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DEVELOPMENT AND CHARACTERIZATION OF BAOBAB BARK FIBRE (*Adansonia digitata*) AND BAMBOO FIBRE (*Bambusa Vulgaris)* REINFORCED POLYVINYL CHLORIDE (PVC) HYBRID COMPOSITES

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***Abstract**: This study investigates the mechanical properties, water absorption behavior, and fibre-matrix interaction of polyvinyl chloride (PVC) composites reinforced with baobab bark and bamboo fibres. The fibres were extracted using water retting, mechanically processed, and treated with sodium hydroxide (NaOH) to enhance their surface properties. Compression moulding was employed to fabricate the composites. The tensile test results showed an increase in tensile strength and elastic modulus with fibre loading, peaking at 20 wt% fibre loading (30.40 MPa and 286.20 MPa, respectively). Beyond this, further fibre loading caused a decline in both properties. Impact strength increased with higher fibre content, with the highest energy absorption at 10/90 wt%. Hardness increased steadily, peaking at 64.28 Hv for a 40/60 composition ratio, but decreased at a 50/50 ratio. Flexural strength decreased as baobab bark fibre content increased, with the highest strength (28.28 MPa) at a 20/80 composition ratio. Water absorption was highest at 50 wt% fibre content and lowest at 10 wt%, with lower fibre concentrations resulting in better encapsulation by the PVC matrix. The results underscore the complex relationship between fibre composition and mechanical properties, providing insights into optimizing fibre loadings for specific applications.*

***Keywords:** Polyvinyl Chloride (PVC) Composites; Baobab Bark Fibres; Mechanical Properties; Water Absorption; Fibre-Matrix Interaction*

1.0 **INTRODUCTION**

1.1 Background of the Study

The growing demand for sustainable and eco-friendly materials has spurred significant interest in natural fibre-reinforced polymer composites (NFRPCs). These composites utilize natural fibres such as flax, jute, hemp, and sisal as reinforcements within polymer matrices to create materials that combine high strength with environmental friendliness (Vijay *et al*., 2014). Composite materials, known for their superior mechanical properties and sustainability, have garnered attention across various industries. A composite material typically consists of at least two distinct constituents, encompassing both traditional materials like bricks, concrete, and wood, and advanced materials such as fibre-reinforced plastics (FRPs) (Anderson *et al*., 2018). FRPs are widely used in modern applications due to their high strength, stiffness, and low weight. Typically composed of synthetic fibres and epoxy resin, they represent high-performance composite materials. In recent years, the trend has shifted toward incorporating natural fibres (NFs) as reinforcements in composite materials to meet the rising demand for sustainability. Natural fibres provide renewable and biodegradable alternatives to synthetic fibres, significantly reducing the environmental impact of composite production while delivering favorable mechanical properties (Chen *et al*., 2021). Natural fibres, including jute, hemp, flax, and sisal, are well-suited for a wide range of applications due to their renewability and desirable mechanical properties (Smith *et al*., 2022). The integration of NFs into composites has led to the development of bio-composites, combining the benefits of both natural and synthetic components. Bio-composites are increasingly utilized in industries such as automotive, construction, packaging, and consumer goods, aligning with global efforts to promote eco-friendly materials and sustainable practices (Johnson *et al*., 2021).Among the various natural fibres, those derived from the baobab tree (*Adansonia spp.*) have gained particular attention. Baobab barks, which form the fibrous outer layer of the tree trunk, are a promising resource for fibre extraction and use in composite materials. This iconic tree, known for its resilience in arid and semi-arid regions, produces bark fibres with a fibrous structure that has been underutilized (Smith *et al*., 2022). Transforming baobab bark fibres into reinforcement materials not only promotes the sustainable use of baobab resources but also opens doors for high-performance composites with unique attributes (Johnson *et al*., 2021). Research indicates that baobab bark fibres possess lightweight properties, good specific strength, and potential thermal benefits, making them an appealing alternative to synthetic fibres (Anderson *et al*., 2018). Studies emphasize the renewable and biodegradable nature of these fibres, underscoring their potential in composite material innovation (Johnson *et al*., 2021; Smith *et al*., 2022). Similarly, other researchers, such as Vijay *et al*. (2014), highlight the advancements in fibre-reinforced polymer composites and their integration into sustainable development practices. Polyvinyl chloride (PVC), a versatile polymer known for its chemical resistance and process ability, has been extensively used as a matrix material in composites. When combined with reinforcing fibres, PVC forms hybrid composites that exhibit enhanced mechanical properties, improved thermal stability, and tailored performance characteristics (Chen *et al*., 2021). However, despite significant progress in hybrid composites, limited research exists on utilizing baobab bark fibres in combination with other natural fibres for PVC-based hybrid composites. This study aims to address this gap by developing and characterizing a hybrid composite reinforced with baobab bark and bamboo fibres in a PVC matrix. The research seeks to harness the unique properties of these natural fibres to create a high-performance, sustainable material suitable for diverse applications. The outcome of this work will contribute to advancing knowledge in the field of hybrid composites and promote the utilization of underexplored natural resources for eco-friendly material solutions.

1.2 An-Overview on Natural and Baobab Fibres

1.2.1 Natural Fibres

Aspect	Details
Definition and Origin	Natural fibres are derived from plants, animals, or minerals and have been used for millennia in applications ranging from clothing to construction materials (Mwaikambo *et al*., 2002).
Advantages	- Biodegradable, renewable, and sustainable (Mahboob *et al*., 2018). - Lightweight, cost-effective, and abundant availability. - High specific mechanical properties, biocompatibility, and non-toxicity (Barbière *et al*., 2020).
Challenges	- Hydrophilicity leading to durability concerns under cyclic loading - Significant moisture absorption affecting mechanical performance, e.g., reduced tensile modulus and strength (Aji *et al*., 2013).
Hybridization and Applications	- Hybridized natural fibres such as kenaf/pineapple leaf have improved mechanical properties and reduced water uptake (Aji *et al*., 2013). - Bamboo, jute, and baobab bark fibres have shown potential for reinforcing PVC matrices, offering biodegradability and favorable mechanical properties (Carter *et al.,* 2020).
Future Trends	- Combining natural and synthetic fibres to overcome challenges and reduce environmentalimpact(Thompson*etal*.,2022). - Blending natural fibres to enhance commercialization potential and competitiveness against glass fibres, which dominate 95% of reinforced composites (Thompson *et al*., 2022).

1.2.2 Baobab (Adansonia digitata)

Aspect	Details
Origin and Potential	- Baobab barks are derived from the African baobab tree, an iconic species known for its fibrous bark. - Considered a waste product, baobab barks offer unique mechanical properties and availability (Smith et al., 2022).
Mechanical Properties	- High tensile strength and modulus make baobab barks suitable for enhancing composite properties (Smith et al., 2022). - Improved tensile and flexural properties were observed when baobab fibres were combined with polymer matrices (Johnson & Brown, 2021).
Fibre Treatment and Adhesion	- Surface treatments, such as alkali treatment, significantly enhance mechanical properties and interfacial bonding (Brown *et al.*, 2019). Hammajam *et al.* (2019), studied that the alkali treatment of the fibre improves the interfacial bonding between the fibre and matrix leading to increase in mechanical properties compared to untreated composites

Processing Techniques	- Compression molding and injection molding impact the mechanical properties of baobab fibre-reinforced composites (Adjei *et al*., 2020). - Selecting appropriate processing techniques is critical to achieving optimal composite performance.
Comparison with Bamboo Fibres	- Bamboo fibre incorporation into PVC composites improves tensile strength, modulus, and thermal stability (Chen *et al*., 2021). - Fibre orientation and processing methods, such as melt blending, significantly influence mechanical properties (Wang *et al*., 2020).
Hybrid Composite Development	- Combining baobab and bamboo fibres with PVC matrices provides a sustainable alternative to synthetic composites. - Research focuses on enhancing fibre-matrix adhesion and optimizing fibre content to improve mechanical properties (Rahman et al., 2019; Liu *et al*., 2020

2.0 MATERIALS AND METHODS

2.1 Materials and Equipment

- **Materials:**
  Baobab bark (5 kg), bamboo fibers (5 kg), polyvinyl chloride (PVC) SE-450 (1 kg), sodium hydroxide (NaOH) (500 g), distilled water, and litmus pH paper were used.
- **Equipment:**
  Various tools like fiber sizer, dryer, two-roll mill, compression molding machine, universal testing machine, micro hardness tester, scanning electron microscope (SEM), and Fourier Transform Infrared (FTIR) spectrometer were employed, sourced from institutions like NILEST, Zaria, ABU Zaria, and OAU Ife.

2.2 Methodology

2.3 Fibre Extraction and Preparation

Fibers from bamboo and baobab bark were extracted using water retting and chemically treated with 5% NaOH solution. The treated fibers were washed to neutral pH, dried at 65°C, and recorded at constant weights (baobab: 272.424 g, bamboo: 269.541 g).

2.4 Formulation and Production of Composite

Composites were formulated by varying baobab bark and bamboo fiber proportions in PVC (10–50 wt%), with a control sample of 100% PVC. Samples were produced by mixing polymer and fillers in a two-roll mill at 180°C, followed by hot pressing at 160°C and 2.5 MPa pressure for shaping.

2.5 Testing and Characterization

- **Tensile Strength:** Measured according to ASTM D-638 using a universal testing machine.
- **Impact Strength:** Evaluated with an Izod impact tester (ASTM D-256).
- **Hardness Test:** Conducted using a micro hardness tester (ASTM D2240).
- **Flexural Strength:** Assessed via a three-point bending test (ASTM D-790).
- **Water Absorption:** Specimens immersed in water for 14 days to measure water uptake (ASTM D570).
- **SEM Analysis:** Used to examine fiber-matrix alignment and bonding.
- **FTIR Analysis:** Conducted to analyze chemical structures in treated and untreated fibers.

2.6 Hypotheses and Data Analysis

The hypothesis posits that incorporating baobab and bamboo fibers improves the composite's mechanical and physical properties. Data were analyzed using single-way ANOVA (Excel 2013) at a 5% significance level.

Sub-Hypotheses:

- **Tensile Strength:** Expected to improve up to an optimal fiber content.
- **Impact Strength:** Anticipated enhancement with fiber addition.
- **Flexural Strength:** Higher in hybrid composites due to fiber synergy.
- **Water Absorption:** Reduced in hybrid composites due to enhanced structure.

2.7 Experimental Design:

- **Independent Variable:** Proportion of baobab and bamboo fibers.
- **Dependent Variables:** Tensile, flexural, impact strengths, hardness, and water absorption.

This methodology aimed to evaluate the mechanical and physical benefits of using baobab and bamboo fibers as reinforcements in PVC composites

3.0 RESULTS AND DISCUSSION

3.1 Tensile Strength Results

Figure 3.1 illustrates the effect of fibre loading on the tensile strength at break of baobab bark and bamboo fibres reinforced polyvinyl chloride (PVC) hybrid composites.

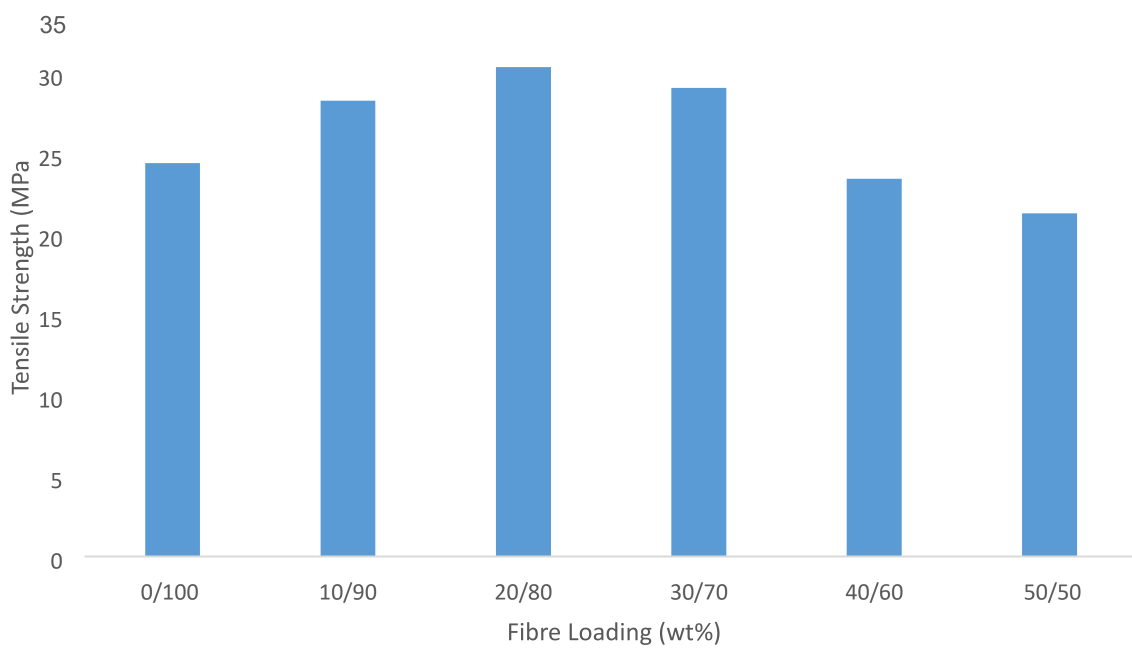

Figure 3.1 Effect of Fibre loading on Tensile Strength at Break of Baobab Bark and Bamboo Fibres Reinforced Polyvinyl Chloride (PVC) Hybrid Composite**.**

The tensile strength results indicate a notable trend, with tensile strength increasing as fibre loading rises, reaching a peak at 20 wt%. At this optimal fibre loading, the tensile strength increases from 24.5 MPa at 0 wt% to 30.40 MPa at 20 wt%. This enhancement can be attributed to the reinforcing effect of the fibres, which enable the composite to distribute applied tensile forces more effectively. The fibres act as stress transfer agents, reducing the concentration of stress within the matrix and enhancing the overall strength of the composite. The improved bonding between the matrix and fibres, as supported by the SEM image in Plate II for the composite with 20% fibre content, further explains this observed improvement. Surface treatment of the fibres using sodium hydroxide likely plays a critical role in enhancing the interfacial adhesion, as reported by Tijjani et al. (2015). This treatment roughens the fibre surface and removes impurities, facilitating better fibre-matrix bonding. However, as the fibre loading increases beyond 20 wt%, a decline in tensile strength is observed. Tensile strength values decrease progressively to 29.11 MPa, 23.47 MPa, and 21.32 MPa at 30%, 40%, and 50% fibre loadings, respectively. This reduction is primarily due to fibre clustering at higher loadings. Fibre clustering leads to uneven stress distribution and the formation of stress concentration points within the matrix, which increases the likelihood of premature failure under tensile loading conditions. Similar observations have been reported in studies by Himanshu et al. (2019) and Daramola et al. (2018).

3.2 Impact Strength Results

The average impact strength test results for the hybrid composite reinforced with baobab bark and bamboo fibers are presented in Figure 4.5.

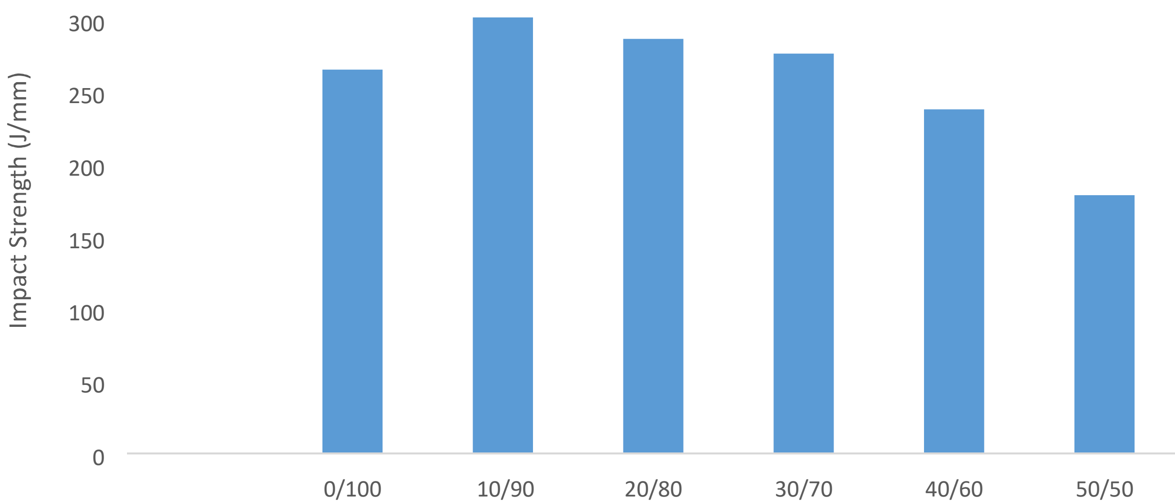

Figure 3.2: *Effect of Fiber Loading on Average Impact Strength of Baobab Bark and Bamboo Fiber Reinforced Polyvinyl Chloride (PVC) Hybrid Composite*

Figure 3.2 highlights the average impact strength of the BBF/r PVC hybrid composite for fiber loadings ranging from 0 to 50 wt %. The results indicate an increase in impact strength from 265.06 J/mm to 301.31 J/mm as the fiber loading rises from 0 to 10 wt %. This enhancement in impact strength at 10 wt % can be attributed to the improved plasticity of the composite, reduced brittleness, and increased flexibility, which enable effective absorption and distribution of impact energy. Similar findings were reported by Li et al. (2020).

3.3 Hardness Test Results

Figure 3.3 depicts the hardness test results of the Baobab Bark and Bamboo Fiber Reinforced Polyvinyl Chloride (PVC) Hybrid Composite.

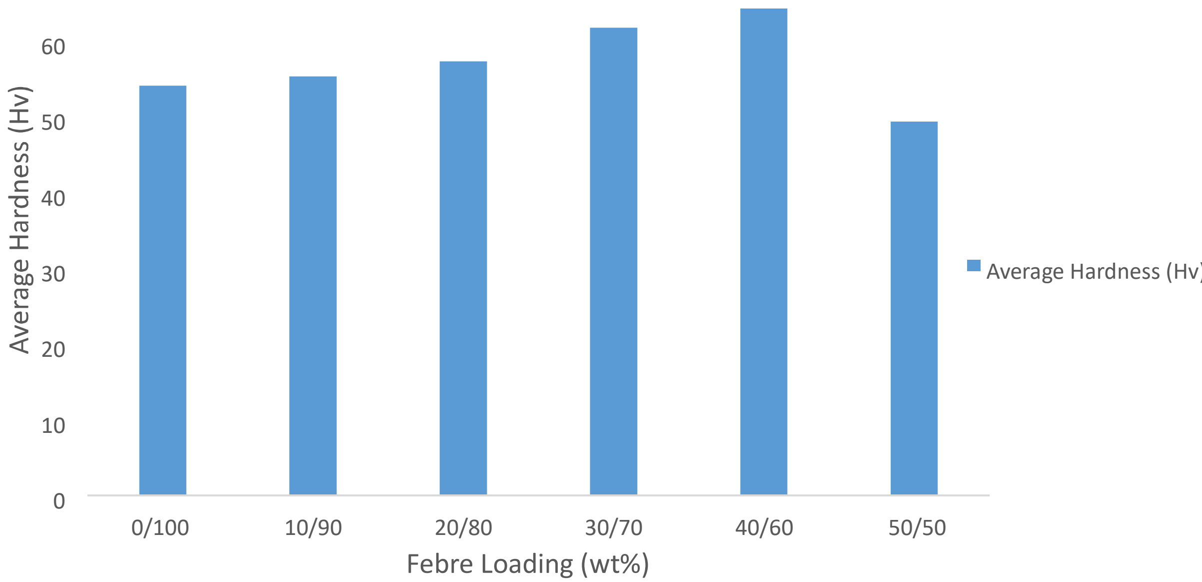

Figure 3.3: *Effect of Fiber Loading on Average Hardness of Baobab Bark and Bamboo Fiber Reinforced Polyvinyl Chloride (PVC) Hybrid Composite*

The graph illustrates the average hardness (measured in Hv) of the hybrid composite at various fiber composition ratios. The data show a rising trend in hardness as the proportion of baobab bark and bamboo fibers increases, reaching a peak value of 64.28 Hv at a composition ratio of 40/60. However, at a 50/50 composition ratio, a noticeable decline in hardness is observed compared to the preceding ratios. This suggests the existence of an optimal composition ratio for maximizing hardness, beyond which the hardness begins to diminish. Similar observations were made by Oladele et al. (2014). Understanding these trends is essential for designing composites with tailored mechanical properties for specific applications, balancing hardness, strength, and durability

3.4 Flexural Strength Test Results

Figure 3.4 presents the flexural strength test results of the Baobab Bark and Bamboo Fiber Reinforced Polyvinyl Chloride (PVC) Hybrid Composite.

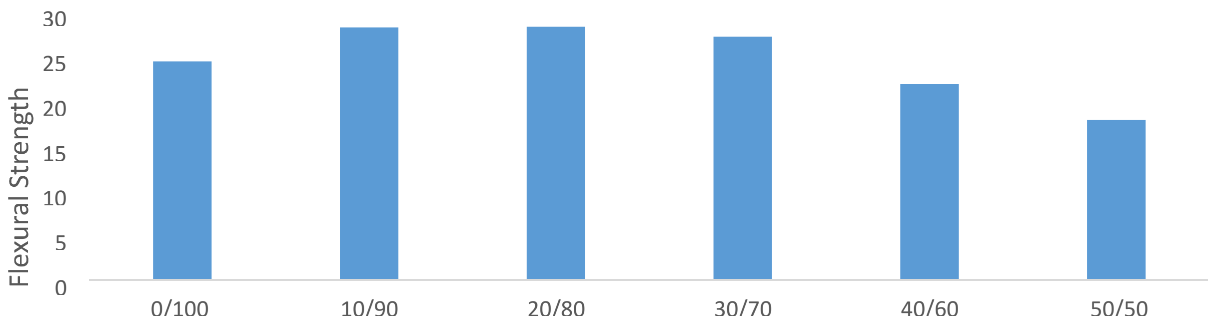

Figure 3.4: *Effect of Fiber Loading on Flexural Strength of Baobab Bark and Bamboo Fiber Reinforced Polyvinyl Chloride (PVC) Hybrid Composite*

The graph in Figure 3.4 indicates a general decrease in flexural strength as the proportion of BBF increases. The composite exhibits its highest flexural strength, 28.28 MPa, at a composition ratio of 20/80 (baobab bark to bamboo fibers). However, further increases in the proportion of baobab bark fibers lead to a gradual decline in flexural strength. This trend suggests that higher proportions of baobab bark and bamboo fibers may negatively affect the flexural strength of the composite.

3.5 Water Absorption Test Results

Figure 3.5 depicts the water absorption behavior of PVC hybrid composites reinforced with baobab bark and bamboo fiber at fiber loading of 10 w%, 20 w%, 30 w%, 40 w% and 50 w%. The graph indicates that the highest water absorption occurs in the composite with a 50 wt % reinforcement, while the lowest is observed in the 10wt. % reinforcement. Initially, at lower concentrations of fiber, the PVC matrix adequately encases them, reducing water intake. However, as the concentration increases, the matrix's encapsulation ability diminishes, allowing greater water absorption. Thus, the results suggest that water absorption correlates with higher concentrations of fiber. Additionally, the graph illustrates that water absorption increases with prolonged immersion time for all composite variations, indicating a time-dependent nature.

The results of water absorption test conducted are presented in Figure 3.5

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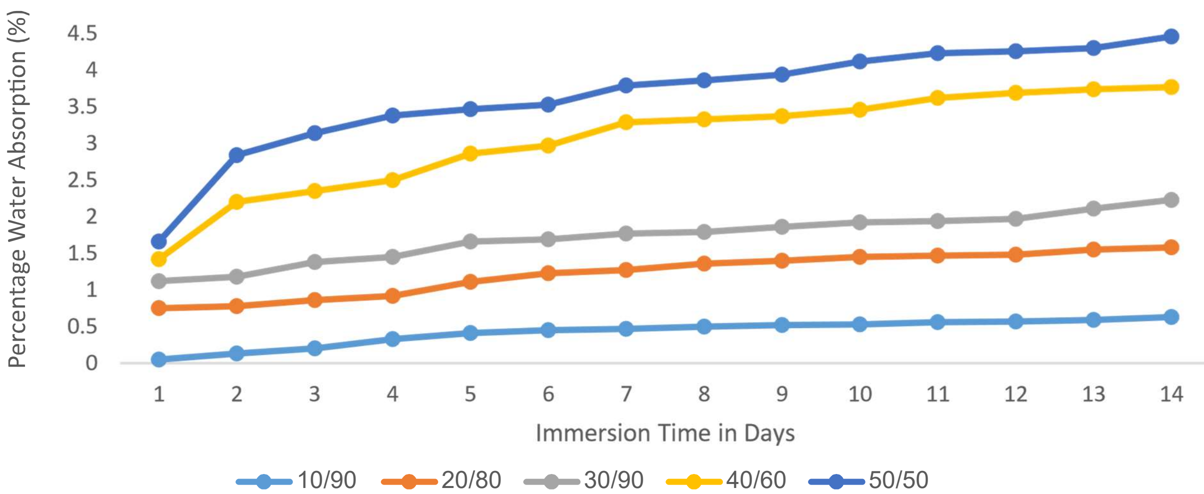

Figure. 3.5: Water Absorption Rate for Baobab Bark/Bamboo Fibre Reinforced PVC Hybrid Composites

3.6 Conclusion

This study demonstrates the potential of baobab bark and bamboo fibres as reinforcements in PVC-based hybrid composites, offering a sustainable alternative to synthetic materials. The optimal fibre content for maximum tensile strength (30.40 MPa) was observed at 20 wt%, with impact strength and hardness also showing significant improvement at specific compositions. Surface treatment of fibres enhanced interfacial bonding, contributing to improved mechanical properties. However, excessive fibre content led to clustering, uneven stress distribution, and reduced performance in tensile and flexural strength tests. These findings underscore the importance of optimizing fibre content and processing techniques to achieve desirable composite properties.

3.7 Recommendations

1. **Optimization of Fibre Content**: Future research should focus on identifying precise fibre loading thresholds to balance mechanical performance and durability in hybrid composites.
2. **Advanced Fibre Treatment**: Exploring alternative fibre treatment methods, such as silane coupling agents or plasma treatments, may further improve fibre-matrix adhesion and mechanical properties.
3. **Application-Specific Designs**: Composite formulations should be tailored for specific applications, considering requirements such as strength, flexibility, or thermal stability.
4. **Environmental and Economic Analysis**: A life-cycle assessment of the hybrid composites is recommended to evaluate their environmental impact and cost-effectiveness compared to synthetic materials.
5. **Industrial Scale-Up**: Pilot studies on large-scale production and real-world applications should be conducted to validate the feasibility of these composites in industries like automotive, construction, and consumer goods.

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