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Original Article

Development and Characterization of a Corn Cob Particulate/Polyester Resin Composite for Use as a Particle Board

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Abstract *- In this research, corn cob particulate/polyester resin composites were developed with varying percentages of corn cob particles (5%, 10%, 15%, 20%, 25%, and 30%). The study aimed to explore the potential of corn cob particles, an agricultural waste material, as a sustainable alternative for producing particle boards. The high rate of deforestation and global warming necessitates alternative methods of producing furniture boards. The research involved characterizing the raw materials, fabricating composite samples using the hand lay-up method, and analyzing the physical and mechanical properties of the hybrid composite. The corn cob particle average density was 281.18 kg/m³. Untreated corn cob particles absorbed water more readily, with a water absorption of 54.60% in the first two hours of immersion, compared to treated corn cob particles, which had a water absorption of 27.30%. The composites with 5% corn cob content had the lowest water absorption percentage of 0.46%, while those with 30% corn cob particles had the highest water absorption of 3.01 %. The density of the fabricated composite samples ranged from 1.12 to 1.129 g/cm³. Among the composites, the sample with 5% corn cob particles exhibited the highest tensile strength of 15.40 MPa, while the sample with 30% corn cob particles had the lowest tensile strength of 1.66 MPa. The composite samples with 10% corn cob particle content showed the highest recorded flexural strength of 26.94 MPa, followed by samples with 5% corn cob particle content at 26.63 MPa. Conversely, the 30% corn cob content samples had the lowest flexural strength of 18.42 MPa. The compressive strength of the samples increased slightly with the inclusion of corn cob particles. The sample with 10% corn cob particles exhibited the highest compressive strength of 84.28 MPa, and the sample with 30% corn cob content had the lowest compressive strength of 30.86 MPa.*

Keywords *- Composite, Corn Cob, Furniture applications, Mechanical properties.*

1. Introduction

There is an increasing demand for wood to be used in furniture applications, resulting in an increased rate of deforestation [1]. The increased rate of deforestation is also fueled by the increasing demand for living space and furniture [2]. The World Bank has speculated that the total population in the world will double; this will put an increasing strain on the forests to provide wood for furniture applications, increasing the demand for furniture [3]. The furniture industry is battling to increase production costs and diminish forests and raw wood materials [4].

The high rate of deforestation and high demand for wood-based furniture have motivated research into more sustainable raw materials for furniture production [5]. Research trends have moved towards exploring the use of agricultural by-products, normally considered waste, to create value-added bio-composites that can be used as substitutes for wood [6]. Agricultural residues and natural fibre-reinforced polymer composites have recently gained great attention and traction due to their potential as sustainable and eco-friendly materials [7]. Agricultural by-products such as rice straw, cotton stalks, wheat straw and corn cob have been used to manufacture bio-degradable composite materials [8].

Particle boards are widely used in making furniture. Conventional particle boards are manufactured from wood chips, wood flakes, or strands. However, these conventional particle boards have a limitation of swelling upon moisture absorption. Particle boards are not only preferred because of preserving trees they also are cheaper as compared to using wood [9]. They are also durable if they are maintained properly. Agricultural residues have recently gained a lot of attention as alternative raw materials for particleboards due to their low cost, density and availability [10].

The use of Corn Cob (CC), a by-product of maize farming, is increasingly gaining popularity due to its renewable and biodegradable nature (Gairola, 2022). Furthermore, corn cob has low density, is readily available, is non-toxic and has good physical properties (Gairola, 2022). Polyester resins are widely used as they have numerous advantages over other thermosetting resins.

The advantages include being able to cure at room temperature and good mechanical properties (Aziz, 2015). Hence, this study seeks to utilize waste corn cob particles and polyester resin to create particle boards. There has not been sufficient research into the effects of varying corn cob volume fractions on the composite mechanical properties.

2. Materials and Methodology

2.1. Preparation of Corn Cob Particles

The corn cobs were soaked in 1% NaOH solution for 2 hours and then oven-dried at 50°C. The treated corn cobs were then ground to particulate size. The ground corn cobs were sieved to obtain particles between 0.5 mm and 2 mm.

2.2. Polyester Resin

General Purpose Polyester Resin NC 901 was used to fabricate the composite samples.

2.3. Corn cob Particles Bulk Density

The bulk density of the corn cob particles was measured about the ASABE standard using a 500 cm^3 measuring cylinder. The measuring cylinder was filled with sieved corn cob particles of approximately 2 mm in size. The bulk density of the corn cob particles was calculated using Equation 1.

$$\rho C = \frac{mC}{V} \tag{1}$$

Where ρC is the density of the corn cob particles, mC is the mass of the corn cob that filled the 500 cm^3 measuring cylinder, and V is the volume of the cylinder occupied by the corn cob particles.

2.4. Experimental Design and Formulations

The experimental design shown in Table 1 was followed in fabricating the composite.

Table 1. Experimental design and formulation

Sample Label	wt.% (Corn Cob)	Mass of Corn Cob (g)	Mass of Resin (g)
5% CC	5	18.40	358.88
10% CC	10	36.80	359.36
15% CC	15	55.20	359.84
20% CC	20	73.60	359.60
25% CC	25	92.00	360.80
30% CC	30	110.40	361.28

Key CC – Corn cob particles

2.5. Fabrication of Composite Samples

The hand lay-up technique was used for composite fabrication. The mould used had dimensions of 200 mm × 200 mm × 8 mm. The composite was allowed to cure at room temperature.

2.6. Characterization of the Composite Samples

The following subsection gives the composite characterization tests, which include water absorption, tensile strength, flexural strength, and compressive strength. For each test, a minimum of 5 samples were tested.

2.6.1. Water Absorption

The water absorption was measured in accordance with ASTM D 5229 with composite samples with dimensions of 100 mm×100 mm×8 mm. The composite samples were then oven-dried for 24 hours at 80°C and weighed to an accuracy of 0.01 g. Thereafter, the composite samples were submerged in distilled water at room temperature and weighed every 24 hours. The results were recorded until no further increase in water absorption was observed.

2.6.2. Tensile Strength

The tensile properties of the composite samples were tested according to the ASTM 638 standard. Rectangular samples were prepared for testing with dimensions of 200 mm × 25 mm×8 mm. A universal testing machine was used at a constant speed of 201 mm/min.

2.6.3. Flexural Strength

Using a Universal Testing Machine, the flexural strength was measured according to ASTM D 790. Rectangular test pieces with dimensions 200 mm×25 mm×8 mm were placed horizontally on a support span with a gauge length of 80 mm. The load was applied to the centre of the test pieces by a loading nose, translating into a three-point bending configuration. The loading continued until the test piece failed. The flexural strength and modulus of the samples were determined using equations 2 and 3.

$$Flexural\ Strength = \frac{3Mx}{2wt^2} \tag{2}$$

$$Flexural\ Modulus = \frac{Mx^3}{4wt^2L} \tag{3}$$

Where M is the maximum load at break, x is the distance between the two support spams at the edges of the sample, w is the width of the sample, t is the thickness of the sample, and L is the deflection.

2.6.4. Compressive Strength

Uniform rectangular test pieces with dimensions 155 mm×25 mm×8 mm were tested for the compression test according to ASTM D 3410. A PROL IKON Automatic Compression Testing Machine, PGC-2002 Model, was used for the compression test. The compression test was performed at a 0,2 kN/sec loading speed.

3. Results and Discussion

3.1. Characterization of the Corn Cob Particles

3.1.1. Bulk Density of Corn cob Particles

The bulk density of the corn cob particles was 279.30-285.80 kg/m^3, with the average bulk density of the corn cob particles being 281.18kg/m^3. The obtained value was consistent with the study by Zhang (2012) [11] who obtained a bulk density of 282.38 kg/m^3. The results also tally with the corn cob particles' bulk densities range of 210-323 kg/m^3 reported by Prasertpong (2022) [12]. The bulk density of the particles plays an important role in determining the dimensional stability of the produced composites. A high bulk density can harmoor interfacial bonding between the corn cob particulate and the matrix [13].

3.1.2. Water Absorption of Corn Cob

Figure 1 shows the results for the water absorption of both the alkaline treated and untreated corn cob particles.

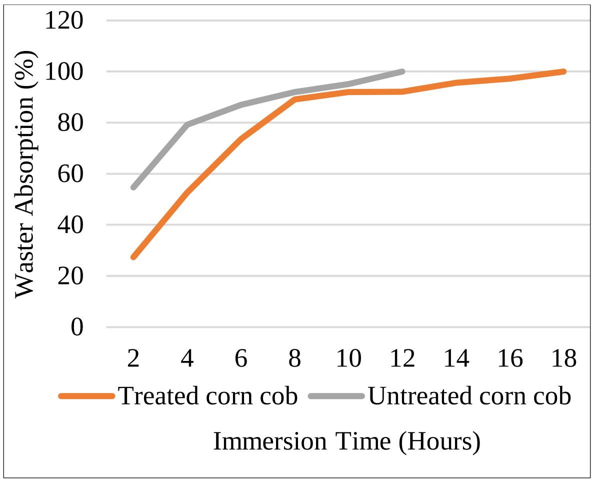

Fig. 1 Water absorption of Corn Cob particles

From Figure 1, it can be observed that both treated and untreated corn cob particles followed a similar trend, whereby the corn cob particles absorbed water more rapidly in the first few hours of immersion. The water absorption increased gradually as immersion time increased until saturation was reached.

Treated corn cob particles absorbed water more readily with a minimum value of 54.60% In the first 2 hours of immersion compared to the minimum value of 27.30% exhibited by untreated corn cobs. Treated corn cobs had a significantly lower water absorption compared to untreated corn cob particles because alkaline treatment with NaOH removes hemicellulose and lignin, which have high affinity for water, hence reducing the water absorption of the treated corn cob particles [14, 15].

Shao (2021) [16], reported results that agree with the current study where the water absorption of corn cob particles reduced after alkaline treatment. From Figure 1, it is shown that treated corn cob particles absorbed water at a slower rate as they reached water absorption saturation of 100% after 18 hours, whereas untreated corn cob particles took 12 hours to reach 100% saturation. Treated corn cob particles took longer to reach water absorption saturation because the alkaline treatment alters the surface characteristics of the particles, thus creating barriers that hinder the passage of water into the particles, while untreated corn cob particles maintain a porous surface that permeates more readily and saturates the particles quicker. [17]. Therefore, alkaline treatment enhances the performance of corn cob particles as reinforcement and filler for composites exhibiting good water and moisture resistance.

3.2. Characterization of Physical and Mechanical Properties of Composite

The following sections analyze the physical and mechanical properties of the developed composites.

3.2.1. Results of Water Absorption Test

Figure 2 shows the graph of water absorption of the corn cob composite samples.

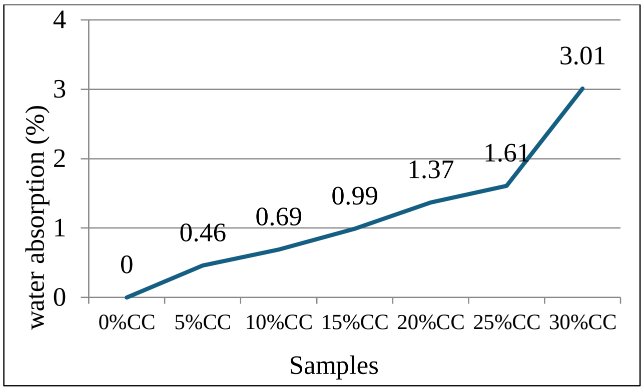

Fig. 2 Water absorption of composite samples

From the results shown in Figure 2, the water absorption generally increases with an increase in corn cob volume fraction. The increase in water absorption as the corn cob loading increases is attributed to the porosity of the corn cob particles and their complex microstructure. As the loading of the corn cob particles increases, more spaces and pathways for water to infiltrate and be absorbed are provided [18]. Furthermore, this trend exhibited by the composites can be attributed to the hydrophilicity of the corn cob particles. Corn cobs contain cellulose and hemicellulose, which are hydrophilic components. When incorporated into a polyester resin matrix, these particles can swell and retain water through capillary action and hydrogen bonding [19]. This absorption ability depends on factors like particle size, surface area, and porosity of the corn cob particles.

0% CC had the lowest water absorption due to the chemical structure of polyester resin, which consists of hydrocarbon and does not favourably interact with water molecules. Furthermore, the crosslinked structure of cured polyester resin and its dense packing of polymer chains create a barrier that restricts the movement of water molecules through the material. The highest water absorption value was obtained for 30% CC due to the high corn cob content.

3.2.2. Results for Density of Composite

Figure 3 shows the composite density results with the corn cob particle content variation.

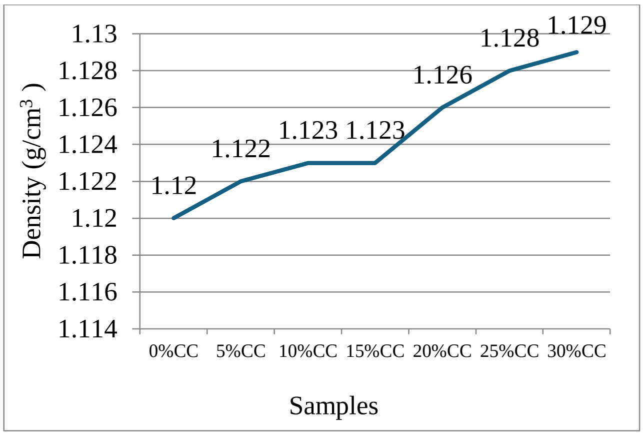

Fig. 3 Density of fabricated composite samples

The density of the developed composite is of uttermost importance as it affects the weight of the final fabricated composite material [20]. The density of the composite material largely depends on the matrix's density. As illustrated in Figure 3, the density of the composite increased gradually from 0-15% CC**,** and there was a sharp increase in density from 15-30% CC. The density increased as the corn cob content increased because the corn cob particles were denser than the polyester resin matrix [21]. Furthermore, as the corn cob particles' content increases, their matrix arrangement becomes more compact and denser. This packing effect leads to less void space between the particles, further increasing the composite's density. This trend resonates with the results reported for parinari polyandra fruit shell-reinforced epoxy composites by Odetoye (2020) [22].

3.2.3. Tensile Strength Properties

Figure 4 shows a graph of the composite tensile strength test.

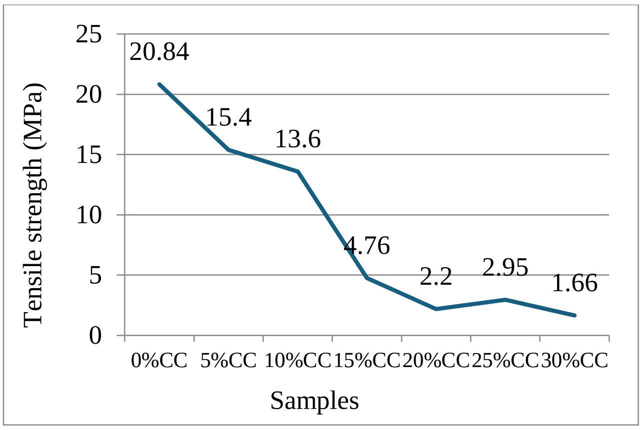

Fig. 4 Tensile strength results

Figure 4 shows that the tensile strength of the composites containing corn cob particles is lower than that of polyester resin neat, which has a tensile strength of 20.84 MPa. The tensile strength decreased from 0% CC to 5% CC with a value of 15.4 MPa. The tensile strength decreased notably from 10% CC to 20% CC. This significant decrease in tensile strength with an increase in corn cob particle loading may be attributed to the poor adhesion between the polyester matrix and the corn cob particles [23].

The minimum value of 1.66MPa was obtained for 30% CC because of poor adhesion between the corn cob particles and the polyester resin matrix. Sandeep (2022) [24] obtained similar results for corn cob filler-based polypropylene composites. The tensile strength of the composite decreases as the corn cob particle content increases because as the content of the corn cob increases, it can introduce discontinuities and potential stress concentrations within the composite material.

The discontinuities act as points of weakness where cracks can initiate and propagate under tensile stress. The strength of the composite becomes predominantly matrix-dominated.

3.2.4. Flexural Strength Properties

Figure 5 shows the effect of increasing corn cob volume fraction on the composite flexural strength.

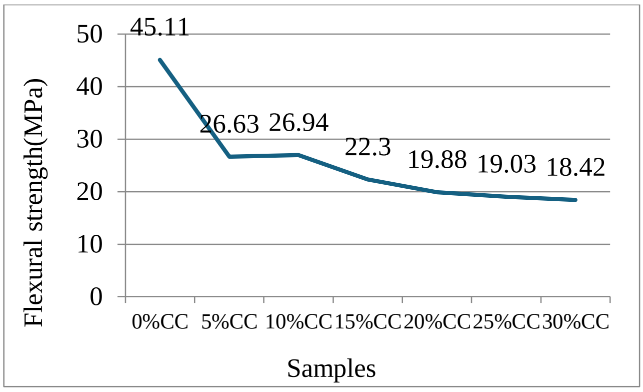

Fig. 5 Flexural strength results

Figure 5 shows that the developed composites' flexural strength was lower than the pure polyester matrix, which had a flexural strength of 45.11 MPa.

The composite samples with 10% corn cob particle content exhibited the highest recorded flexural strength of 26.94 MPa, followed by samples with 5% corn cob particle content at 26.63 MPa. On the other hand, the samples with 30% corn cob content exhibited the lowest flexural strength of 18.42 MPa.

Generally, the flexural strength decreased as the percentage of corn cob content increased. However, an anomaly was observed with the sample containing 10% corn cob particles, which exhibited higher flexural strength compared to the sample containing 5% corn cob particles. The higher flexural strength observed in the sample with 10% corn cob content can be attributed to the even distribution of particles within the composite, leading to a slight increase in flexural strength.

This distribution effect promotes better load distribution and enhances the overall mechanical properties of the composite, resulting in improved flexural strength compared to the sample with 5% corn cob particle content. Furthermore, the steady decrease in flexural strength with corn cob loading may be attributed to poor particle dispersion, resulting in particles clumping together and leading to regions of weakness and stress concentrations.

Onuoha (2017) [19] obtained different results for composite from recycled polypropylene and corn cob particles. The flexural strength of the composite increased with corn cob filler loading. This discrepancy in results can be attributed to the difference in particle sizes. Finer has better rigidity and stiffness, resulting in a fair dispersion and distribution of the corn cob particles, effectively hindering chain movement during deformation [25].

Flexural Modulus Properties

Figure 6 shows the resultant flexural modulus of the developed composite.

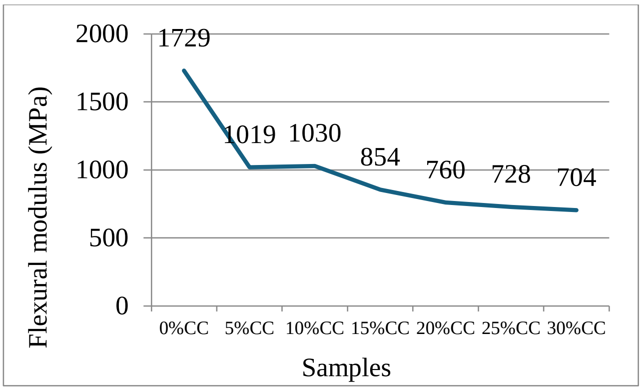

Fig. 6 Flexural modulus of composites

The flexural modulus plays a significant role in determining the stiffness and rigidity of composite materials. From the plotted graph in Figure 6, it was observed that the polyester matrix 0% CC had the highest flexural modulus of 1729 MPa, while 30% CC had a minimum value of 704 MPa. There was a linear decrease in flexural modulus from 0% CC to 30% CC due to low crosslinking density and agglomeration at high weight fraction at high weight fraction of CCPs. Onuoha (2017) [19] reported different results for corn cob particle hybrid composite with recycled polypropylene composites. The flexural modulus of a composite material, such as corn cob/polypropylene and corn cob/polyester resin, can vary significantly with changes in the content of corn cob filler due to several key factors. In the case of the corn cob/polypropylene composite, an increase in corn cob content typically leads to an increase in flexural modulus [26]. This can be attributed to the reinforcing effect of corn cob particles or fibers within the polypropylene matrix. As the filler content increases, more corn cob particles interact with the polymer matrix, enhancing load transfer and stiffness. The fibrous nature of corn cob can effectively reinforce the matrix, thereby increasing the composite's resistance to bending forces.

Conversely, in the corn cob/polyester resin composite, the flexural modulus tends to decrease with higher corn cob content. This phenomenon arises from several factors specific to polyester resin matrices. Polyester resins often exhibit lower stiffness than polypropylene, and excessive filler loading can disrupt the resin's molecular structure or reduce its ability to transfer loads effectively. Additionally, poor adhesion between corn cob and polyester resin may weaken load transfer mechanisms, leading to a decrease in overall stiffness. These combined effects result in a reduction of the composite's flexural modulus as corn cob content increases in polyester resin matrices.

3.2.5. Compressive Strength Properties

Figure 7 shows the composite compressive strength with varying corn cob particle loading. Figure 7 shows that the highest compressive strength of 84.28 MPa was observed in the sample with 10% corn cob particle content, followed by 83.53 MPa in the sample with 5% corn cob particle content. These values were higher than the compressive strength of the polyester matrix, which was 82.08 MPa. However, there was a significant decrease in compressive strength from 84.28 MPa to 65.80 MPa as the corn cob particle content increased from 10% to 15%. The sample with 30% corn cob content exhibited the lowest compressive strength of 30.86 MPa. The observed increase in compressive strength with the incorporation of corn cob particles can be attributed to the particle-matrix interaction, where the corn cob particles contribute to the load-bearing capacity of the composite. However, beyond 10 %, the excessive presence of corn cob particles leads to a disruption in the composite structure, resulting in a rapid decrease in compressive strength [27].

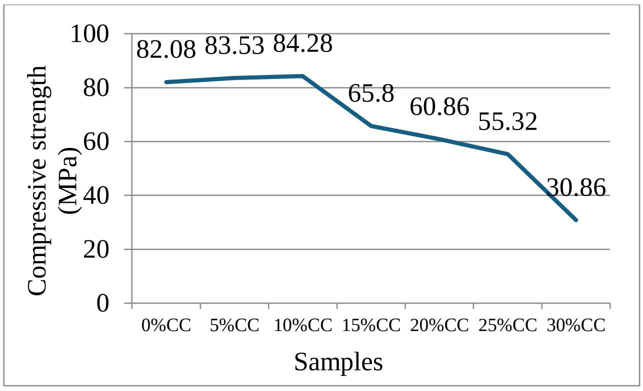

Fig. 7 Compressive strength of composite samples

Furthermore, it could be due to CCPs acting as reinforcement within the composite material, helping to resist compressive forces through additional support and preventing crack propagation. A sudden decrease in compressive strength was observed for 15% CC owing to the weak interfacial bonding between the matrix and the CCPs, leading to a decrease in compressive strength. The minimum compressive strength was recorded for 30% CC with a value of 30.86 MP. The low compressive strength may be due to CCPs agglomeration, which causes uneven distribution of the filler within the matrix, which creates weak spots and stress concentrations, which leads to low compressive strength [28]. Kiran (2015) [29] obtained similar results for particulate-reinforced hybrid composites. However, Salmah (2013) [30] obtained different results. The compressive strength was found to decrease with the loading of kernel shell particles due to weak interfacial bonding between the matrix and the reinforcement.

4. Conclusion

Several conclusions were drawn from the study, as follows. The bulk density of the corn cob particles of 281.18 kg/m³ used in the composite material is consistent with the 210 – 323 kg/m³ values reported in the previous study conducted by Prasertpong in 2022 [12]. This suggests that the corn cob particles used in the research project have a density within the expected range for similar materials. The consistency in bulk density implies that the corn cob particles can be suitable for use in composite materials. It was observed that untreated corn cobs exhibited higher water absorption. In the first 2 hours of immersion, untreated corn cob particles reached a minimum water absorption percentage of 54.60, while treated corn cob particles had a lower minimum percentage equilibrium of water absorption, measuring at 27.30. Additionally, untreated corn cob particles took 12 hours to reach 100% saturation of water absorption, whereas treated corn cob particles took 18 hours. This indicates that alkaline treatment enhances the water absorption properties of corn cob particles by eliminating lignin and hemicellulose, which have a strong affinity for water molecules.

Composite water absorption showed an increasing trend with the addition of corn cob particles. The lowest water absorption percentage of 0.46% was observed in composites with 5% corn cob content, while the highest water absorption of 3.01% was observed in composites with 30% corn cob particles. Therefore, corn cob particles were responsible for the increased water absorption in the corn cob/polyester resin composite. The density of the fabricated composite samples ranged from 1.12 to 1.129 g/cm^3. There is mostly an increase in density as the volume fraction of the corn cob particles increases.

The lowest tensile strength of 1.66 MPa was observed in the sample containing 30% corn cob particles, while the highest tensile strength of 15.40 MPa was recorded in the sample with 5% corn cob particles. The decrease in tensile strength with an increase in the percentage of corn cob particles can be attributed to the weaker mechanical properties inherent to the corn cob particles, which have a bearing on the overall strength of the composite material.

The composite samples with 10% corn cob particle content exhibited the highest recorded flexural strength of 26.94 MPa, followed by samples with 5% corn cob particle content at 26.63 MPa. On the other hand, the samples with 30% corn cob content exhibited a minimum flexural strength of 18.42 MPa. Generally, the flexural strength reduced as the volume fraction of the corn cob content increased. The highest flexural modulus of 1030 MPa was recorded in the sample with 10% corn cob particle content, while the lowest flexural modulus of 704 MPa was observed in the sample with 30% corn cob particle content. As the corn cob particle content increased from 15% to 30%, there was a decrease in flexural modulus. The decrease in flexural modulus with increasing corn cob particle content can be attributed to the lower stiffness and reinforcing capability of the corn cob particles compared to the polyester matrix, leading to a reduction in the overall rigidity of the composite material.

The compressive strength of the fabricated samples increased slightly with the incorporation of corn cob particles, with the highest compressive strength of 84.28 MPa exhibited by the sample with 10% corn cob particles content, followed by 83.53 MPa exhibited by the sample with 5% corn cob particles content which was higher than that of the polyester matrix which had a compressive strength of 82.08. However, there was a rapid decrease in compressive strength from 84.28 MPa to 65.80 MPa as the corn cob particles increased from 10% to 15%. The lowest compressive strength was recorded for the sample with 30% corn cob content, which had a value of 30.86 MPa.

The fabricated composite showed feasibility in use as a substitute material for wood in furniture applications and some construction and packaging-related applications. There is a need for further research into the other applications of the corn cob composite material.

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