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Research Article
Mechanical Properties of Tropical Bamboo Reinforced PVA for Fibreboard Production

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Abstract
Background and Objective: Cost of fibreboard production in sub-Saharan African is increasing; the use of bamboo will provide alternative to synthetic raw material for re-enforced fibreboard production. Bamboo is sustainable and environmentally friendly. The objective of the study was to determine the mechanical properties of polyester based composites reinforced with Tropical Bamboo (*Bambusa vulgaris*) fibers. **Materials and Methods:** The bamboo fiber (BF) was extracted through a mechanical process known as scouting and after subjecting them to some chemical modifications, composites were formed using hand lay-up and compression technique with ployvinyl acetate emulsion as a chemical binder. Three levels of BF content by weight (20, 40 and 60%) were used in the study. The engineering properties of the developed fiber board were determined using the method described by the ASTM. **Results:** Results showed that, in terms of tensile strength, the 60% BF content composite board with a value of 32.895 N/mm^2 was significantly superior ($p<0.05$) than the others. There was no significant difference ($p>0.05$) in the flexural, compressive, hardness and impact strength between the 20, 40 and 60% BF composites. **Conclusion:** Bamboo is a better alternative to synthetic raw materials as seen from the results of this study. The mechanical properties of the reinforced PVA based composites fibreboard from bamboo can be used in furniture and soundproofing industries.

Key words: Fibre-reinforced composites, bamboo fiber, *Bambusa vulgaris*, fibreboard production, compression technique, synthetic raw materials

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The use of fiberboard for product development is gaining popularity but limited studies have been done on the use of bamboo fiber as substitute to synthetic fibers. The trust of the study is to gain increased understanding on the mechanical behavior of bamboo fiber as a load-bearing constituent in structure components. The potential and comparative advantages of using bamboo fiber as a substitute to synthetic fiber board are numerous .These include low cost, low density, ecological friendliness, sustainability and biodegradability. A composite material can be defined as a combination of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components[1]. The matrix, normally a form of resin, forms the bulk of the composite and keeps the reinforcement in the desired orientation. It also protects the reinforcement from chemical and environmental attack and bonds the reinforcement so that applied loads can be effectively transferred. The reinforcement is used to fortify the matrix in terms of strength and stiffness. The reinforcement fibres can be cut, aligned, placed in different ways to affect the properties of the resulting composite. Matrix material may be metals, ceramic or polymer depending on the intended use. Reinforcing materials may be synthetic fibers such as glass fiber, carbon fiber, etc or natural (cellulose) fiber such as cotton, jute, kenaf and most importantly bamboo[2-7]. Natural fibres present many advantages as a reinforcement material when compared to synthetic fibres. They are environment friendly, fully biodegradable, abundantly available, renewable and cheap[8,9]. Bamboo fibres (BF) are particularly attractive as a reinforcement material for composites.

Bamboos are fast growing perennial woody plant of the grass family which is found mostly in tropical and subtropical areas[10]. There are more than 70 genera and over 1000 species which have been proposed in botanical literature[11]. The plant's stems, called culms, consist of hollow sections called internodes which are interrupted by fairly regularly spaced nodes, giving bamboo its jointed appearance[10]. Bamboo's use has a long history with humankind. Bamboo chips were used to record history in ancient China. It is also one of the oldest building materials used by humans (Lakkad and Patel)[12] and are still extensively used in the building industry. The high strength with respect to weight is derived from the fact that the fibres are longitudinally aligned in its body[13]. Apart from the above mentioned properties of natural fibres, bamboo fibers (BF) have high specific properties because of their low density[14]. The abrasive nature of bamboo fibers are also much lower which leads to advantages in regard to manufacturing and recycling processes of the composite material in general[15,16]. The use of bamboos as a continuous source of fiber supply will therefore result in a significant material cost saving to the plastic industry.

The extent that strength and elasticity are enhanced in a fibre-reinforced composites depends, not only on the mechanical properties of both the fibre and matrix, but their volume relative to one another as well as the dispersion, aspect ratio, fibre length and orientation within the matrix[17]. The objective of this study was to determine the mechanical properties of fiber board produced from polyester based composites reinforced with different levels of Tropical Bamboo (*Bambusa vulgaris*) fiber content.

MATERIALS AND METHODS

For fibreboard extraction, treatment, mat reinforcement and formation, this work adopted the methods used by Kushwaha and Kumar[18]. International organizational standards were also used for material testing and evaluation.

Sample selection and harvesting: The Bamboo (*Bambusa vulgaris*) samples for the research work were collected from Nsukka (Latitude 6°51 24"N and Longitude 7°23 45"E) in Enugu State, Nigeria. Bamboos of the same sizes, i.e., about 12-15 cm in diameter and of good grades with no appearance of defects were selected and harvested. Five different stands of bamboo trees were selected and from each stand, 10 bamboo culms were selected and harvested giving a total of 50 culms.

Fibre extraction and treatment: Samples for the study were taken 60 cm above the base of each culm. Each sample was first treated with Sodium Pentachlorophenate solution to protect it against biodegradation. A mechanical procedure known as scouting was used to extract the fibre. The samples were subjected to a series of mechanical beating, breaking and scraping of the bamboo culms to release the non-fibrous mater after which the individual fibres were carefully combed out by hand. In order to obtain a higher fiber matrix interaction, fibers were subjected to two chemical modifications. Neatly separated and pre-treated fibers were immersed for 1 h in Silane (3-amino propyl ethoxy silane) dissolved in a water acetone mixture (pH = 9.0) after which the solution was decanted and the fibre sun-dried. The fibre samples were then subjected to mercerization by immersion in a 1% sodium hydroxide (NaOH) solution for 1 h. This was to assist in degrading lignin and softening the fibre physically and chemically resulting in higher fibre yield and reduced breakage and damage of the fibre[18]. The fibers were then washed thoroughly with water containing a few drops of HCL to remove all traces of the alkali and then allowed to oven dry at 65°C.

Fibre mat reinforcement formation: After oven drying, the fiber was measured by weight fraction into samples of 20, 40 and 60%, each in four replicates. For each sample, chopped strand mats were produced by holding together approximately 50 mm randomly oriented chopped strands of bamboo fibers using poly-vinyl acetate (PVA) emulsion as a chemical binder. The mat formed was fed into a mould coated with releasing agent (universal mould release wax and PVA). The composite laminates of bamboo fiber/polyester resin were produced using the hand lay-up and compression processing technique. The dry fiber mats (chopped strand bamboo fibers) were placed into various mould cavities. Small quantity (0.5 mg) of cobalt Naphthenate and methyl ethyl ketone peroxide (MEKP) were used as accelerator and catalyst which was thoroughly mixed with polyester resin and applied to the dry plies with hand brush. After a targeted thickness was reached, the mould was closed and pressure (1.0-2.0 bars) applied while the tool temperature was held at 50°C during the lamination. After lamination, the laminates were cured for 24 h in the mould at a temperature of 80°C. They were then allowed to cool overnight by hot stacking at room temperature (Fig. 1). After 3 days of fabrication, the panels formed were subsequently trimmed into desired dimensions. The process was illustrated in Fig. 2.

Mechanical testing of the composite: The tensile strength, flexural strength, compressive strength and hardness of the fabricated fiber board specimens were tested using the Hounsfield (Monsanto) tensometer type of universal testing machine at a crosshead speed of 2 mm min^{-1} as prescribed by the relevant ASTM standards (Table 1). The impact strength tests on the materials were also carried out according to ASTM standard using the Impact Testing Machines (Model: IT-30, IT-30 (D). The size of the specimens used in the testing is as shown in Table 1. Four specimens were used per level of fiber content per test. In all the tests, the samples were first conditioned in an environment of 23°C and 50% relative humidity for 6 days.

Experimental design and data analysis: Completely randomized design (CRD) with one factor (level of BF content) and 4 replications was adopted as the experimental design.

Fig. 1: Fabricated bamboo fibre reinforced composites

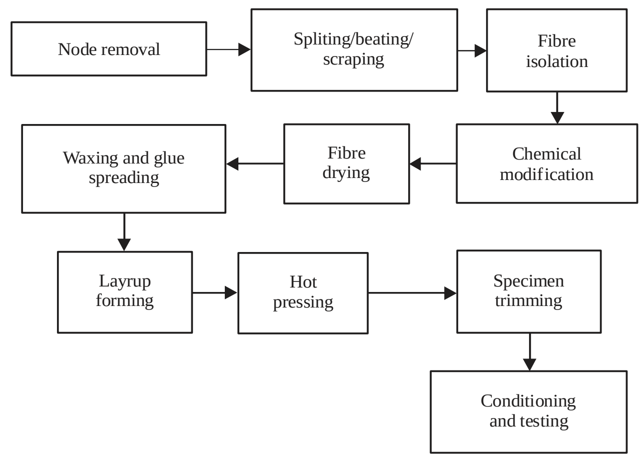

Fig. 2: Fibreboard production process

Table 1: Dimensions of test samples

	Size of specimen (mm)			
Type of test	Length	Width	Depth	Standard
Tensile	100.0	19.0	3.2	ASTM D638
Flexural	300.0	19.0	3.2	ASTM D790
Compressive	40.0	20.0	20.0	ASTM D695
Hardness	20.0	20.0	20.0	ASTM E10
Impact	55.0	10.0	10.0	ASTM D526

Statistical analyses were conducted using GenStat Discovery edition (VSN International 2011 software). One way analysis of variance (ANOVA) was performed at 5% significant level ($p<0.05$). Mean separation was done using Duncan Multiple Range Test (DMRT) at 5% probability level.

Duration of the study: The study was conducted for 16 months. The starting date was 1st August, 2016-30 December, 2017.

RESULTS AND DISCUSSION

The mean values of the tensile, compressive, flexural and impact strength as well as the hardness of the BF reinforced composite were shown in Table 2.

Effect of fiber content on tensile strength of the composites: The variation of the tensile strength of the produced composite with different BF weight content was shown in Table 2 and presented graphically in Fig. 3. The tensile strength increased from 21.38 MPa at 20% BF content to 32.895 N mm^{-2} at 60% fibre content level. Generally the results revealed that the tensile strength improved with increment in percentage fiber content. This increase in tensile strength with fibre content had been observed by other researchers using different combinations of BF and matrices[9,19-21]. The range of tensile strength observed in this study also agreed with previous reports of 23.40 N mm^{-2} by Amada and Untao[22], 24.60 N mm^{-2} by Amada *et al*.,[23] and 28.67-36.57 N mm^{-2} by Olajide *et al*.,[24] for BF reinforced composites, although the researchers used different methods of extraction of bamboo fiber.

The result of the analysis of variance (ANOVA) carried out on the tensile strengths showed that there was no significant difference ($p<0.05$) in the mean tensile strength of the 20 and 40% BF content polymer composite (Table 1). The highest recorded tensile strength of 32.895 N mm^{-2} at 60% was, however, significantly higher ($p<0.05$) than the other values.

Effects of fibre content on compressive strength: The compressive strength of the composite samples was shown in Table 2. As seen from the Table 2, there was a decrease from 25.63 N mm^{-2} at 20% BF content to 19.75 N mm^{-2} at 40% BF content by weight, after which the compressive stress increased to 22.31 N mm^{-2} at 60% BF content. The sharp decrease at 40% BF content may be attributed to pores or voids in the matrix-rich regions within the composites as reported by Harris[25]. There was no significant difference ($p<0.05$) in the compressive strength of the various samples with the different percentages of BF contents.

Effect of fibre content on flexural strength of composites: Flexural property is important in understanding the fracture behavior of the composite materials. As seen from Table 2, the flexural strength of the composite increased with increase in the fiber content from 10.97 N mm^{-2} at 20% BF content to 18.21 N mm^{-2} at 40% after which there was only a 0.01 increase to 18.22 N mm^{-2} at 60% BF content. This result was in line with that of Hussain *et al*.[9], who reported that the flexural strength of short bamboo-polyester reinforced composites increased with increase in fiber loading up to 38.98 MPa at 30% fibre content and then decreased with further increase in the fiber content. It also agrees with the result of Sreenivasulu and Reddy[21] who also achieved a flexural strength of 38.989 MPa at 30% BF content by volume using BF-polyester composite. This result, however, contradicts that of Hussain *et al*.[26] whose result of flexural strength of coconut reinforced HDPE polymer composite decreased with increase in fiber percentage volume. The differences may be as a result of the type of polymer and fiber used. Further improvement could be achieved by reinforcing and improving the fiber/matrix bonding[27].

The differences in values recorded may be as a result of differences in heating time as this has been shown to have effect of the strength of BF-polyester composites[19]. The result of the analysis of variance (ANOVA) on the flexural strength of the composites, showed that there was no significant difference ($p<0.05$) in the mean values.

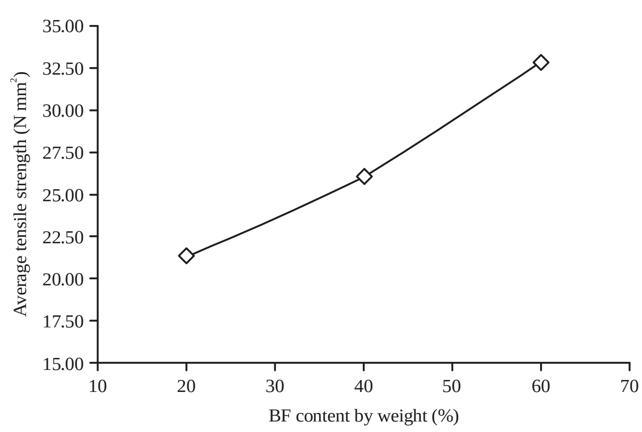

Fig. 3: Variation of tensile strength with percentage BF content

Table 2: Mean values of the engineering properties of reinforced composite

Fiber content (Wt %)	Tensile strength (MPa)	Compressive strength (MPa)	Flexural strength (MPA)	Hardness (BHN)	Impact strength (J m^{-1})
20	21.38 ± 0.01^{a}	25.63 ± 0.21^{a}	10.97 ± 0.9^{a}	4.44 ± 0.11^{a}	1.16 ± 0.01^{a}
40	26.11 ± 0.11^{a}	19.75 ± 0.1^{a}	18.21 ± 0.7^{a}	4.56 ± 0.09^{a}	1.08 ± 0.014^{a}
60	32.895 ± 0.08^{b}	22.31 ± 0.02^{a}	18.22 ± 11^{a}	4.45 ± 0.91^{a}	1.05 ± 0.17^{a}

Values with the same alphabet are not statistically different ($p<0.05$) according to DMRT

Table 3: Comparisons of engineering properties of the reinforced fibre board with that of previous researchers

Composites	Tensile strength (Mpa)	Compressive strength (Mpa)	Flexural strength (Mpa)	Hardness strength	Impact strength (J m^{-1})	Sources
Bamboo fiber reinforced polyester composite	32.865	25.63	18.22	4.56 (BHN)	1.16	Present study
Bamboo fiber reinforced polyester composite	17.20	_	13.78	_	1.40	Hussain *et al.*[26]
Short bamboo fiber reinforced epoxy composite	15.45	_	31.27	47.5 (Hv)	1.57	Saurav[29]
Natural fiber reinforced cement-based composite	9.80	59.70	_	_	_	Ismail[30]
Fibrillated polypropylene fibers reinforced concrete	3.64	33.04	_	_	_	Vairagade *et al.*[28]

Effect of fiber content on hardness of composites: The results in Table 2 showed that with the increase in fiber content, hardness of the bamboo-polyester composites, measured as Brinell Hardness Number (BHN), increased from 4.44 at 20% BF content to a maximum of 4.561 at 40%. It then decreased to 4.452 at 60% BF content. It was evident that the hardness strength at 40% fiber content (4.561) showed a better engineering property than at 20 or 60% BF content. Thus the fiber hardness (HBN) value of the composites was improved up to 40% after which it decreased. There was no significant difference ($p<0.05$) in the mean values of the hardness for the different levels of BF content by weight.

These values when compared with the reported micro-hardness values of glass-polyester composites[28] clearly indicates that inclusion of bamboo fiber in the polyester matrix body results in improvement of the hardness although this improvement is marginal. As reported by Saurav[29] the decrease in hardness at higher fibre content may be attributed to insufficient resin content which may not have allowed for good binding resulting in higher void content in the composites. As can be observed from Table 2, the hardness strength of the composite increased with decrease in compressive strength. This was to be expected because the harder the material, the more brittle and the less the compressive strength.

Effect of fiber content on impact strength of composites: The impact strength is a predominant property in processing of composite materials. The impact strength of the BF reinforced composite decreased steadily from 1.16 J m^{-2} at 20% to 1.05 J min^{-1} at 60% BF weight content as seen in Table 2; implying that impact strength decreased with increase in fibre content. The analysis of variance (ANOVA) tests showed there were no significant differences ($p<0.05$) in the mean impact strength values for the different levels of fibre weight content.

These results, when compared with Hussain *et al.*[26], are similar, though results attained an optimum impact strength at 30% fibre content. The differences may be attributed to different fiber and matrix used by Hussain *et al.*[26] in their study.

Comparison of engineering properties: Some of the engineering properties of bamboo fiber reinforced composite were compared with results from previous researchers using the optimum fiber content values as shown in Table 3. It was observed that BF reinforced polyester composite from the present study gave a maximum tensile strength of 32.865 MPa which was higher than the value of 17.20 MPa reported by Hussain *et al.*[26] for BF reinforced polyester composite. Fibrillated polypropylene fibers reinforced concrete was observed to have the lowest strength[28] of 3.64 MPa. The compressive strength of the BF reinforced polyester composite showed a lower compressive strength of 25.63 MPa compared to natural fiber reinforced cement-based composite and fibrillated polypropylene fibers reinforced concrete with optimum compressive strength of 59.7 and 33.04 MPa, respectively. The maximum flexural strength of the BF reinforced polyester composite of 18.22 MPa was found to be higher than the optimum value reported by Hussain *et al.*[26] for BF reinforced polyester composite with flexural strength of 13.78 MPa. But Short bamboo fiber reinforced epoxy composite showed a better flexural strength[29] of 31.27 MPa.

The impact strength of the bamboo reinforced composite from this study showed a lower impact strength of 1.16 J min^{-1} than short bamboo fiber reinforced epoxy composite and bamboo fiber reinforced polyester composite with impact strength of 1.57 and 1.4 J min^{-1}, respectively.

The optimum compressive strength of 25.63 N mm^{-2} at 20% BF content, flexural strength of 18.22N mm^{-2} at 60% BF content, hardness strength of 4.56 BHN at 40% BF content and the optimum impact strength of 1.16 J min^{-1} at 20% BF content were the best values recorded. Moreover, according to the result of the ANOVA tests, there was an indication that whether 20, 40 or 60% BF content were use, they will be good and adequate for manufacturing of composite products.

Optimum fiber content of reinforced polyester composite: The optimum fiber content in the bamboo fiber reinforced composites for different requirements was presented in Table 4. The composite presents the best tensile strength of 32.895 N mm^{-2} at 60% BF content. For materials requiring high tensile strength 60% BF content is preferred for the

Table 4: Optimum fiber content in bamboo fibre reinforced composites

Test specimen	Optimum strength (%) fibre content by weight	Remarks
Tensile strength (N mm^{-2})	60 wt % (32.895)	60 wt % will be good for product development
Impact strength (J m^{-1})	20 wt % (1.16)	20-60 wt % BF content were found adequate for product development
Compressive strength (N mm^{-2})	20 wt % (25.63)	BF content of 20-60 wt % were found adequate for product development
Flexural strength (N mm^{-2})	40 or 60 wt % (18.22)	40 or 60 wt % specimens were found adequate for product development
Hardness strength (BHN)	40% (4.56)	40 wt % and all percentage specimens were found adequate for product development

product development. For material that requires improved impact, compressive, flexural or hardness strength any of the percentage BF content studied in this work may be adequate since the analysis of variance (ANOVA) results showed that there was no significant difference ($p<0.05$) whether 20, 40 or 60% BF content were used for product development.

CONCLUSION

From the experimental investigation of the effects of different levels of BF content on the engineering properties of bamboo fiber reinforced polyester composite carried out in this study, the following conclusions can be drawn:

- The engineering properties of the bamboo fiber reinforced polyester composite such as tensile strength, compressive strength, flexural strength, hardness strength and impact strength are greatly affected by the fiber content
- On the basis of tensile strength, 60% fiber content by weight shows superior property. However, in terms of compressive strength, flexural strength, hardness strength and impact strength, the BF content within the range of 20-60% by weight do not significantly affect the properties
- Bamboo fiber reinforced composite offers a good potential material for fiberboard product development

SIGNIFICANCE STATEMENT

The work provided additional knowledge on the production of reinforced PVA based composites fiberboard from tropical bamboo. The work only focused on tropical bamboo and analyzed its mechanical properties. The unique extraction, treatment and reinforcement materials used in the study brought a significant result and thus a new contribution to knowledge.

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