# Parametric Study on Bamboo Fibre Reinforced Polyester Composites: Role of Soaking Time, Catalyst Ratio, and Alkali Treatment

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**Abstract**
Bamboo fibres were treated with varying conditions of soaking time, accelerator/catalyst ratio and NaOH treatment concentration. These parameters play a major role in determining the performance properties of the developed polyester composite for structural applications. The reinforced 10 – 40 wt% bamboo fibre–polyester composites were fabricated using the hand layup technique and the mechanical properties (tensile, hardness, impact and flexural strength) were evaluated using a universal testing machine and Charpy impact tester. Due to the varying conditions of the parameters, the Taguchi L16 orthogonal array was employed to design the experiment. Microstructural analysis was conducted using a scanning electron microscope to study the surface morphology of the composite. The mechanical properties of the developed bamboo fibre reinforced polyester composite were evaluated considering the bamboo fibre (BF), soaking time (ST), accelerator/catalyst ratio (ACR) and NaOH treatment concentration. The study revealed that wt% of the bamboo fibre improves the properties at 30 - 40 wt% as 30 wt% attained the optimum for hardness (121.16 Hv) and flexural strength (93.99 MPa) while 40 wt% for tensile (78.53 MPa) and impact strength (4.85 $KJ/m^2$). Soak time enhanced the properties within 2 – 3 hrs with an optimum of 2 hrs for tensile strength (77.68 MPa) and 3 hrs for impact (5.52 $kJ/m^2$) and flexural strength (89.04 MPa). The ratio of accelerator/catalyst displayed optimum at 1.2 mix for hardness (119.54 Hv), flexural (93.61 MPa) and tensile strength (70.34 MPa). High volume of accelerator to catalyst mix leads to brittleness, debonding of the polymer composite. Lower NaOH treatment concentration achieved the optimum for the mechanical properties. However, higher NaOH concentration degrades the fibres and reduces their strength and stiffness, ultimately decreasing the composite properties. This study provides the relationship amongst the process parameters and their influence on the mechanical properties of bamboo fibre reinforced polyester composite for structural applications.

**Keywords:** Bamboo fibre, Polymer matrix composite, Taguchi orthogonal array, SEM analysis.

## 1. Introduction

Natural fibres are suitable replacement for synthetic fibres with high strength and high modulus (Hasan *et al.,* 2023). Synthetic fibres such as glass, carbon and aramid have been used for several years in many applications, varying from aerospace components to civil infrastructures. However, the high cost of production and materials of the fibres has limited their application in composite development.

Natural Fibres have been considered as a close substitute to synthetic fibres due to their light weight, renewability, biodegradability, low cost, low energy requirement, high strength and high modulus (Elfaleh *et al.,* 2023; Li *et al.,* 2007). However, it is important to characterise and improve the strength properties of natural fibres, tailoring them to a variety of applications in fibre-reinforced composites. Among the common natural fibres, bamboo has one of the most favourable combinations of low-density and high stiffness and strength and it has shown significance in composite development (Osorio *et al.,* 2011).

Bamboo fibre are extracted by different process such as retting, steam explosion, alkali treatment, degumming, grinding and crushing (Baley *et al.,* 2018; Prasob and Sasikumar, 2019), among all this extractive methods, alkali treatments such as sodium hydroxide (NaOH) are commonly used for treatment of bamboo fibres due to low cost and its effectiveness to modify the surface structure of fibres there by enhancing the fibre to matrix adhesion, although, other chemicals are used such as nitric acid, potassium chlorate ($HNO_3$ – $KClO_3$), sodium hyperchlorite (NaClO), benzoate (Jayabal *et al.,* 2012; Liu and Hu, 2008; Liu *et al.,* 2012; Chen *et al.,* 2018).

Many research investigations reported on bamboo fibre polyester composite have shown improved mechanical properties. For instance, Mohanty and Nayak (2010) developed short bamboo fibre reinforced HDPE polyester composites with varying fibre content and found that these composites possess good tensile and flexural strength with fibre loading from 10 to 30%, beyond which there was a decline in the mechanical strength.

Takagi and Ichihara (2004) found that the strength of bamboo fibre reinforced composites was strongly affected by fibre aspect ratio. Manalo *et al.* (2013) indicated that the good mechanical properties of bamboo fibre composites can certainly have an edge over conventional panel products used in the construction industry. However, most of the studies on bamboo fibre reinforced composites focused mainly on tensile strength characterisation. Thus, Khalil *et al*. (2012) suggested that more analysis and testing are necessary to comprehensively characterise the mechanical properties of bamboo fibre-based composites.

The alkaline treatment of bamboo fibre has shown a significant improvement in tensile strength, flexural strength and impact strength of composites. Several studies have shown that alkali treatment increased the strength of natural fibre composites (Nayak *et al.,* 2010; Prasad *et al.,* 1983).

Sodium hydroxide removes lignin, hemicellulose and other alkali-soluble compounds from the surface of the fibres to increase the number of reactive hydroxyl groups on the fibre surface available for chemical bonding (Mwaikambo and Ansell, 2002). Therefore, mechanical interlocking at the interface could be improved.

Some researchers had used different concentrations of NaOH and soaking times to mercerise various natural fibres. Kushwaha & Kumar (2012), immersed bamboo fibres in 5 wt% NaOH concentration for 30 minutes at room temperature. They reported an increase in tensile strength and elastic modulus of the produced bamboo fibre-epoxy composite by 40% and 35%, respectively.

Roy *et al.,* (2012), found the maximum tensile strength of alkaline-treated jute fibre to be at 0.5% NaOH for 24 hours. Nugroho and Ando (2001), used 5 and 10 wt% concentration of NaOH at one (1) hour for pineapple and sisal fibre. They observed that at 10 wt%, the polyester composites produced with the fibres became weaker. John *et al.* (2008), used 0.5, 1, 2 and 4 wt% NaOH for 1 hour on sisal and oil palm fibre. Shehu *et al.* (2017), used 2, 4, 6, 8 and 10 wt% NaOH for a soaking time of 1200 seconds (20 minutes) on baobab pod fibres; they found that 10 wt% NaOH treatment gave the highest tensile strength. Most studies also investigated bamboo fibre-epoxy composite, which showed excellent mechanical properties, chemical resistance and thermal insulation. Although previous studies on bamboo fibre weight fraction, the effects of NaoH concentrations and the soaking time have been investigated but there are few researches on the effect of varying the ratio of accelerator/catalyst.

In this study, bamboo fibre was extracted by alkali treatment at different concentrations (2 to 8%), soaking time (1 to 4 hrs), fibre volume fraction (10 to 40 wt%) and accelerator /catalyst (1.2 to 3.0) at varying intervals.

This study aims to study the effect of varying soaking time, NaOH concentration, bamboo weight fraction and ratio of accelerators/catalysts on the mechanical properties of bamboo fibre reinforced polymer matrix composite.

## 2. Materials and Methods

### 2.1 Bamboo fibre and polyester resin

The following materials were used for this study: bamboo fibre, methylketoneperoxide (MEKP), cobalt naphthenate, sodium hydroxide (NaoH) and polyester resin. The bamboo fibre was extracted from the culm of bamboo and shredded into random fibres using the shredding machine. The polyester resin was mixed with accelerator (Methylketoneperoxide) and catalyst (Cobalt Naphthenate) in the ratio 2:1 for the composite formulation.

### 2.2 Fibre soaking and alkaline treatment

All parameters for this study were considered based on four (4) varying conditions, for alkali treatment using NaOH concentration (2, 4, 6 and 8 %), bamboo fibre (10, 20, 30 and 40 wt% ) soaking time (1, 2, 3 and 4 hrs) and accelerator/catalyst ratio mix (1.2, 1.8, 2.4 and 3.0) while maintaining the ratio 2:1 for the cobalt naphthenate as accelerator and MEKP as catalyst. All these conditions were based on literature findings (Prasad *et al*, 1983; Mwaikambo and Ansell,2022; Ray *et al*,2001) for the composite development. Table 1 shows the process conditions of all parameters using the L16 Taguchi orthogonal array design.

Table 1: Taguchi Orthogonal Array design for the process conditions for composite development

| Process parameters | Unit | Levels | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| **A**: Bamboo fibre | wt% | 10 | 20 | 30 | 40 |
| **B**: Soaking time | hrs | 1 | 2 | 3 | 4 |
| **C**: Accelerator (MEKP )/catalyst (Cobalt Naphthenate) ratio (2:1) mix | | 1.2 | 1.8 | 2.4 | 3.0 |
| **D**: NaOH treatment concentration | % | 2 | 4 | 6 | 8 |

### 2.3 Fibre treatment and preparation

Bamboo fibre was extracted from the culm of the bamboo and ground into short fibres as shown in Plate 1. It was treated with sodium hydroxide solution at varying percentage concentration so as to remove the lignin-containing materials such as pectin, waxy substances and natural oils covering the external surface of the fibre cell wall. This reveals the fibrils and gives a rough surface topography to the fibre as shown in Plate 2.

*Plate 1: Bamboo Fibre*

*Plate 2: Treated Bamboo fibres*

### 2.4. Composites preparation

Development of the composite material was conducted using a mould made from wood. The hand lay-up technique was used for all 16 experimental runs from the Taguchi orthogonal array design derived for the composite formulations. The treated bamboo fibres were distributed randomly in the matrix system consisting of unsaturated polyester resin, cobal naphthenate as accelerator and MEKP catalyst in the ratio 2:1. For each of the experimental samples developed using the L16 taguchi design, the dimension 180 mm × 180 mm × 3 mm was used as shown in Plate 3. The samples were placed under atmospheric conditions to allow them to cure for 24 hrs.

### 2.5 Mechanical testing

The mechanical properties of the developed composite samples were evaluated using the ASTM standard. Tensile test samples were analysed based on ASTM D3039, Flexural test samples characterised using ASTM D 790-10 and an impact test was carried out according to the standard specified by ISO 179.

#### *2.5.1 Tensile test*

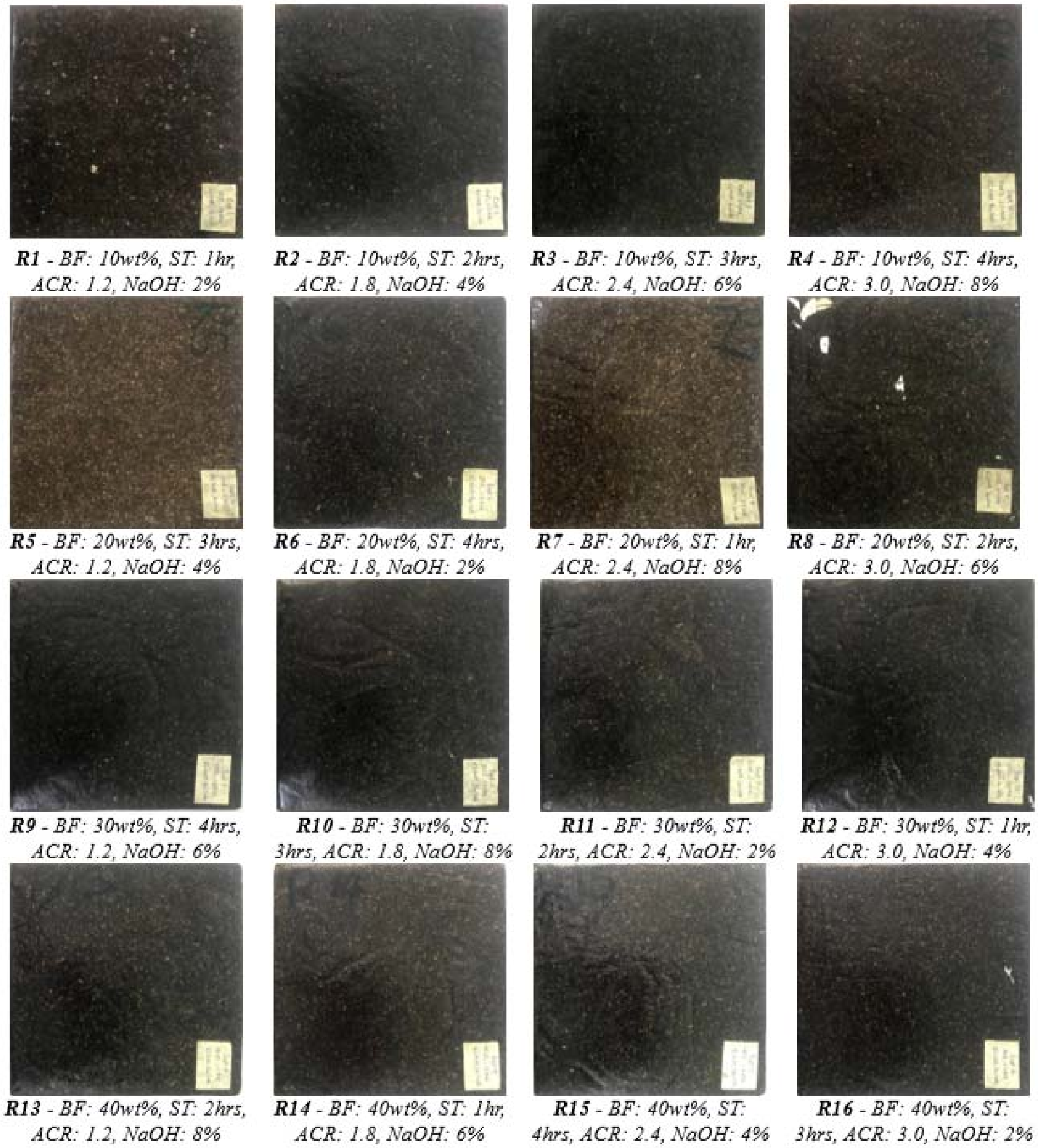
Tensile strength was performed based on the ASTM D303-08 standard. method using a universal tensile test machine with a load cell of 5 kN and a regular speed rate of 2 mm/min to estimate the tensile value of the composite. The composite plate was machined into dumb bell shaped tensile specimen with a dimension of 150 mm x 10 mm x 3 mm at a gauge length of 150 mm. Tensile tests were conducted using a computerised universal testing machine. The speed of the crosshead was 2 mm/min; average data samples of each category were evaluated. Tensile strength was reported in MPa.

#### 2.5.2 Flexural test

Flexural strength was performed at ambient temperature via a three-point bending test using a computerised universal materials testing machine (Enerpac) Cat Nr. 261-100KN capacity. The specimen composite was prepared according to ASTM D790 with a dimension of 125 mm × 15 mm × 3 mm. The rate of the crosshead was 3 mm/min. The composite specimen was freely supported by using a beam and the point load was exerted in the centre of the composite specimen. The flexural strength was reported in MPa.

#### 2.5.3 Impact test

The impact test was carried out by subjecting the composite samples to a Charpy impact testing machine, in accordance with ISO 179 standard. Samples were cut into dimensions 80 mm × 10 mm × 2 mm were placed horizontally on the machine with the notched surface directly opposite the swinging pendulum. The initial readings of the sample gauge length and the thickness were recorded into the computer system attached to the machine before switching on the machine. The pendulum of the machine swung freely through an angle of 180° and fractured the sample. Three samples were tested and the mean value was evaluated and presented.



**R1** - *BF: 10wt%, ST: 1hr, ACR: 1.2, NaOH: 2%*
**R2** - *BF: 10wt%, ST: 2hrs, ACR: 1.8, NaOH: 4%*
**R3** - *BF: 10wt%, ST: 3hrs, ACR: 2.4, NaOH: 6%*
**R4** - *BF: 10wt%, ST: 4hrs, ACR: 3.0, NaOH: 8%*
**R5** - *BF: 20wt%, ST: 3hrs, ACR: 1.2, NaOH: 4%*
**R6** - *BF: 20wt%, ST: 4hrs, ACR: 1.8, NaOH: 2%*
**R7** - *BF: 20wt%, ST: 1hr, ACR: 2.4, NaOH: 8%*
**R8** - *BF: 20wt%, ST: 2hrs, ACR: 3.0, NaOH: 6%*
**R9** - *BF: 30wt%, ST: 4hrs, ACR: 1.2, NaOH: 6%*
**R10** - *BF: 30wt%, ST: 3hrs, ACR: 1.8, NaOH: 8%*
**R11** - *BF: 30wt%, ST: 2hrs, ACR: 2.4, NaOH: 2%*
**R12** - *BF: 30wt%, ST: 1hr, ACR: 3.0, NaOH: 4%*
**R13** - *BF: 40wt%, ST: 2hrs, ACR: 1.2, NaOH: 8%*
**R14** - *BF: 40wt%, ST: 1hr, ACR: 1.8, NaOH: 6%*
**R15** - *BF: 40wt%, ST: 4hrs, ACR: 2.4, NaOH: 4%*
**R16** - *BF: 40wt%, ST: 3hrs, ACR: 3.0, NaOH: 2%*

Plate 3: Developed composite samples from L16 Taguchi orthogonal array design

### 2.6 Water Absorption Determination

The sample was prepared and distilled water was used as a medium. The percentage of water absorbance was calculated from the difference between the final and initial weights before and after immersion in the water bath for 24 h. In each test, three samples were tested and average values were reported. The testing was performed until the percentage of water absorption reached equilibrium. The calculation was based on the following equation 1:

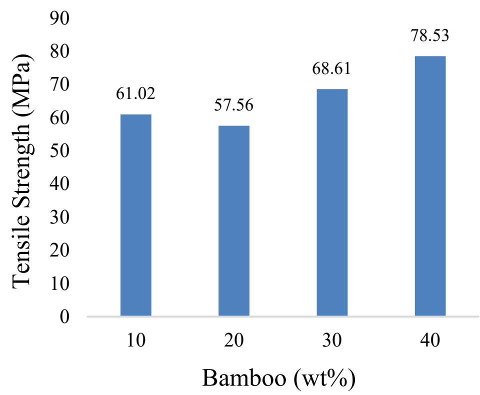
$$\text{Water absorption } (w_A)\ (\%) = \frac{W2-W1}{W1} \times 100 \quad \ldots (1)$$

where: $w_1$ = initial weight, $w_2$ = final weight

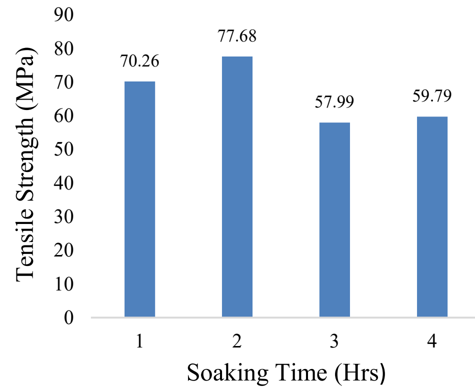
## 3. Results and Discussion

### *3.1 Effects of bamboo fibre, soaking time, NaOH concentration and accelerator/catalyst ratio on tensile strength of the developed composite*

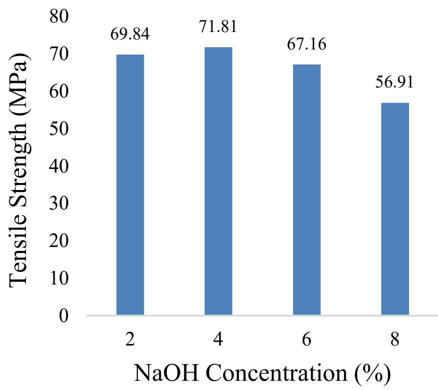
The tensile strength of the developed composite in Fig. 1(a) recorded a decrease at 20 wt% from the 10 wt% value achieved. A further increase in the wt% of bamboo fibre to 30 wt% and 40 wt% increases the tensile strength to 68.61 MPa and 78.53 MPa, respectively. This is attributed to high adhesion between the matrix and reinforcement when compared to the adhesion at 20 wt%, which recorded a lower strength.



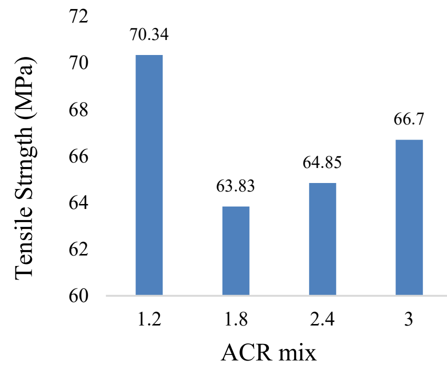

(a) wt % bamboo fibre




(b) soaking time




(c) NaOH concentration (%)




(d) accelerator/catalyst ratio

Fig 1: Influence of varying (a) wt% bamboo fibre, (b) soaking time, (c) NaOH concentration, and (d) accelerator/catalyst ratio, on the tensile strength of bamboo fibre reinforced polyester composite

Figure 1(b) shows the variation of tensile strength with soaking time. The tensile strength tends to decrease at high soaking times of 3hrs and 4hrs which might be due to high diffusion of water molecules within the polymer matrix which result to hydrolysis, interface debonding, matrix swelling and interface degradation. A similar condition was observed in the work investigated by Kini *et al.,* (2023) on the effect of different types of water soaking and re-drying on the mechanical properties of glass fibre-epoxy composites.

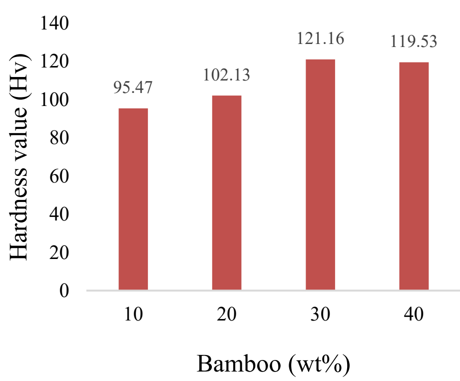
Figure 1(c) shows the variations in tensile strength with NaOH concentration. The tensile strength increased from 2% to 4% and further increase in NaOH concentration lead to a decrease in the tensile strength of the composite due to the hydrogen bonding of the fibre, which changes its hydrophilic nature into hydrophobic by removing the hemicellulose and lignin content. It also increased the adhesion between fibre and matrix and modified its surface structure. The optimal value was achieved at 4% with a value of 71.81 MPa. Reduction in tensile strength at high concentration can also be attributed to low interior reinforcing efficiency caused by delignification, which also weakens the load transfer capacity of the fibre (Chin *et al.,* 2020)

In Figure 1(d) the tensile strength of the composite tends to increase at low and high ratios of accelerator/catalyst mix and reduces at 1.8 and 2.4. This may be attributed to incomplete curing, resulting in a weaker material. Insufficient accelerator can hinder the cross-linking process thereby reducing the material's tensile strength, weak bonding between the resin and fibres, leading to reduced tensile strength while at 1.2 and 3.0 there seems to be a high tensile strength due to increased cross linking between the matrix and fibre (Lee *et al*, 2019; Kim *et al.,*2020). The optimal value at attained at 1.2 and 3.0, which corresponds to 70.34 MPa and 66.70 MPa, respectively.

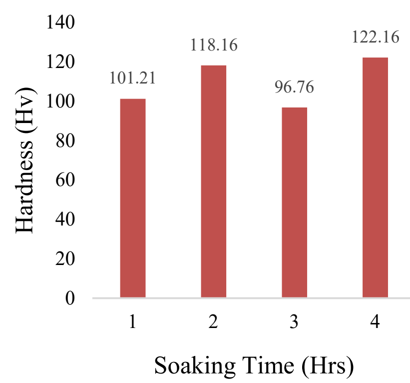
***3.2 Effects of bamboo fibre, soaking time, NaOH concentration and accelerator/catalyst ratio on hardness of the developed composite***

Figure 2(a) shows the effect of bamboo fibre on the hardness value of the composite. The hardness value increases to 30 wt% with a hardness value of 121.16 Hv and later decreases at 40 wt%. At high fibre loading, there is a reduction in the hardness value due to the build-up of stress and fibre agglomeration. This result is similar to the outcome obtained from previous work investigated by (Uzun *et al.,* 2011; Daramola *et al*, 2017). The authors reported a reduction in the mechanical properties of their composites developed at a higher weight fraction of the reinforcement. Fig. 2(b) shows the hardness value of the composite with the soaking time. The increase in hardness at 2 hrs and 4 hrs might be attributed to resin redistribution and densification. The decrease at 1 hr and 3 hrs is attributed to interfacial debonding between the matrix and the reinforcement. The optimal value was observed at 4 hrs with a hardness value of 122.16 Hv.

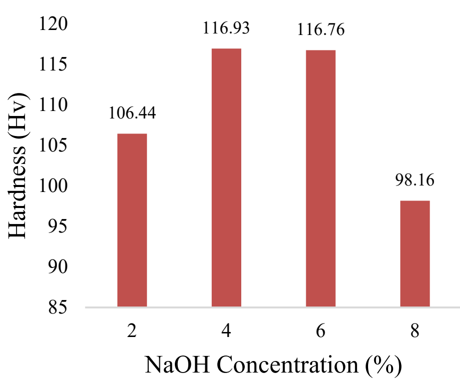
Hardness value of the composite in Fig. 2(c) shows that at 4% and 6% it has a hardness value of 116.93 Hv and 116.76 Hv, respectively, due to high cross-linking density, increase in crystallinity, fibre orientation and fibre alignment. The NaOH concentration at 2% shows a hardness value of 106.44 Hv and at 8%, 98.16 Hv. It is observed that higher concentration of NaOH of 8% leads to low hardness due to excessive fibre treatment, which damages the fibre structure, excessive cross-linking between polymer chains leading to brittleness of the composite, degradation in matrix materials and debonding between fibre-matrix (Fang *et al.,* 2025; Liu *et al.,* 2019; Sahari *et al.,* 2020; Ishak *et al.,* 2020). The hardness value of the composite with 1.2 ACR mix attained 119.45 Hv in Fig. 2(d), but a further increase in the ACR at 1.8 and 2.4 led to a decrease in the hardness. Though at 3.0 ACR mix, the hardness increased to 111.29 Hv, which is less than the value achieved at 1.2 ACR mix. These trends may also be attributed to improved interfacial adhesion and curing reaction, increased cross-linking density, while the reduction in the hardness may be related to the presence of void content and reduction in molecular weight (Kumar *et al.,* 2023; Jawaid *et al.,* 2020; Daramola *et al.,* 2019; Zang *et al.*,2020).



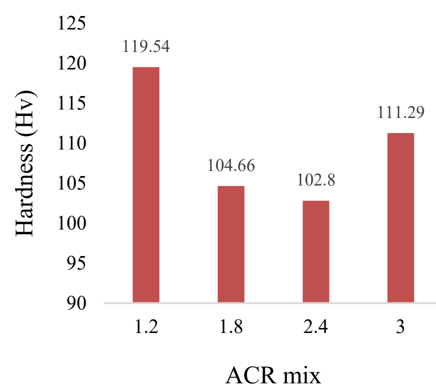

(a) wt % bamboo fibre




(b) soaking time




(c) NaOH concentration (%)

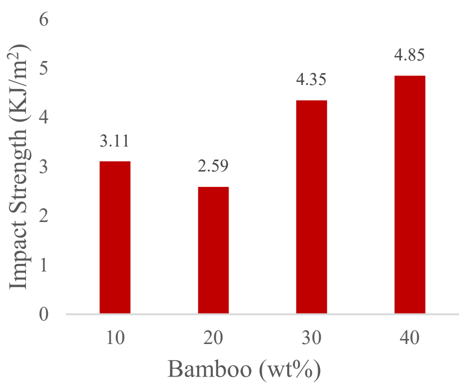



(d) accelerator/catalyst ratio

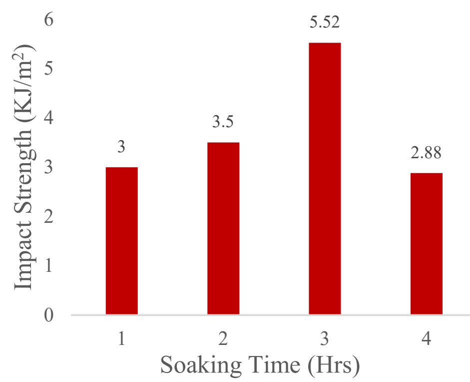
Fig 2: Influence of varying (a) wt% bamboo fibre, (b) soaking time, (c) NaOH concentration, and (d) accelerator/catalyst ratio, on the hardness value of bamboo fibre reinforced polyester composite

***3.3 Effects of bamboo fibre, soaking time, NaOH concentration and accelerator/catalyst ratio on impact strength of the developed composite***

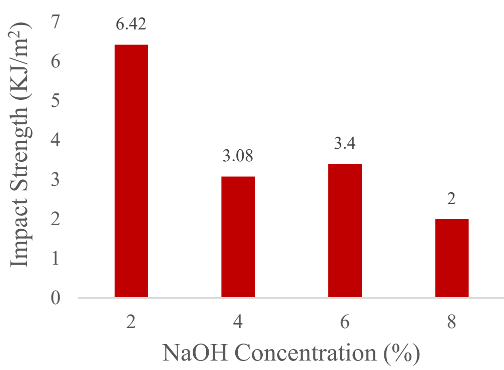
Fig. 3(a) shows the effect of bamboo fibre on impact strength of the developed composite. The impact strength tends to increases at 30 wt% and 40 wt% with an impact strength of 4.35kJ/m$^2$ and 4.85kJ/m$^2$ respectively which might be due to high fibre to matrix adhesion and the composite absorbing more strain energy. However, the impact strength decreases at 20 wt% weight fraction of bamboo fibre which may be due to agglomeration, micro spacing between the fibre and the matrix leading to crack intiation and propagation during impact which are similar to the study conducted by (Li *et al.*, 2019) on the mechanical performances and water uptake behavior of bamboo fibre reinforced with high density polyethylene composite. The impact strength increases as the soaking time increases to 3 hrs as shown in Fig. 3(b), this condition is ascribed to improved fibre–matrix adhesion, increased roughness of the fibre surface and increased crystallinity of the fibres. Further increase in the soaking time lead to a decrease in the impact strength due to debonding as a result of over saturation of fibre and hydrolysis of cellulose in the bamboo fibres. (Zhang *et al.,* 2020; Li *et al.,* 2019; Sapuan *et al.,* 2019; Chahar *et al.,*2024).



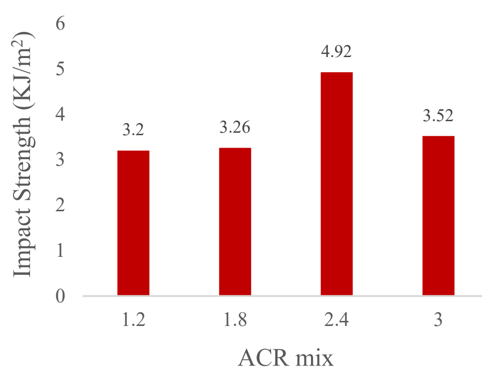

(a) wt % bamboo fibre




(b) soaking time




(c) NaOH concentration (%)



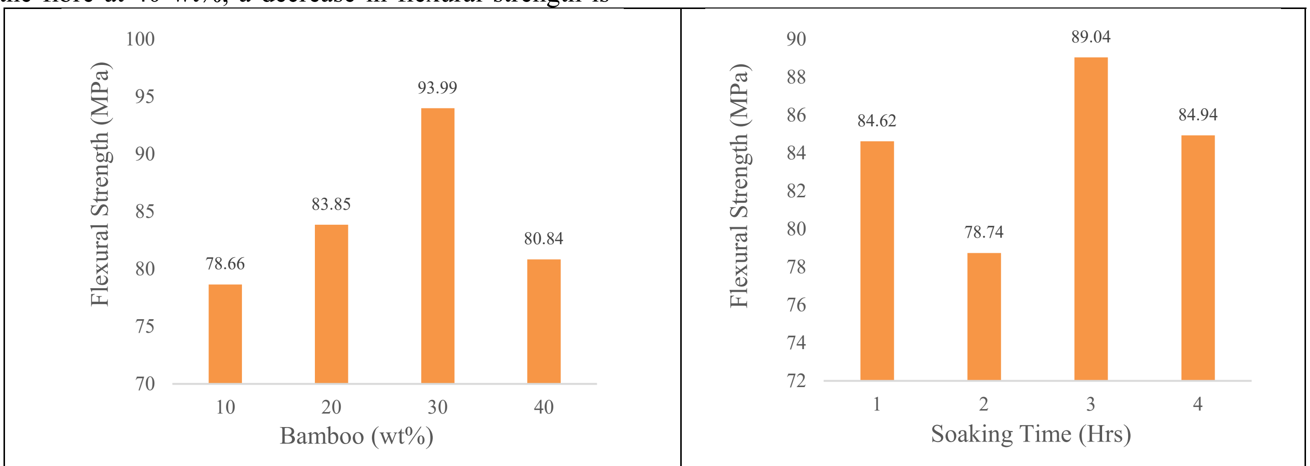

(d) accelerator/catalyst ratio

*Fig 3: Influence of varying (a) wt% bamboo fibre, (b) soaking time, (c) NaOH concentration, and (d) accelerator/catalyst ratio, on the impact strength value of bamboo fibre reinforced polyester composite*

The impact strength of the composite in Fig. 3(c) achieved 6.42 KJ/m$^2$ with NaOH concentration of 2%, however, as the concentration increases, the impact strength reduces at 4% and slightly increases at 6%. At low concentration of NaOH, there is modification of the fibre surface, which in turn improves the adhesion to the matrix, thereby increasing the impact strength. Furthermore, NaOH hydrolyses fibres, which in turn breaks down impurities and creates a cleaner surface for bonding with the matrix, thereby allowing the composite to absorb more energy before fracture. On the other hand, at higher concentrations of 8%, a drastic reduction was experienced; higher concentrations of NaOH degrade the fibres and reduce their strength and stiffness, and ultimately decreasing the composite's impact strength (Ishak *et al.,* 2020; Sapuan *et al.,*2019). Fig. 3(d) shows there is a similar trend in the impact strength at 1.2 and 1.8 ACR mix. However, a sudden increase is achieved in the impact strength at 2.4 with a 65% increase, which is attributed to increased interfacial adhesion, improved cross-link density and reduced void content (Prome *et al.,* 2025).

***3.4 Effects of bamboo fibre, soaking time, NaOH concentration and accelerator/catalyst ratio on flexural strength of the developed composite***

Fig. 4(a) shows the variations of flexural strength with an increase in the weight fraction percentage of bamboo fibre. The flexural strength increases from 78.65 MPa to 93.99 MPa as the wt% increases from 10 to 30 wt%. The increased strength is due to increased matrix-to-fibre adhesion and reduced dominance of the matrix as the fibre wt% increases. A further increase in volume of the fibre at 40 wt%, a decrease in flexural strength is experienced, which may be ascribed to inhomogeneity of stress transfer between the fibre and the matrix. This outcome is in congruence with findings in (Ishak *et al.*,2020). In Fig. 4(b), the variation of flexural strength with soaking time (hrs) of bamboo fibre. The flexural strength tends to increase at 1 hr and 3 hrs, which may be due to improved fibre adhesion and reduced fibre damage. The decrease in strength at 2 hrs and 4 hrs of soaking time may be attributed to fibre swelling, which may lead to debonding between matrix and fibre (Chahar *et al.,* 2024; Prome *et al.,* 2025).




(a) wt % bamboo fibre | (b) soaking time | (c) NaOH concentration (%) | (d) accelerator/catalyst ratio

*Fig 4: Influence of varying (a) wt% bamboo fibre, (b) soaking time, (c) NaOH concentration, and (d) accelerator/catalyst ratio, on the flexural strength of bamboo fibre reinforced polyester composite*

Varying the NaOH concentration of bamboo fibre Fig. 4(c) shows that the flexural strength decreases as the concentration increases. This may be attributed to over-modification of the fibre surface, removal of lignin and hemicellulose, increased fibre swelling and presence of defects which resulted due to the effect of higher concentration (Ishak *et al.*,2020). In Fig. 4(d), the flexural strength decreases with an increase in the ratio of accelerator/catalyst. This is ascribed to over-acceleration, incomplete curing, increased residual stress, increased brittleness, reduced molecular weight, and increased void content (Sapuan *et al.*,2019; Chahar *et al.*,2024; Prome *et al.,* 2025).

**3.5. Water Absorption Property**

The water absorption of the developed bamboo fibre reinforced polyester composite increases with varying the weight percent of fibre. However, a further increase beyond 30 wt% gradually reduces the percentage of water absorption. As the fibre wt% increases, the interface between the fibres and the matrix increases, providing more pathways for water to penetrate the composite.

Also, with more fibres, the surface area of the fibres increases, allowing more water to be absorbed by the fibres. In addition, as the fibre wt% increases, the likelihood of voids and defects in the composite also increases, providing more sites for water to accumulate.

The decrease in water absorption at 40 wt% implies that at higher fibre wt%, the fibres may be more closely packed, leading to improved adhesion between the fibres and the matrix thereby reducing the pathways for water penetration.

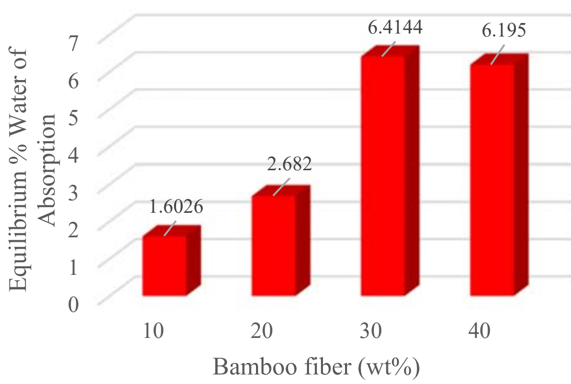



Fig 5: Variation of equilibrium % water absorption with varying wt% of bamboo fibre in the composite

Moreover, the matrix may be less porous, reducing the amount of water that can penetrate the composite. At high fibre wt%, the fibres may interact with each other, reducing the amount of water that can be absorbed by the fibres (Wang *et al.,* 2020; Sapuan *et al.,* 2019; Jawaid *et al.,* 2020; Dhakal *et al.,* 2013).

### 3.6 Scanning Electron Microscopy (SEM) Analysis

From Fig 6(a-d) there seems to be a variation in the fibre to matrix adhesion of the bamboo fibre polyester composite which might be due to agglomeration or soaking time of the fibre which showed different disparities in the mechanical properties of the composite. Fig. 6(a) shows an uneven texture with distinct light and dark regions likely corresponding to the polyester and fibre. The surface is relatively smooth and the dispersion of the fibre is uneven. There is also an indication of minor porosity in some areas in Fig. 6(b), the surface appears more textured compare to 10 wt% bamboo fibre reinforced composite. Also, the SEM image revealed areas with cluster of fibres and polyester. The dark region suggest the presence of major pores or void. The presence of major void may be attributed to the low value of impact strength at 20 wt% loading.

Fig. 6(c) revealed a degree of roughness due to higher fibre content. The dispersion of the fibre and polyester is uneven and micro pore are more visible. In Fig. 6(d) the micrograph revealed a rough surface.The pores are visible within the composite and the appear small. The roughness in the composite can be attributed to ridges like structure on the surface of the composite.

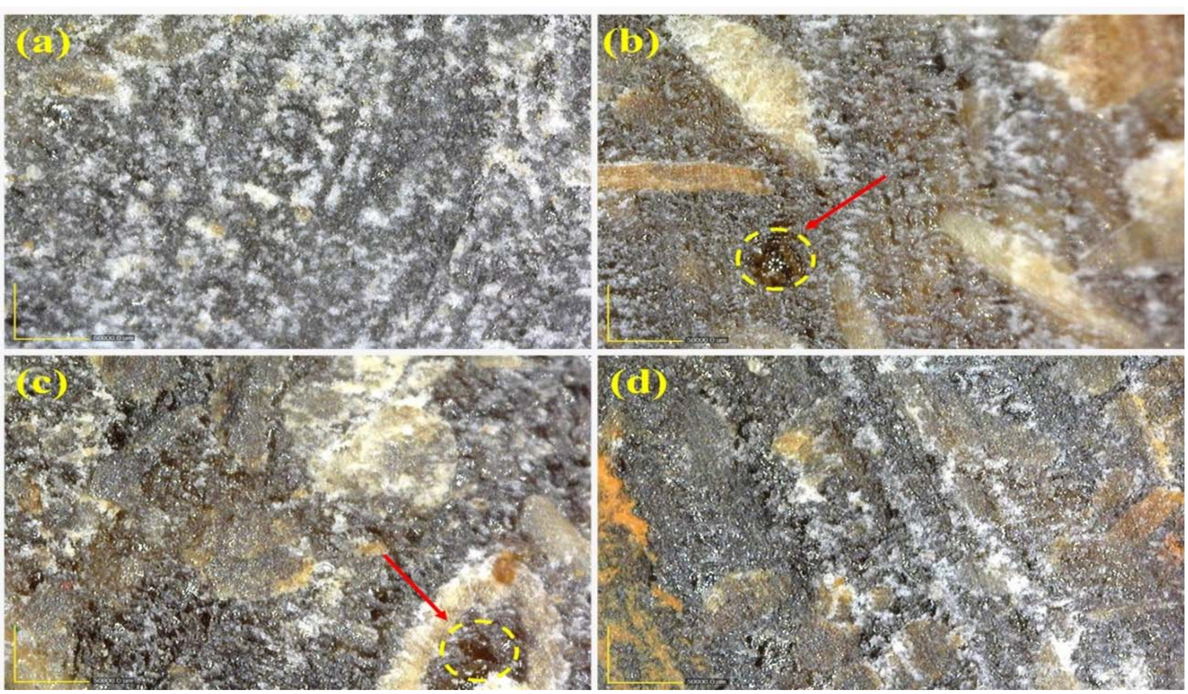



Fig. 6. SEM micrographs of (a) 10wt%, (b) 20wt%, (c) 30wt%, and (d) 40wt% bamboo fibre reinforced composite.

**Acknowledgement**

The authors appreciate the financial support provided by Tertiary Education Trust Fund (TETFund) under the Institution Based Research (IBR) grant and the Air Force Institute of Technology (AFIT), Kaduna for facilitating the implementation of the research. The authors will also like to thank the Nigerian Institute of Leather and Science Technology (NILEST), Zaria for the sample preparation and development of the composite and Ahmadu Bello University (ABU), Zaria for the experimental test conducted.

**Conclusion**

The influence of wt% of bamboo fibre, soaking time, ratio of accelerator to catalyst and NaOH treatment concentration on the mechanical properties of the developed bamboo fibre reinforced polyester composite has been analyzed. The study showed that the various parameters exhibited significant improvement on the mechanical properties of the composite. Based on the result of the study, the following conclusions were drawn:

i. The wt% of the bamboo fibre on the mechanical properties of the polymer composite shows that reinforcement of 30 – 40 wt% signficantly improves the properties as 30 wt% attained optimum for hardness (121.16 Hv) and flexural strength (93.99 MPa) while 40 wt% for tensile (78.53 MPa) and impact strength (4.85 KJ/m$^2$).
ii. The soaking time showed that between 2 – 4 hrs the mechanical properties of the composite is enhanced indicating values for 2 hrs soak time at 77.68 MPa for tensile strength, 4 hrs at 122.16 Hv for hardness value and 3 hrs at 5.52 kJ/m$^2$ and 89.04 MPa for impact and flexural strength respectively.
iii. The ratio of accelerator to catalyst mix displayed optimum value at 1.2 for hardness (119.54 Hv), flexural (93.61 MPa) and tensile strength (70.34 MPa). However, the impact strength (4.92 KJ/m$^2$) attained optimum at 2.4 ACR mix. This implies that high volume of accelerator to catalyst mix at 1.8 and 3.0 may lead to brittleness, debonding of the polymer composite.
iv. NaOH treatment concentration showed that at low concentration the mechanical properties of the composite improved with optimal value at 4% for tensile strength (71.81 MPa), 4% for hardness (116.93 Hv), 2% for impact strength (6.42 kJ/m$^2$) and 2% for flexural strength (93.19 MPa). At higher concentrations of 6 and 8%, NaOH degrades the fibres and reduces their strength and stiffness, and ultimately decreasing the composite properties.
v. The water absorption properties of the composite increased with increasing the wt% of the bamboo fibre from 10 – 30 wt%, attaining optimum at 30 wt%. However, a gradual decrease is experienced beyond 30 – 40 wt%. This may suggest that at higher fibre wt%, the fibres are more closely packed, leading to improved adhesion between the fibres and the matrix thereby reducing the pathways for water penetration.
vi. The SEM micrograph revealed the surface morphology of the developed composite indicating regions of relatively smooth surfaces, variation of fibre-matrix adhesion, minor and major porosity and rough surfaces which accounts for the various disparity of the composite properties.

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