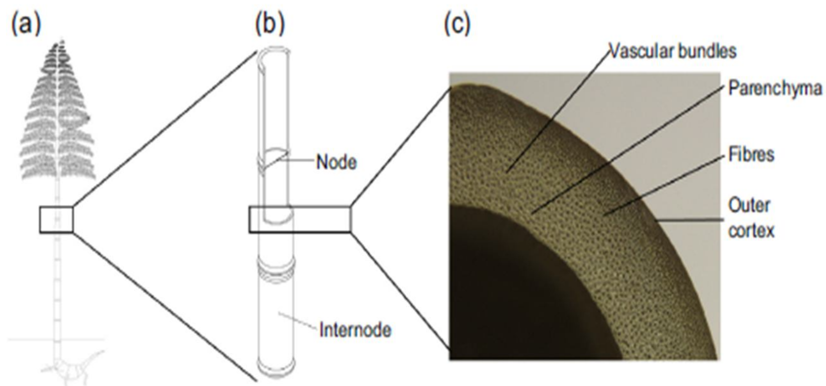

Figure 1: Anatomy of bamboo culm [13]

Table 1: Properties *Gigantochloa Scortechinii* bamboo

Age	Average density	Average fibre dimensions	Vascular bundle frequency	Moisture content	Average modulus of elasticity	Modulus of rupture	Compression strength	Shear strength
Mature, 3 year old	557 kg/m^3	Length = 4.24 mm, diameter = 17µm, wall thickness = 8µm	1.83/mm^2	90%	4960 N/mm^2	59.43 N/mm^2	28.79 N/mm^2	4.52 N/mm^2

Sources: Gigantochloa Scortechinii (PROSEA) [14]

As for the treatment, the epoxy resin (CP362A) and hardener (CP362B) were supplied by Vistec Technology Sdn. Bhd. The physical and chemical characteristics of epoxy resin and hardener are tabulated in Table 2. Meanwhile, the acetone (CH_3O_2) was supplied by Polyscientific Enterprise Sdn. Bhd.

Table 2: Physical characteristics of CP362 epoxy resin

Part	Code	Chemical type	Viscosity(cps)	Colour	Gel time (25°C)	Post cure (25°C)	Final viscosity(cps)
Epoxy	CP362A	Epoxy DGEBA	1300	Transparent	35 minutes	9.5 hours	8500
Hardener	CP362B	Modified Polyamine	400	Transparent			

Sources: All Purpose Epoxy [15]

Expanded Polystyrene (EPS) foam with dimensions 60cm x 90 cm supplied by Hi-Scan Wholesale Sdn. Bhd, Shah Alam, Malaysia. EPS is a white foam plastic material produced from solid beads of polystyrene. EPS foam were cut into 30.0cm length and 6.0cm width according to the size of each sample.

Calcium Carbonate in powder form were manufactured by Chemiz (M) Sdn. Bhd, Shah Alam, Malaysia. The physical and chemical properties of Calcium Carbonate powder are tabulated in Table 3.

Table 3: Physical and chemical properties of $CaCO_3$ powder

Appearances	Molecular weight	pH	Melting point/Freezing point	Relative density	Water solubility
Form= powder Colour = white	100.09 g/mol	8.0	800°C- decomposes on heating	2.93 g/cm^3 at 25°C	Insoluble

Sources: Safety Data sheet of Calcium Carbonate [16]

B. Chemical Treatment

The chemical solution which are epoxy and hardener were prepared and mixed (within gel time) with suggested ratio by weight prior diluted using acetone with 1:5 ratio. Next, the bamboo strips were immersed into the epoxy dilution with the immersion time of 5 minutes at room temperature. During this process, all the impurities were removed and simultaneously giving a thin layer of epoxy coating to the bamboo strips thus improve the mechanical properties. The epoxy coated of bamboo strips were finally taken out and oven-dried for 24h with temperature of 80˚C.

C. Sample Preparation

Both coated and uncoated bamboo laminate composite were used hand layup technique. Fibre orientation used for uncoated and coated bamboo laminate composite with Expanded Polystyrene (EPS) foam core were simplified as in the Table 4 below. PVC sheet was used as mould and the size of the mould for both samples of coated and uncoated were cut according to the thickness of the layer of bamboo samples. Table 5 showed the dimensions of the mould for each sample. EPS foam is also cut as the same shape of PVC sheet moulds. The resin, hardener, EPS foam and bamboo fibre was weighed using weighing scale before sample got fabricate based on the amount of bamboo layer. Each ratio of fibre weight to resin weight for bamboo with one, two, and three layers were 45:55, 40:60, and 35:65. A small safety factor which is 5% were added so that enough resin is mixed for the layup. Calcium Carbonate ($CaCO_3$) powder with 20 wt.% was first added and mixed with epoxy for 5 minutes followed by mixed with hardener (within gel time). The suggested ratio used for epoxy and hardener were 2:1. Before resin was poured into the mould, the internal surfaces of the mould were sprayed with a release agent to facilitate easy removal of the bamboo. A mixture of the epoxy, hardener, and $CaCO_3$ is applied in the form of thin layer in between bamboo strips and Expanded Polystyrene (EPS) foam to make hybrid composite. The assembly of bamboo strips and EPS foam with different orientation were illustrated in Figure 2, Figure 3, and Figure 4.

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Sample with one layer of bamboo orientation were B0˚/C. First, the mixture was poured inside the mould until it covered the lower surface. Then, 5 bamboo strips were placed slowly in longitudinally direction on the top of the lower surface to wet it. Afterwards, the mixture was poured on the top surface of the strips and spread in one direction by using a scraper to ensure that the resin fully enclosed the strips. EPS foams were placed slowly on top of wet bamboo strips and the mixture was poured immediately on top of it afterwards. At this stage, special care was taken to eliminate all air bubbles possible and to make sure the resin filled every corner of the mould by spread in one direction with a scraper. The HDPE plastic was placed on top of the hybrid composite to avoid the formation of air bubbles after lamination. The final step was to place a load on the composite to give pressure and stored the composite at room temperature for a period 24 hours to allow gelling and curing to progress before removal.

The second orientation with two layers of bamboo were B0˚/C/B0˚. First, the mixture was poured inside the mould until it covered the lower surface. Then, 5 bamboo strips were placed slowly in longitudinally direction on the top of the lower surface to wet it. Afterwards, the mixture was poured on the top surface of the strips and spread in one direction by using a scraper to ensure that the resin fully enclosed the strips. EPS foams were placed on top of wet bamboo strips and the mixture was poured immediately on top of it afterwards. Another 5 bamboo strips were placed slowly in longitudinally direction on top of wet EPS foam. A mixture was poured immediately on the top surface of the strips. A scrapper was used to eliminate all air bubbles possible and to make sure the resin filled every corner of the mould by spread the resin in one direction. The HDPE plastic was placed on top of the hybrid composite to avoid the formation of air bubbles after lamination. The final step was to place a load on the composite to give pressure and stored the composite at room temperature for a period 24 hours to allow gelling and curing to progress before removal.

There are two sample with three layer of bamboo orientation which were B0˚/C/B0˚/B0˚ and B0˚/C/B0˚/C/B0˚. For B0˚/C/B0˚/B0˚ orientation, the mixture was poured inside the mould until it covered the lower surface. Then, 5 bamboo strips were placed slowly in longitudinally direction on the top of the lower surface to wet it. Afterwards, the mixture was poured on the top surface of the strips and spread in one direction by using a scraper to ensure that the resin fully enclosed the strips. EPS foam were placed on top of wet bamboo strips and the mixture was poured immediately on top of it afterwards. Later, 5 bamboo strips were arranged slowly in longitudinally direction on the top of wet EPS foam. A mixture was poured immediately on the top surface of the strips. Another 5 bamboo strips were placed slowly in longitudinally direction on top of wet bamboo strips and followed with the mixture was poured on top surfaces of bamboo strips to wet it. A scrapper was used to eliminate all air bubbles possible and to make sure the resin filled every corner of the mould by spread the resin in one direction. The HDPE plastic was placed on top of the hybrid composite to avoid the formation of air bubbles after lamination. The final step was to place a load on the composite to give pressure and stored the composite at room temperature for a period 24 hours to allow gelling and curing to progress before removal.

Another sample with three layer of bamboo orientation were B0˚/C/B0˚/C/B0˚. First, the mixture was poured inside the mould until it covered the lower surface. Then, 5 bamboo strips were placed slowly in longitudinally direction on the top of the lower surface to wet it. Afterwards, the mixture was poured on the top surface of the strips and spread in one direction by using a scraper to ensure that the resin fully enclosed the strips. EPS foam were placed slowly on top of wet bamboo strips and the mixture was poured immediately on top of it afterwards. Later,5 bamboo strips were arranged slowly in longitudinally direction on the top of wet EPS foam. A mixture was poured immediately on the top surface of the strips. EPS foam were placed slowly once again on top of wet bamboo strips and the mixture was poured immediately on top of it afterwards. Another 5 bamboo strips were placed slowly in longitudinally direction on top of wet bamboo strips and followed with the mixture was poured on top surfaces of bamboo strips to wet it. A scrapper was used to eliminate all air bubbles possible and also to make sure the resin filled every corner of the mould by spread the resin in one direction. The HDPE plastic was placed on top of the hybrid composite to avoid the formation of air bubbles after lamination. The final step was to place a load on the composite to give pressure and stored the composite at room temperature for a period 24 hours to allow gelling and curing to progress before removal.

Table 4: Fibre orientation for coated and uncoated bamboo laminated composite

Sample	Sample code	Layer of bamboo	Sample orientation
Uncoated bamboo	UBC	1	B0°/C
	UBCB	2	B0°/C/B0°
	UBCBB	3	B0˚/C/B0˚/B0˚
	UBCBCB		B0˚/C/B0˚/C/B0˚
Coated bamboo	TBC	1	B0°/C
	TBCB	2	B0°/C/B0°
	TBCBB	3	B0˚/C/B0˚/B0˚
	TBCBCB		B0˚/C/B0˚/C/B0˚

Note: Expanded Polystyrene foam (C); Bamboo at 0˚orientation angle (B0˚)

Table 5: Sample dimensions of coated and uncoated bamboo laminated composite

Sample	Layer of bamboo	Sample orientation	Sample dimensions
Coated and uncoated bamboo	1	B0°/C	Length x Width: 30 cm x 6cm Thickness :1cm
	2	B0°/C/B0°	Length x Width: 30 cm x 6cm Thickness :1.5 cm
	3	B0˚/C/B0˚/B0˚	Length x Width: 30 cm x 6cm Thickness: 2.0 cm
		B0˚/C/B0˚/C/B0˚	Length x Width: 30 cm x 6cm Thickness: 2.3 cm

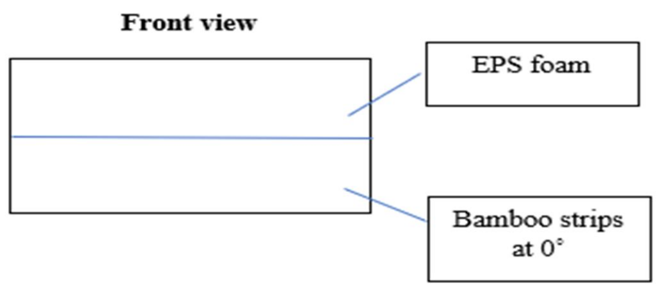


Figure 2: Illustrations for assembly of one layer bamboo strips and EPS foam

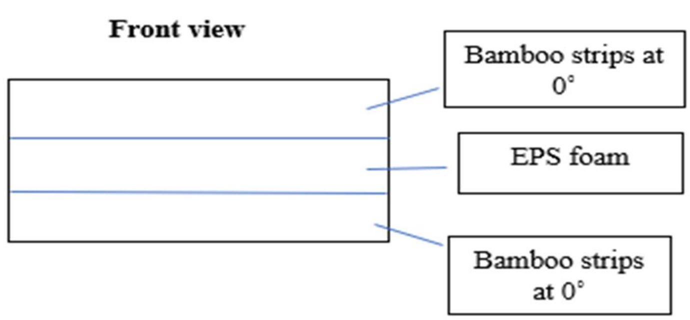
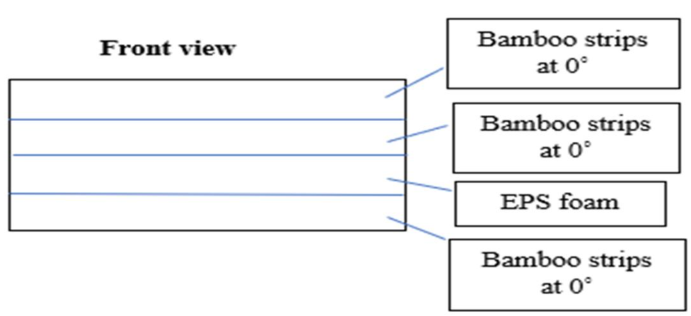


Figure 3: Illustrations for assembly of two layers bamboo strips and EPS foam



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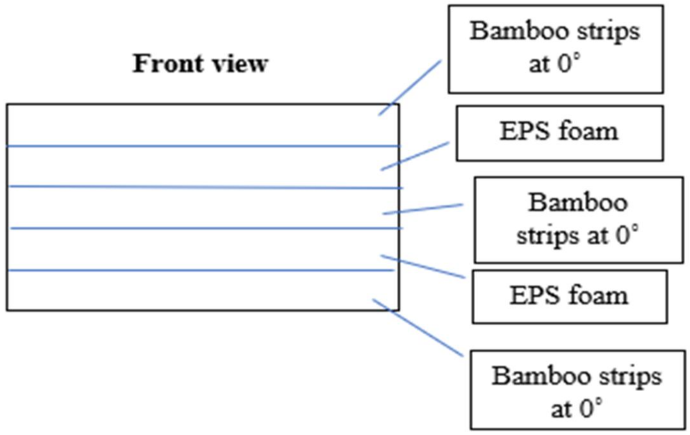

Figure 4: Illustrations for assembly of three layers bamboo strips and EPS foam

D. *Mechanical Testing*

Five test specimens were prepared for each coated and uncoated bamboo laminate composite. For flexural test, the specimens were prepared as ASTM D790 by using SHIMADZU Universal Testing Machine (AGX-20kN). The type of flexural test used was 3-point bending test. The crosshead speed used for all samples was 10mm/min. The sample dimensions for flexural test of coated and uncoated bamboo laminate composite were tabulated in Table 6.

Table 6: Sample dimensions for flexural test of coated and uncoated bamboo laminate composite

Sample	Layer of bamboo	Sample orientation	Sample dimensions
Coated and uncoated bamboo	1	B0˚/C	Length x Width: 15cm x 2.5cm Thickness: 1cm
	2	B0˚/C/B0˚	Length x Width: 15cm x 2.5cm Thickness: 1.5cm
	3	B0˚/C/B0˚/B0˚	Length x Width: 15cm x 2.5cm Thickness: 2cm
		B0˚/C/B0˚/C/B0˚	Length x Width: 15cm x 2.5cm Thickness: 2.3cm

E. *Physical Testing*

1) *Density Test*

For density test, the composite samples were cut according to the standard prior to calculate the density. The sample dimensions for density test of coated and uncoated bamboo laminate composite were tabulated in Table 7. All samples were oven dried for 24 hours at 103°C before being weighted. Density meter was used to obtain the density and was calculated using formula as in Equation (1). The results were expressed as average value of five excremental runs.

$$\text{Density} = (\text{Oven weight} - \text{dry weight}) / (\text{Volume of sample}) \quad (1)$$

The percentage of differences between measured and theoretical density in the prepared composites was determined according to ASTM D2734 as in Equation (2) and Equation (3).

$$\text{Differences (\%)} = (\rho\ \text{theoretical} - \rho\ \text{experimental}) / (\rho\ \text{theoretical}) \quad (2)$$

$$\rho\ \text{theoretical} = 1/(Wf/\rho f + Wm/\rho m) \quad (3)$$

where W_f is the reinforcement weight fraction, W_m is the matrix weight fraction, P_f is the reinforcement density, and P_m is the matrix density.

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Table 7: Sample dimensions for density test of coated and uncoated bamboo laminate composite

Sample	Layer of bamboo	Sample orientation	Sample dimensions
Coated and uncoated bamboo	1	B0˚/C	Length x Width: 2cm x 2cm Thickness: 1cm
	2	B0˚/C/B0˚	Length x Width: 2cm x 2cm Thickness: 1.5cm
	3	B0˚/C/B0˚/B0˚	Length x Width: 2cm x 2cm Thickness: 2cm
		B0˚/C/B0˚/C/B0˚	Length x Width: 2cm x 2cm Thickness: 2.3cm

2) Water Absorption Test

The composite samples were cut according to the standard prior to calculate the percentage increase in weight during immersion. The sample dimensions for water absorption test of coated and uncoated bamboo laminate composite were tabulated in Table 8. The samples are tested according to ASTM D750 where the specimen was conditioned in the laboratory for 24 hours. Immediately after that the specimens are weighed. The material is then emerged in distilled water at agreed upon conditions, often 23°C for 24 hours or until equilibrium. Specimens are removed, patted dry with tissue, and weighed using analytical balance. The percentage increase in weight during immersion was calculated to the nearest 0.01% as in Equation (4).

$$\text{Increase in weight, \%} = (\text{wet weight} - \text{conditioned weight}) / (\text{conditioned weight}) \times 100 \quad (4)$$

Table 8: Sample dimensions for water absorption test of coated and uncoated bamboo laminate composite

Sample	Layer of bamboo	Sample orientation	Sample dimensions
Coated and uncoated bamboo	1	B0˚/C	Length x Width: 2cm x 2cm Thickness: 1cm
	2	B0˚/C/B0˚	Length x Width: 2cm x 2cm Thickness: 1.5cm
	3	B0˚/C/B0˚/B0˚	Length x Width: 2cm x 2cm Thickness: 2cm
		B0˚/C/B0˚/C/B0˚	Length x Width: 2cm x 2cm Thickness: 2.3cm

3) Rockwell Hardness Test

For hardness test, the composite samples were cut according to the standard prior to calculate the sample hardness. The sample dimensions for hardness test of coated and uncoated bamboo laminate composite were tabulated in Table 9. The hardness test was conducted by using INSTRON Wilson/Rockwell Series 600 Digital Hardness Tester machine with HRR scale. The load is applied by using a ball indenter made of a steel ball.

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Table 9: Sample dimensions for hardness test of coated and uncoated bamboo laminate composite

Sample	Layer of bamboo	Sample orientation	Sample dimensions
Coated and uncoated bamboo	1	B0˚/C	Length x Width: 5cm x 5cm Thickness: 1cm
	2	B0˚/C/B0˚	Length x Width: 5cm x 5cm Thickness: 1.5cm
	3	B0˚/C/B0˚/B0˚	Length x Width: 5cm x 5cm Thickness: 2cm
		B0˚/C/B0˚/C/B0˚	Length x Width: 5cm x 5cm Thickness: 2.3cm

4) Flame Retardancy Test

The test employed in this study is horizontal burning which is technically equivalent to ASTM D635 (rate of burning and/or extent and time of burning of plastics in a horizontal position). A bar specimen with dimensions of 125mm x 13mm x actual thickness of specimen (≤ 13mm) was prepared and supported horizontally at one end. The free end was subjected to the flame and the flame was removed from the specimen after 30 s. The timer was started when the flame hit the first gauge length (25 mm) and the elapsed time for the flame to travel from the 1st gauge mark (25mm) to the 2nd gauge mark (100mm) was recorded in seconds (t) and the burn length (L) was recorded as 75 mm. The total elapsed time for the flame to move from the 1st gauge mark to the 2nd gauge mark was recorded and the linear burning rate (V) was calculated according to Equation (5).

$$V\ (\text{mm min}^{-1}) = L/t\ (60) \quad (5)$$

Here, L = the burned length (75 mm) and t = the elapsed time in seconds for the burning from the 1^{st} gauge mark to the 2^{nd} gauge mark. The front view of set up procedure was illustrated in Figure 5.

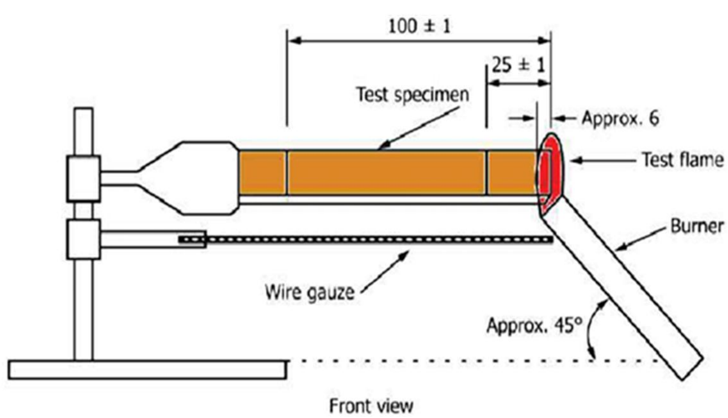

Figure 5: The front view of set up procedure [17]

III. RESULTS AND DISCUSSIONS

A. Mechanical Testing

Three points bending test has been performed and flexural properties for coated and uncoated bamboo composites are illustrated in Figure 6 and Figure 7. The maximum flexural strength for one layer of coated bamboo composite (TBC) was 31.31 MPa whereas uncoated bamboo composite (UBC) was 33.32 MPa which are the highest flexural strength among bamboo laminate composites. When the maximum load reaches there had failure happened in one layer for coated and uncoated bamboo composite during flexural test. These types of failure are core breaking and delamination.

When two layers of bamboo was added on one layer of EPS foam core, there is slight increment of flexural strength for coated bamboo composite (TBCB) which are 31.99 MPa. Flexural strength for uncoated bamboo composite (UBCB) was decreased to 27.79 MPa. Delamination happened which are a little crack was observed in between layer of bamboo and EPS foam core for coated, whereas crack was occur on top layer of bamboo for uncoated bamboo composite when the maximum load was reached.

A slight decrease of flexural strength happened for coated bamboo composite (TBCBB) which are 31.62 MPa when three layers of bamboo was added on one layer of EPS foam core. Flexural strength for uncoated bamboo composite (UBCBB) was increased to 33.04 MPa. Major failures of delamination happened which are cracking of EPS foam core and breakage of bamboo in between layer of sample for coated and uncoated bamboo composite.

Coated (TBCBCB) and uncoated (UBCBCB) bamboo composite had the lowest flexural strength due to the increases of the sample thickness when three layers of bamboo was added on two layers of EPS foam core. Flexural strength for coated and uncoated bamboo composites was 17.45 MPa 15.61 MPa respectively.

It can be concluded that increasing number of bamboo layers did not influence the flexural strength as for one, two, and three layers of coated and uncoated bamboo laminate composite had not so much different value of flexural strength.

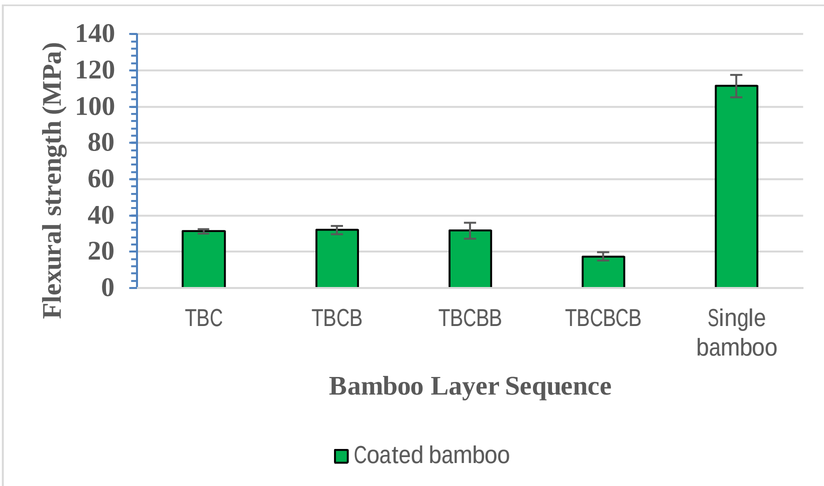

Figure 6: Flexural test for coated bamboo composite

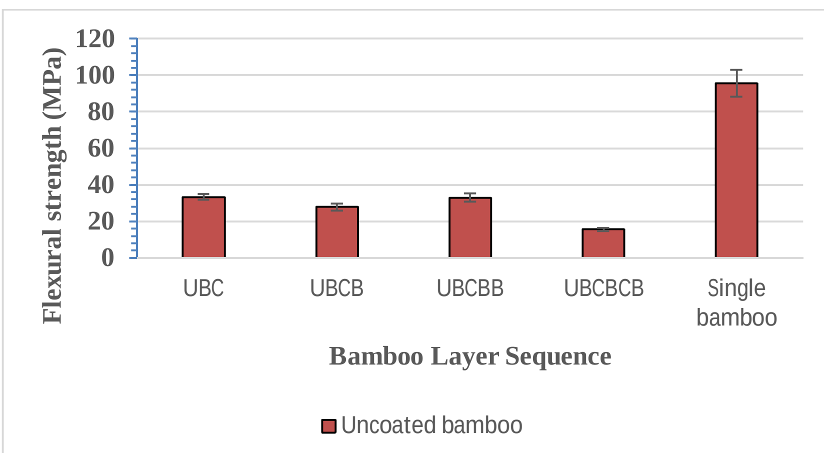

Figure 7: Flexural test for uncoated bamboo composite

B. *Physical testing*

1) *Density Test*

Table 10 presents influence of filler loading and bamboo treatment composite on density (theoretical and experimental) and percentage differences (theoretical and experimental density). It has been observed that measured density is less than the theoretical density, which might be due to the presence of voids in composites [18].

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Composite with three layer of coated and uncoated bamboo was analysed. It has been observed that when the bamboo was added into three layers, there was an increment of density for coated and uncoated bamboo (B0°/C/B0°/B0°) composites. When the bamboo and EPS foam was arranged alternately (B0°/C/B0°/C/B0°) there was a sudden drop of density for coated bamboo composite, whereas for uncoated bamboo there was not so much difference in density value. On the other hand, the coated bamboo composite (B0°/C/B0°/B0°) has lower percentage differences (theoretical and experimental density) compared to all the other composites, due to the better compatibility between epoxy resin, filler, and EPS foam. It can be observed that an increase of bamboo layer in composites leads to a reduction of percentage differences for coated and uncoated bamboo composites. Uncoated one layer bamboo presents a higher amount of percentage difference (0.72%). It can be concluded that the incorporation of bamboo, Calcium Carbonate powder filler, and EPS foam can reduce the percentage difference and enhance the physical properties of composites.

Table 10: Theoretical and measured densities comparison composite laminates

Bamboo composite sequences		Measured density (g/cm^3)	Theoretical density (g/cm^3)	Differences (%)
Coated bamboo with $CaCO_3$ filler	B0°/C	0.423	0.426	0.70
	B0°/C/B0°	0.620	0.623	0.48
	B0°/C/B0°/B0°	0.718	0.719	0.14
	B0°/C/B0°/C/B0°	0.570	0.571	0.18
Uncoated bamboo with $CaCO_3$ filler	B0°/C	0.416	0.419	0.72
	B0°/C/B0°	0.562	0.565	0.53
	B0°/C/B0°/B0°	0.629	0.630	0.16
	B0°/C/B0°/C/B0°	0.624	0.625	0.16

2) Water Absorption Test

The water absorption properties of 20 wt.% of Calcium Carbonate filler-based bamboo epoxy composites with or without coating treatment was indicated in Figure 8 and Figure 9. It was observed that coated bamboo composites absorbed more water compared to uncoated bamboo composites. Coated bamboo composite had a higher water absorption rate due to the existence of pores and voids [19]. Water absorption initially increases with time however it saturates after a period of 29 days.

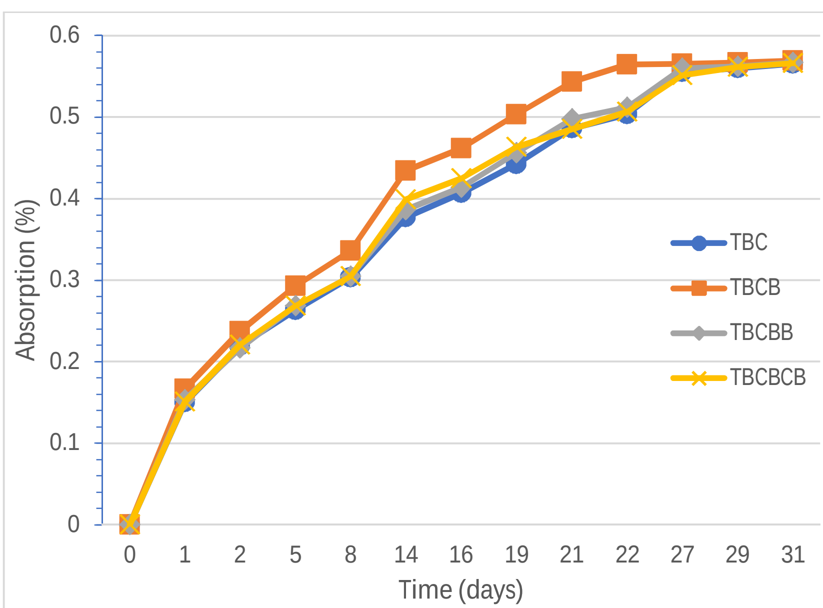

Figure 8: Water absorption for coated bamboo filled composites.

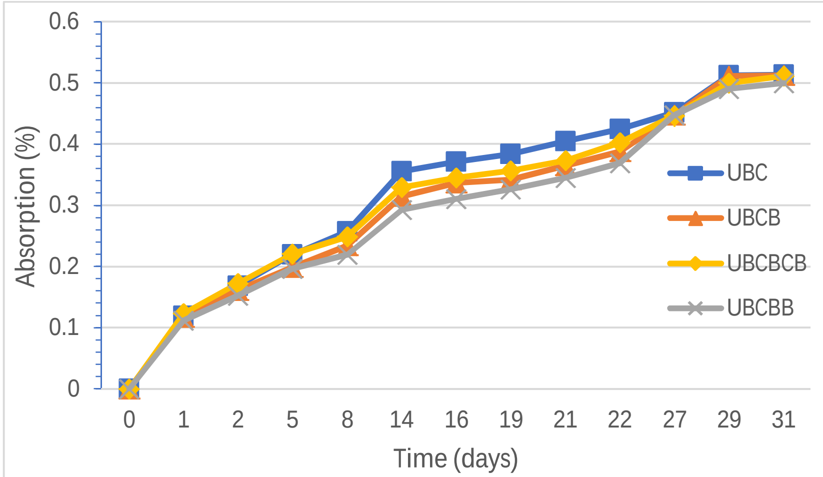

Figure 9: Water absorption for uncoated bamboo filled composites.

3) Rockwell Hardness Test

The hardness result of 20 wt.% of Calcium Carbonate filler-based bamboo epoxy composites with or without coating treatment was presented in Figure 10 and Figure 11 and it is noticeable that the stacking sequence for coated bamboo had a higher hardness compared to uncoated bamboo composite. This is due to the higher density and hardness value of bamboo fibre in the composite laminate. Other possible reasons that might increase the hardness of coated bamboo which are in situ cleaning of bamboo strip surface during epoxy coating treatment because of the existence of acetone thus improves the adhesive characteristics of bamboo fibre surface by removing hemicellulose and lignin. This surface offers an excellent fibre-matrix interface adhesion and results in an increase in the mechanical properties. Penetration of epoxy resin into bamboo might increase the hardness of bamboo. On the other hand, a composite with three layers of coated and uncoated bamboo was analysed. It had been observed that when bamboo was added into three layers, there was an increase in hardness value for coated (TBCBB) and uncoated bamboo (UBCBB) composites. When the bamboo and EPS foam was arranged alternately there was a sudden drop of hardness for coated bamboo (TBCBCB) composite, whereas there is not so much different in hardness value for uncoated bamboo (UBCBCB) composite.

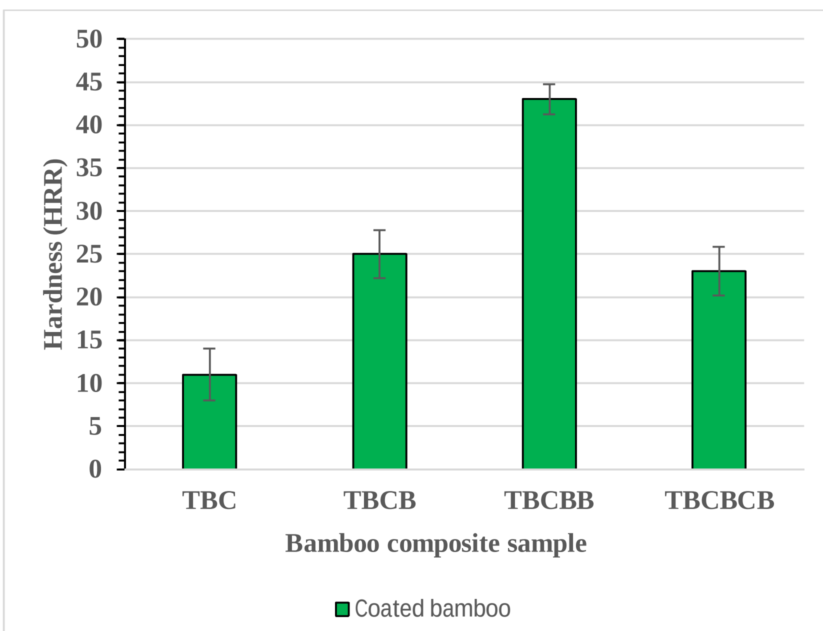

Figure 10: Hardness value for different layer of coating treatment bamboo composite sample

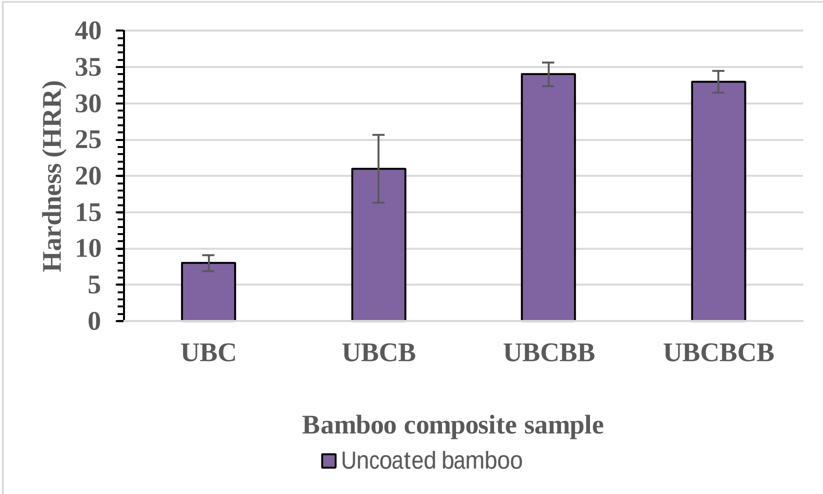

Figure 11: Hardness value for different layer of uncoated bamboo composite sample

4) Flame Test

The flammability assessment of bamboo/epoxy composite with filler has been analysed using UL-94 horizontal burning test. During the test, flame was applied to one end of the specimen for 30 second and the time required to burn 100 mm length of each sample has been evaluated. The burning rates along with burning behaviours are listed in Table 11. It has observed the rate of burning of bamboo fibre reinforced composites increase with increase in fibre loadings. This is because natural fibers are readily combustible, and as their weight percentage increases in composite materials, the likelihood of ignition also rises, speeding up the burning process [20]. Moreover, with greater fibre loading, there may be a potential that the fibers won't get properly soaked, leaving the cellulosic fibers exposed to the free air and making them more prone to catching fire [21].

The horizontal burning test also showed the combustion rates of uncoated bamboo laminate composites higher than the coated bamboo laminate composites. The burning rate of uncoated bamboo (UBCBCB) composite was highest among the coated and uncoated bamboo laminate composite. It might be due to the incompatibility of both fibers with the matrix, the fiber's cellulosic material was left exposed and caught fire [22]. Among all bamboo laminate composites, coated bamboo (TBC) laminate composites showed lowest burning rate, it may be due to better compatibility of fibers and matrix that created a hurdle in burning sample. The results exhibited the effect of fibre loading and stacking sequences that have influenced the flammability properties of the bamboo laminate composites.

Table 11: The UL-94 flammability characteristics of bamboo and its composites

Bamboo laminate composite		Burning rate (mm/min)	Visual observations
Uncoated bamboo with $CaCO_3$ filler	UBC	15.56	Less dripping, burning slowly, and smoke produces
	UBCB	16.15	Less dripping, burning slowly, and smoke produces
	UBCBB	17.0	Slow dripping, continuous burning, and high smoke produces
	UBCBCB	18.0	No dripping, burning very slowly, and high smoke produces
Coated bamboo with $CaCO_3$ filler	TBC	14.54	Dripping, burns rapidly, smoke free flame, and no residue
	TBCB	15.45	Less dripping, burning slowly, and smoke produces
	TBCBB	16.03	Dripping, burning slowly, and smoke produces
	TBCBCB	16.74	Dripping, continuous burning, and smoke produces

IV. CONCLUSION

The epoxy composites of bamboo fibre reinforced with non-reinforcing filler were made to evaluate the effect of $CaCO_3$ filler and coating treatment on physical and mechanical properties of the composite. From the results of this study, the following conclusions are drawn:

1) Incorporation of filler in bamboo fibre composites enhance the properties of the resulting composites.
2) Increasing number of bamboo layer significantly does not influence the flexural strength of laminate bamboo sequence.
3) Epoxy coating gives optimum water absorption up to (0.570%).
4) The bamboo fibres were successfully treated with epoxy to produce a thin layer of epoxy coating that will protect the fibre structure and strengthen the bond between the fibres.

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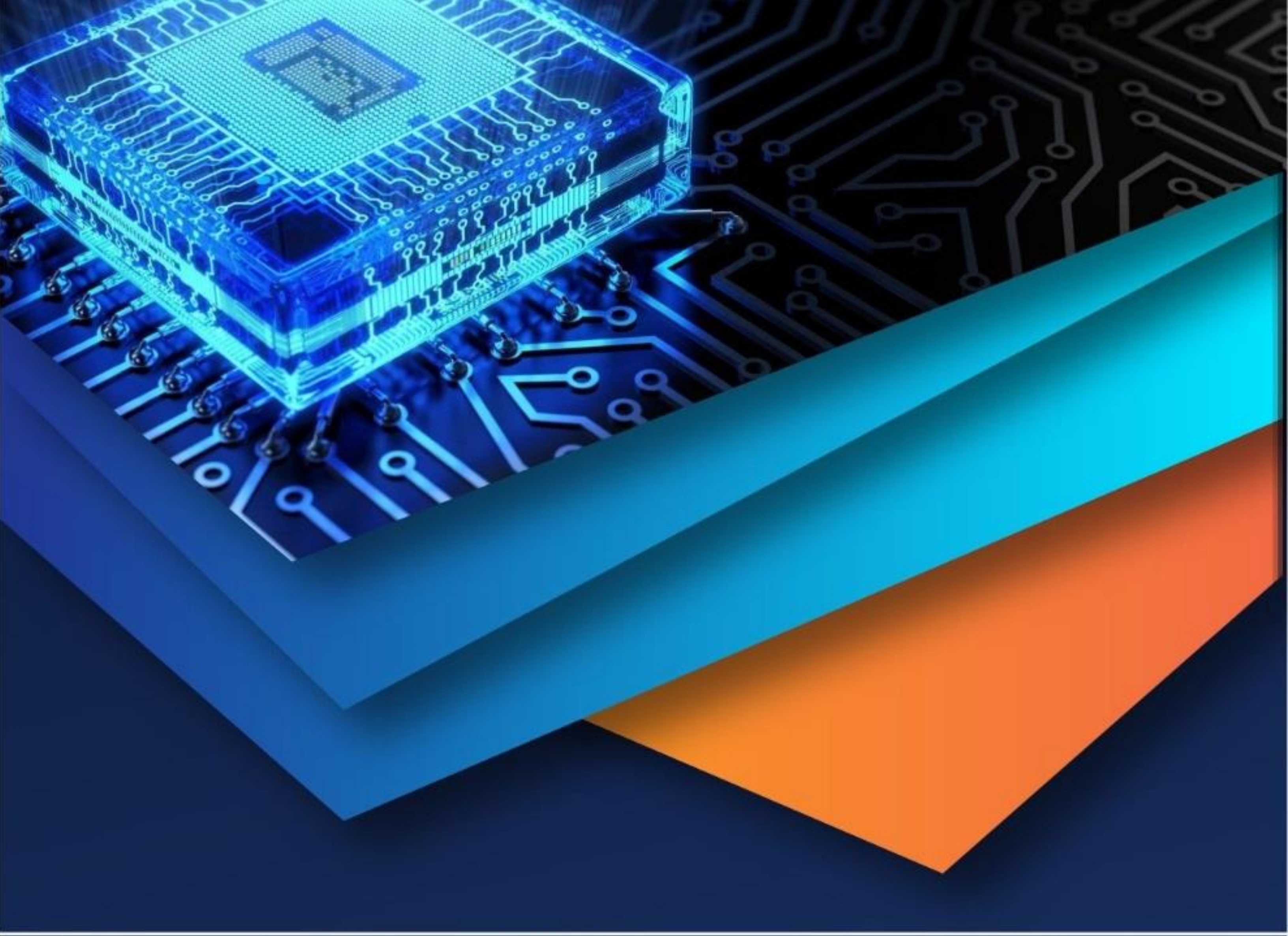

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