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Mechanical Modelling of Bamboo Sawdust/polyester Composites Fabricated by Hot Pressing Method

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Abstract

Bamboo fibres of 1 to 3 mm sizes were milled to particle size of approximately 100μm using a hammer mill. The bamboo sawdust (BS) was chemical treated using NaOH of concentration 6 % wt/v for 72 h at room temperature. Dried bamboo sawdust was mixed with polyester at different weight ranging from 0 % to 24 % wt. %. The composites were tested for the tensile properties. Theoretical mechanical equations were used to predict the properties. Polyester curve showed linear deformation behaviour with the stress rising to a maximum value with signs of yielding before fracture. The tensile strength of polyester was 49.38 MPa, increasing to a maximum of 76.47 MPa at 24 % wt. of BS. At zero wt. % of BS the modulus was 1381 MPa, and increased to 2587.08 MPa at 24 % wt. The strain decreased from 5.5 % at pure polyester to 3.32 % at 24 % wt. of BS. A maximum percentage decrease of ≈ 40 % for the strain was recorded, an indication of the brittleness of the composites. Prediction of mechanical properties using published theories of mechanical equations (tensile strength and Young' modulus) with experimental results of bamboo sawdust reinforced polyester composites was investigated. The models used were rule of mixture (Parallel and Series), Hirsch's and Halpin-Tsai models. Irrespective of the equation used tensile strength increased with increase in the volume fraction of BS. The best correlation between theoretical and experimental tensile strength was predicted using the Halpin-Tsai model, followed by Hirsch, Parallel and Series respectively. Depending on the volume or weight fraction the percentage prediction was between 79 and 88 % for Parallel and Series models and between 97 and 99 % for Halpin-Tsai and Hirsch models.

Keywords: strength, modulus, mechanical theories, modelling.

1. INTRODUCTION

A composite is a material comprising of a mixture of two or more (insoluble in each other) constituents, which differ in chemical and form composition. One major advantage of composites material is the high specific strength and stiffness compared to the individual components. A composite can be produced from a mixture of a polymer matrix and a synthetic fibre acting as a reinforcing material (Bledzki and Gassan, 1999). Aramid, glass and carbon fibres are often used as reinforcement for polymer composites. The major reason for the wide usage is their strength and availability. The applications of these fibre reinforced composites cut across building materials, civil engineering, boat hulls, automobile and aerospace industries (Manalo *et al.,* 2015; Huang and Young, 2019). Besides, demanding energy (Zhang *et al.,* 2018), involved in the usage of synthetic fibres, has brought about environmental concern due to the none-biodegradability (Huang and Young, 2019). The aforementioned problems on synthetic fibre can be fixed by using the natural fibres as reinforcement for polymer composite fabrication (Faruk *et al.,* 2014)

Natural fibre can be considered as an alternative to synthetic fibre reasons been due to their high strength, low cost, lightweight, biodegradability, renewability, low cost, low energy requirements, ease of separation, abundant and local availability (Li *et al.,* 2007). Examples of natural fibres that have attracted research include sisal, kenaf, jute, coir flax, and bamboo fibre (Baley *et al.* 2018; Prasob and Sasikumar, 2019; Koronis *et al.,* 2017; Sen and Reddy 2011; Saba *et al.,* 2015). Natural fibres can be grouped according to their origin; these are animals, plants, or minerals. Fibres from animal can be found in sea shells example is crab (Ofem, 2018). Plant fibres, can be subdivided into non-wood fibres (leaf, seed-hair and bast fibres) and wood fibres (softwood and hardwood fibres). The major constituents of vegetable fibres are lignin, cellulose, and matrix polysaccharides (Akil *et al.,* 2011)

Bamboo is one of the fast growing, low-cost and locally available natural materials in most developing countries. Bamboo being a natural hierarchical cellular material can give good mechanical properties, along its fibre direction (Wegst and Ashby, 2004). Among numerous natural fibres, bamboo fibre has drawn specific consideration due to its low-density, high stiffness, high strength and rapid growth (Okubo *et al.,* 2009; Osorio *et al.,* 2011). Several treatments of bamboo culm are needed to obtain bamboo fibre. Extraction methods needed to obtain bamboo fibre from bamboo culm include retting, alkali treatment, crushing, grinding, milling and degumming (Zakikhani *et al.,* 2014; Rao and Rao 2007; Biswas *et al.,* 2013). The extraction method can affect the quality and strength of the fibres.

Alkali treatment of bamboo fibre has being the most commonly used and comparatively economical chemical treatment (Izani *et al.,* 2013; Senthilkumar, *et al.,* 2019). The essence of the chemical treatment is to effectively modify the fibre surface to boost the interfacial adhesion between the fibre and the polymeric matrix (Reddy *et al.,* 2013). Other chemicals used for modification of fibre surfaces are maleic anhydride-grafted (Chen et al. 1998) sodium hydroxide (Huang and Young, 2019; Izani *et al.,* 2013; Senthilkumar *et al.,* 2019; Khan *et al.,* 2017), Sodium hypochlorite (NaClO) (Li *et al.,* 2007), and benzoate (Chen *et al.,* 2018). Huang and Young (Huang and Young, 2019) reported the mechanical, hygral, and interfacial strength of continuous bamboo fibre reinforced epoxy. Sodium hydroxide (0.1 N of NaOH at 100°C for 12 h) was used to modify the surface area of the fibre. At 42 % volume fraction alkali treatment improved the adhesion between epoxy polymer and bamboo fibre.

The effect of maleic anhydride-grafted polypropylene (MAPP) on the mechanical properties of bamboo fibre-reinforced composite has been reported (Chen *et al.,* 1998). At 24 wt. % of MAPP, while the tensile strength of the composite was 32–36 MPa, tensile modulus was 5–6 GPa. It was observed that the composite is lighter, water-resistant, cheaper, and has a tensile strength three times higher than the commercially available wood pulp board. The effect of sodium silicate modification on moso-bamboo particles reinforced PVC has been reported (Wang *et al.,* 2010). Sodium silicate aqueous solutions were varied (0.5%, 1%, 2%, 5% and 10%). The result showed that the tensile strength and modulus of elasticity of the bamboo particles reinforced PVC composites increased to 15.72 MPa and 2956.80 MPa respectively at 5% concentration of sodium silicate solution.

Therefore, this work is to investigate the effect of loading on the mechanical properties of polyester resin reinforced bamboo sawdust. Four model equations will be used to predict the tensile strength and elastic modulus of the composite. To best of our knowledge the mechanical properties of bamboo sawdust reinforced polyester have not been reported. Modelling of the mechanical properties of bamboo fibre using established equations is limited in literature. Due to the strength of epoxy, most authors have reported the properties of bamboo fibre/epoxy composites. In this research, bamboo sawdust will be obtained from bamboo fibre after milling and chemical treatment using an alkali. Modelling of the tensile strength and modulus will be evaluated. Scanning electron microscopy (SEM) will also be used to characterize the composites.

2.0 THEORETICAL MODELLING OF MECHANICAL PROPERTIES

There is wide-ranging literature dedicated to the modelling of mechanical properties of polymers reinforced natural or synthetic fibres. The modelling is exceedingly significant and sheds light on the relationship between the composite structure and the properties of the composite. The mechanical properties (tensile and elastic) of polymer reinforced composites can be experimentally determined from a variety of mathematical models. Properties such as Poisson's ratio, elastic modulus, shear modulus, tensile strength, and relative volume fractions of both matrix and fibre are the important input properties needed to predict the mechanical properties of the composite. In some models, aspect ratio and orientation of fibre play a significant role. Many theoretical models have been reported to model the tensile strength and Young's modulus of composites. These include Rule of mixture (Parallel or Series) model, Halpin-Tsai equation, modified Halpin-Tsai equation, Hirsch's model, Einstein and Guth equations, Cox Model and Guth's Equation, Nicolais-Narkis theory and modified Bowyer and Bader's model**.** In this research, we will limit ourselves to Rule of mixture (Parallel or Series) model, Halpin-T-sai equation, modified Halpin-Tsai equation, and Hirsch's model equations(Facca *et al.,* 2006; Facca *et al.,* 2007; Kalaprasad *et al.,* 1997; (Fornes *et al.,* 2003; Shindea *et al.,* 2017)..

2.1 Rule of Mixtures Model (Parallel and Series model)

The Rule of mixtures model comprises of the parallel and the series models. They are the simplest models used to predict the elastic and tensile properties of composite materials. The applications got across both particulate and fibrous reinforcement. The parallel and series equations give the maximum and minimum possible values for E_c and T_c. The parallel model assumes iso -strain conditions for both matrix and fibre while series models assume uniform stress in both matrix and fibre. Equations 1, 2, 3 and 4 are the Rule of mixture for modulus and tensile strength (Facca *et al.,* 2006; Facca *et al.,* 2007; Kalaprasad *et al.,* 1997). The role of mixture assumes that the aspect ratio ξ approaches infinity or zero, respectively.

Parallel model

$$E_c = E_f V_f + E_p \ V_p \tag{1}$$

$$T_c = T_f V_f + T_p \ V_p \tag{2}$$

Series model

$$E_c = \frac{E_m E_f}{E_m V_f + E_f V_m} \tag{3}$$

$$T_c = \frac{T_m T_f}{T_m V_f + T_f V_m} \tag{4}$$

E_m, E_c and E_f are the elastic moduli of matrix, composite and filler, respectively. V_f and V_p are the volume fractions of filler and polymer. Tc, T_f and T_p, are the Tensile strength of composite, filler and polymer matrix, respectively.

2.2 Halpin-Tsai (H-T) Model

A semi-empirical equation to predict the elastic properties of short fibres reinforced polymer matrix was developed by Halpin and Tsai (Fornes *et al.,* 2003). The H-T models' assumed that the particle is isolated, the matrix is isotropic, viscosity is constant, filler well dispersed, has uniform shape and dimension, and is firmly adhered to the matrix. The volume fraction of the filler and its orientation are accounted by using the aspect ratio, $\xi = 2l/D$ swhere l is the length of the fibre and D the diameter or thickness of the fibre depending on the shape. The Halpin and Tsai equations are given in Equations 5-8.

$$E_c = E_m \left\{ \frac{1 + \xi\eta V_f}{1 - \eta V_f} \right\} \tag{5}$$

$$T_c = T_m \left\{ \frac{1 + \xi\eta V_f}{1 - \eta V_f} \right\} \tag{6}$$

$$\eta = \frac{E_f / E_m - 1}{E_f / E_m - \xi} \tag{7}$$

$$\eta = \frac{T_f / T_m - 1}{T_f / T_m - \xi} \tag{8}$$

where

E_c = composites' modulus

E_m= the matrix modulus

T_c= composites' Strength

T_m = the matrix Strength

ξ = the shape factor which relates to the filler aspect ratio

V_f= the volume fraction of the filler

2.3 Hirch's Model

Hirsch's model is a combination of series and parallel models. Hirsch's model is applicable for particulate and fibrous reinforcements. The Young's modulus and tensile strength can be calculated using the following equations (Kalaprasad *et al.,* 1997; Shindea *et al.,* 2017)

Series model

$$E_c = \chi(E_f V_f + E_p) + (1 - \chi)$$

$$V_p \frac{E_m E_f}{E_m V_f + E_f V_m} \tag{9}$$

$$T_c = \chi(T_f V_f + T_p) + (1 - \chi)$$

$$V_p \frac{T_m T_f}{T_m V_f + T_f V_m} \tag{10}$$

χ is the stress transfer parameter. χ is 0.1 for randomly oriented fibres composite.

3.0 MATERIALS AND METHODS

The following are the major materials used; bamboo chips were locally source (Ugep, Nigeria), Sodium Hydroxide (NaOH), and unsaturated polyester resin (35% solution at 20°C, M_w 600,000), Cobalt naphthanate as accelerator and methyl ethyl ketone peroxide (MEKP) from Sigma-Aldrich is used as catalyst. Bamboo fibres were cut into different sizes of between 1 to 3 mm washed in water to remove impurities like sand, debris etc. Washed fibres were dried in sun until the weight of fibre was constant. Chemical treatment of the bamboo fibre was performed using NaOH of concentration 6% wt./v for 72 hrs at room temperature. After 72 hrs the bamboo fibres were removed and soaked in distilled water to reduce the brittleness and also dilute the alkaline content. Washing of the fibre is done in running water until the pH of the fibre is neutral. Sawdust of bamboo was prepared by crushing the fibres to particle size of approximately 100 μm using a hammer mill. The bamboo sawdust was dried in an oven at a temperature of 60°C for 24 hrs or until the weight is constant. Treated bamboo sawdust was mixed with polyester (after mixing with accelerator and catalyst at room temperature for curing at 1% by volume of resin) at different weight ranging from 0 to 24% wt. of bamboo. The mixing was done by dispersion and hot pressed using 120 ton hydraulic hot press to make samples for tensile testing. The composite specimens were cured for 24 hrs and post cured for another 3 hrs at 60°C

3.1 Characterisations of Composite

Mechanical properties were evaluated using Instron Universal Testing Machine (Instron 1121), fitted with a 20KN load Cell. The tensile test was performed at a crosshead speed of 2 mm/min. Films were conditioned in desiccators under 50% RH, at 25°C, for 48 h before being characterized for mechanical properties. A micrometre screw gauge was used to measure the thickness. Measurements were taken from three different positions and an average value was used. Between 3 and 5 specimens were tested for each % weight. The mechanical properties were measured according to ASTM D882-02 (2002). The fracture surface of BS-P composites was examined by scanning electron microscopy (SEM) to investigate the failure mechanism of fracture. An EVO 60 scanning electron microscope was used to study fracture surfaces. Using a low-vacuum sputtering machine, samples were coated with gold mounted on a silver-paint holder before inserted into the SEM chamber. SEM imaging was employed using an accelerating voltage of 5 kV. To prepare specimens for SEM, fracture surfaces were first flushed with distilled water to remove any debris. Table 1 is the nomenclature of bamboo sawdust/polyester resin.

Table 1: Nomenclature of BS/P blended specimen

Abbreviations	Full name
P	Neat Polyester film
BS	Bamboo Sawdust
BS/P10	Polyester blend (10 wt.% bamboo sawdust)
BS/P12	Polyester blend (12 wt.% bamboo sawdust)
BS/P14	Polyester blend (14 wt.% bamboo sawdust)
BS/P16	Polyester blend (16 wt.% bamboo sawdust)
BS/P18	Polyester blend (18 wt.% bamboo sawdust)
BS/P20	Polyester blend (20 wt.% bamboo sawdust)
BS/P22	Polyester blend (22 wt.% bamboo sawdust)
BS/P24	Polyester blend (24 wt.% bamboo sawdust)

4.0 RESULTS AND DISCUSSION

4.1 Tensile Behaviour

Results of mechanical properties were compared using ANOVA multiple comparison tests ($p < 0.05$). Tensile properties were measured according to ASTM D882-02 (2002) standard. Figure 1 is the stress-strain curves of polyester and bamboo fibre. Alkali or acid hydrolysis is used in chemical processing to remove the amorphous regions of raw cellulose fibre. It is worth noting that the alkali solution influences not only the cellulosic components inside the plant fibre, but also the noncellulosic components (hemicellulose, lignin, and pectin). A typical stress-strain plot for the resin and bamboo fibre is shown in Figure 1. Polyester curve shows linear deformation behaviour with the stress rising to a maximum value which shows sign of yielding (σy) before fracture occurred (σf). The Young's modulus, E, of the polyester resin was calculated from the slope of the curve. Fracture toughness is a measure of a material's resistance to crack propagation, but in a composite this can be hard to measure accurately. However, the stress strain curve of the resin system on its own provides some indication of the material's toughness. Generally the more deformation the resin will accept before failure the tougher and more crack-resistance the resin will be. The bamboo fibre has a significantly higher tensile strength with, a significantly lower failure strain.

Various authors have reported divergent properties of bamboo reinforced composites. The differences in properties are attributed to the method of preparation, growth, source and method extraction, percentage

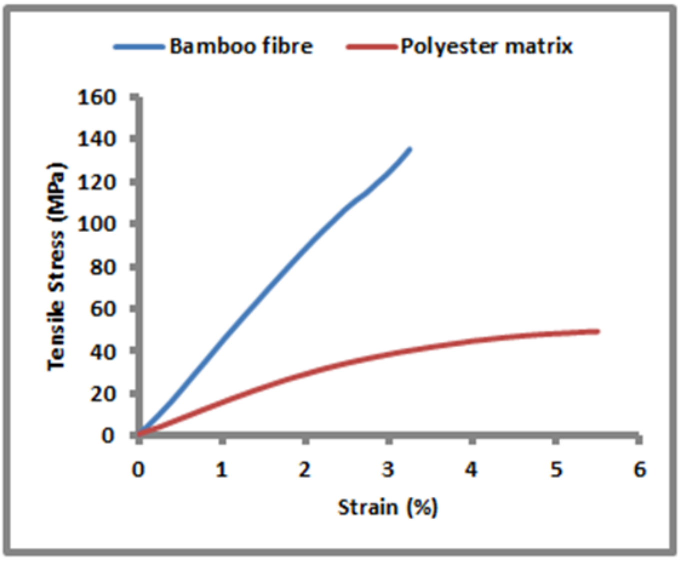


Figure 1: Stress-strain curves of polyester and bamboo

Figure 2 is the stress-strain curves of polyester reinforced bamboo composites. The tensile strength of pure polyester is 49.38 ± 2.34 MPa, and this value increases to a maximum of 76.47 ± 5.23 MPa at 24 % wt. of polyester. The same pattern of increment for Young modus was observed. At zero wt. % of polyester the modulus is 1381.2 ± 134.21 MPa, it increases to 2587.08 ± 148.22 MPa at 24 % wt. For the strain, it decreases from 5.50 ± 0.15 % at pure polyester to 3.32 ± 0.72% at 24 % wt. It should be noted that the maximum percentage decrease of the strain is ≈ 40% an indication of the brittleness of the composites. The increase in tensile strength with increase in filler contents may be attributed to the likely homogeneous dispersion of bamboo sawdust within the polyester matrix and the resulting compatibility. The compatibility is possible due to a large number of hydroxyl groups in their structures. Due to the compatibility structural defects within the composite is maintained at minimum even at higher loading leading to better mechanical performance (Ni *et al.,* 2006).

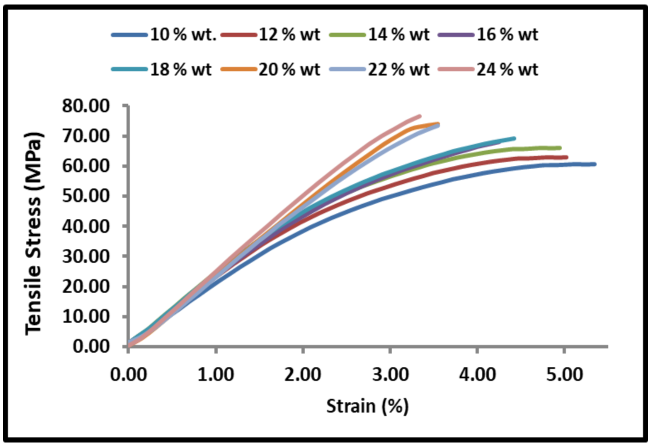
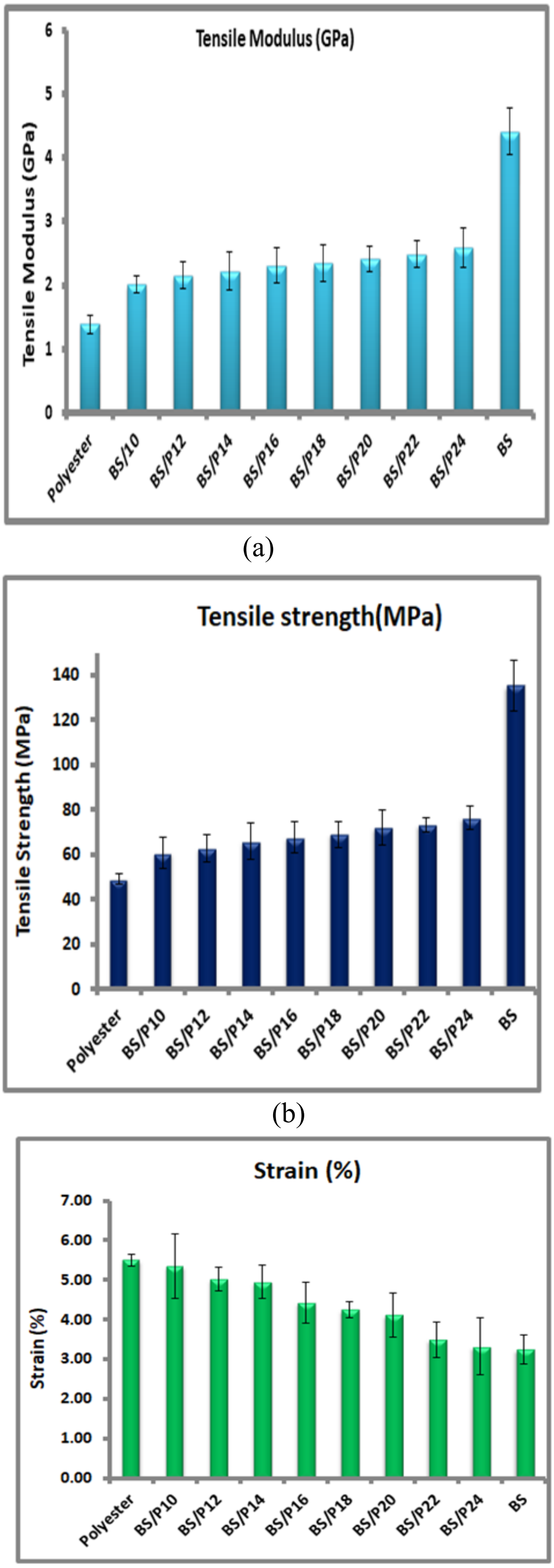


Figure 2: Stress-strain curves of polyester reinforced bamboo composite

weight of bamboo, chemical modification or treatment of bamboo, time is taken to process the blend, type and amount of plasticizer used (Zhang *et al.,* 2018; Osorio, *et al.,* 2011). Zhang *et al.,* (2018), reported an increase in Young modulus, tensile strength and elongation at break and with an increase in wt. % of NaOH when 30 wt. % of epoxy reinforced bamboo fibre were fabricated. Tensile strength increases from 262 MPa of untreated bamboo to 362 MPa at 6 wt. % of NaOH. The same pattern was observed for Young modulus. While the strain continued to increase beyond 6 wt. % of NaOH, tensile strength and modulus dropped to 235 MPa and 6.1 GPa (from 9.8 GPa for untreated bamboo) respectively.

It was reported that at 2 wt.% NaOH treatment only a small part of the surface substances could be removed, an indication that large quantity of sticky materials still can still be found, acting as constraint among cellulose chains. This constraint would check the fibrils from repositioning themselves in a dense manner along the direction of force during the tensile testing. At 6 wt. % NaOH treatment, 38% and 14%, increment was recorded, the constrain at 2 wt. % NaOH treatment must have been removed. In this research 6 wt. % NaOH treatment was carried out. The gradual increase of mechanical properties even at 24 wt. % of bamboo sawdust is an indication that all sticky materials which could have acted as constrain have been removed at 6 wt. % NaOH treatment. In addition agglomeration at this wt. % does not exist. According to Bledzki and Gassan (1999); and Sydenstricker *et al.,* (2003) removal of lignin and hemicellulose in bamboo fibres can be achieved by moderate treatment with alkali. The removal of hemicellulose and lignin will lead to increase in cellulose crystallinity invariably improved both fibre tensile strength and modulus.



(a)

(b)

(c)

Figure 3: (a) Tensile Strength, (b) Tensile Modulus and (c) Tensile Strain of bamboo fibre reinforced Polyester matrix at different fibre weight fraction .

4.2 Modelling of Mechanical properties.

Tables 2 and 3 are the properties of Polyester and bamboo fibre needed for the modelling of the mechanical properties of Polyester reinforced bamboo sawdust. Figure 4 shows a comparison of differences in theoretical and experimental tensile strengths of Polyester reinforced bamboo sawdust composites. Theoretical values were calculated using rule of mixture (Parallel and Series), Halpin-Tsai, and Hirsch, models. In all cases, tensile strength increases with increase in the volume fraction of bamboo. The best correlation between theoretical and experimental tensile strength is predicted using the Halpin-Tsai model, followed by Hirsch, Parallel and Series respectively. Depending on the volume or weight fraction the percentage prediction is between 79 and 88 % for Parallel and Series models and between 97 and 99 % for Halpin-Tsai and Hirsch models. Parallel and Series models may be used to describe the strength of both particulate and fibrous reinforced composites (Facca *et al.,* 2007) and give the maximum and minimum values respectively for both tensile strength and Young modulus of the composites. While Series model assumes uniform stress, Parallel model assume uniform strain. The stress transfer mechanism for particulate or short reinforced composites is different from that of the continuous fibre composites. For a short fibre composite the stress transfer depends on the stress concentration at the ends of the fibre, type and amount of plasticizer, critical length fibre, method of preparation of films, modification of fibre and orientation of fibre, among others. From Figure 4 irrespective of the volume fraction H-T model agrees between 97.62 (24% weight of bamboo sawdust), and 99.28% (10% weight of bamboo sawdust), with the experimental values. For Parallel model is between 82% (24 % weight of bamboo sawdust) and 88.53% (10% weight of bamboo sawdust). The high percentage agreement with experimental values is an indication that uniform strain or stress has been achieved in the composite. Hirsch model is an equation that combined the Series and Parallel models, with the insertion of a parameter χ. Like Series and Parallel models, Hirsch model is compatible with particulate and fibrous reinforcements. The theoretical and experimental values can have between 98.13% and 99.98 % irrespective of the volume fraction when the value of χ in Equation 10 is 0.55. Bearing in mind the assumption made for Series and Parallel models which are applicable here, it will be right to conclude that at χ= 0.55 uniform stress and strain have been achieved, that is χ is a parameter which defines the level of stress transfer between matrix and fibre. For a short fibre, the governing indices for the value of χ are fibre orientation, fibre length and stress concentration at the ends of fibre (Kim *et al.,* 2003).

Figure 5 shows a comparison of the difference in theoretical and experimental elastic modulus of bamboo sawdust reinforced polyester composites. From the figure Series model could give a correlation between theoretical and experimental values up to 75 % at 10% weight fraction. Contrary to the tensile modelling, Halpin-Tsai model could give up to 87.5 % at 10% weight fraction and 86.59% at 24% weight fraction. Both Hirsch and Parallel, could predict between 95.18 and 99.61%. For Hirsch model this percentage can only be achieved when the value of χ in Equation 9 is 0.99. The constraint of the models used here mainly depends on different factors among which are micro-voids be-

Table 2: Physical and mechanical properties of polyester

Density (g/cm^3)	Tensile strength at break (MPa)	Elongation at break (%)	Modulus of elasticity (MPa)
1.2	49.38	5.50	1381.2

Table 3: Mechanical properties of bamboo fibre

Density (g/cm^3)	Tensile strength at break (MPa)	Elongation at break (%)	Modulus of elasticity (MPa)	Aspect ratio
0.7	135.3	3.25	4324.82	1.4

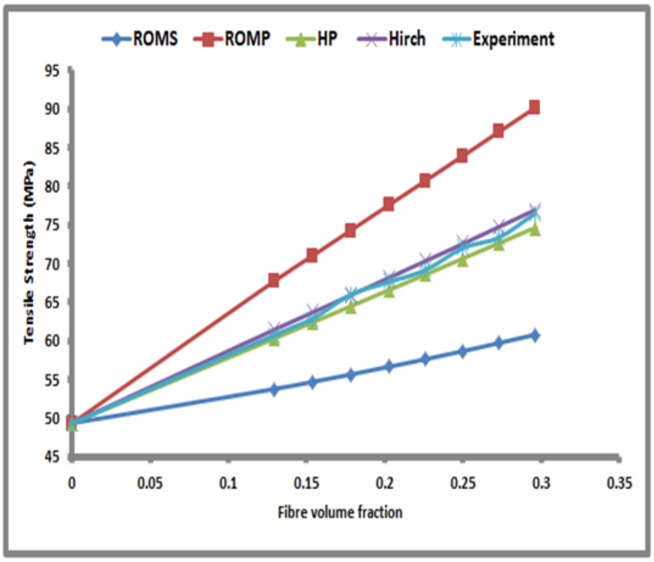


Figure 4: Tensile strength of Bamboo/Polyester composite modelled by Parallel, Series, Halpin-Tsai, and Hirsch

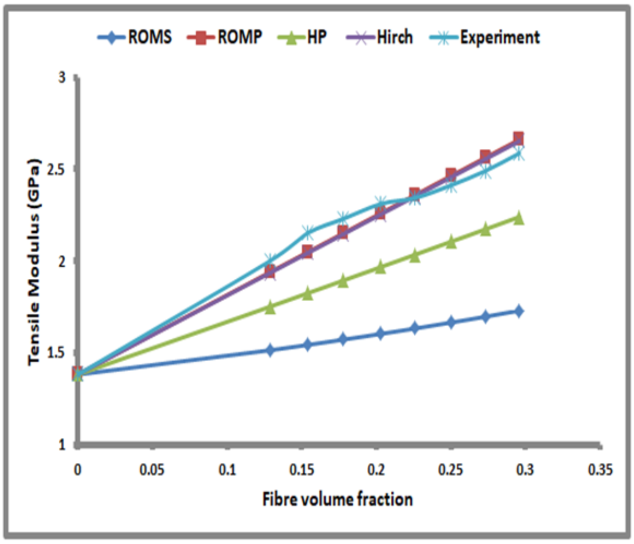


Figure 5: Elastic modulus of Bamboo/Polyester composite modelled by Parallel, Series, Halpin-Tsai, and Hirsch

tween fibre and matrix during composites formation; this factor is not taken care of in the cause of the model formulation.

5.1 Morphology

The SEM images of fractured polyester, bamboo fibre and bamboo sawdust/polyester composites are shown in Figure 6. A - F. Figure 6A shows the SEM images of fractured surface of neat polyester. The surface is relatively smooth but appeared ductile. In the absence of fibre in the matrix the crack growth will transmit in an unstable manner upon application of external loading. A matrix plastic deformation can be observed at the crack tip of the matrix. No significant fibre pull-out was observed in the entire composites irrespective of the filler loading. Fibre pull-out will be depicted by extruding fibres and holes. The low fibre pull-out could be attributed to smaller particles (approximately 100 µm) of fibres in the form of sawdust. Another reason could be attributed to good fibre dispersion within the matrix. Fibre pull-out is unfavourable to the strength and modulus of composites. However, it provides a major energy dissipation source during material failure (Jiang *et al.,* 2010). In terms of viscosity, polyester matrix was capable of entering the flaws in bamboo sawdust there by eliminating voids between fibre sawdust. This will result into better load transfer between the fibres and the matrix and subsequently better mechanical properties even at higher loading in other words there is an effective stress transfer between matrix and fibre sawdust. The gradual increase in tensile stress and modulus at higher loading is an indication that the flow rate of resin to infiltrate the voids between the fibres is not reduced.

4.0 CONCLUSION

A comparison between experimental results and the prediction from theories of mechanical properties (tensile strength, elongation at break, and Young's modulus) of bamboo fibre sawdust reinforced Polyester composites has been presented. The models used were Parallel and series model of rule of mixture, Hirsch's model, and Halpin-Tsai model. Properties of bamboo sawdust composites were presented as a function of volume fraction of the resin. All models were applied in tensile strength and Young modulus.

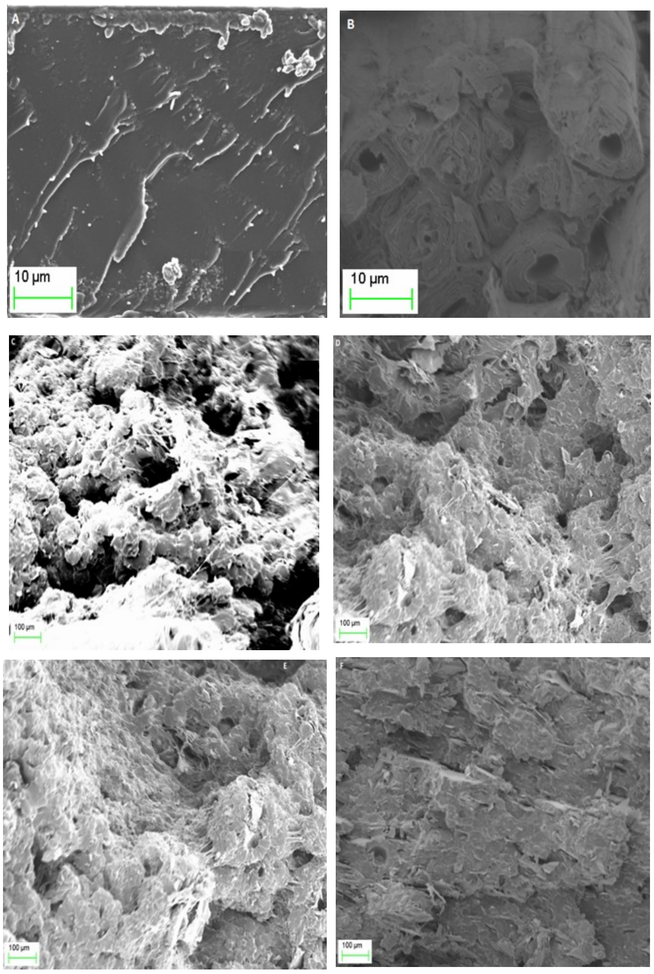


Figure 6: SEM images of polyester, bamboo, and bamboo sawdust/polyester composite after fracture (A) Polyester, (B) Bamboo fibre, (C) 10 %wt., (D) 14 % wt., (E) 18% wt., and (F) 22% wt.

The tensile strength of polyester increases from 49.38 MPa, to a maximum of 76.47 MPa at 24 % wt. of BS. At zero wt. % of BS the modulus of polyester is 1.38 GPa, this value increases to 2.59 GPa at 24 % wt. The strain decreases from 5.5 % at pure polyester to 3.32 % at 24 % wt. of BS an indication of increase in brittle of composite. Irrespective of the theory equation used, tensile strength increases with increase in the volume fraction of BS. The best correlation between theoretical and experimental tensile strength is predicted using the Halpin-Tsai model, followed by Hirsch, Parallel and Series respectively. Depending on the volume or weight fraction the percentage prediction is between 79 and 88 % for Parallel and Series models and between 97 and 99 % for Halpin-Tsai and Hirsch models. Halpin-Tsai model could predict up to 87.5 % of modulus at 10% weight fraction and 86.59% at 24% weight fraction. Both Hirsch and Parallel, could predict between 95.18 and 99.61% of the modulus. For Hirsch model this percentage can only be achieved when the value of χ in equations is 0.99.

REFERENCE

Akil, H., Omar, M., Mazuki, A., Safiee, S., Ishak, Z., and AbuBakar, A. (2011). Kenaf fibre reinforced composite; A review. Materials and Design, 32:4107-4121.

Baley, C., Lan, M., Bourmaud, A., and Duigou, A. Le. (2018). Compressive and tensile behaviour of unidirectional composites reinforced by natural fibres: influence of fibres (flax and jute), matrix and fibre volume fraction. Material Today Communication 16:300–306.

Bledzki, A. and Gassan, J. (1999). Composites reinforced with cellulose based fibres. Progress in Polymer Science, 24:221-274.

Biswas, S., Ahsan, Q., Cenna, A., Hasan, M. and Hassan, A. (2013). Physical and mechanical properties of jute, bamboo and coir natural Fibre. Fibers Polymer, 14:1762–1767.

Chen, X., Guo, Q. and Mi. Y. (1998). Bamboo Fiber-Reinforced Polypropylene Composites: A Study of the Mechanical Properties. Journal of Applied Polymer Science, 69:189-1899.

Chen, H., Zhang, W., Wang, X., Wang, H., Wu, Y., Zhong, T. and Fei B. (2018). Effect of alkali treatment on wettability and thermal stability of individual bamboo fibers. Journal of Wood Science, -405.

Facca, A. G., Kortschot, M. T. and Yan, N. (2006). Predicting the elastic modulus of natural fiber reinforced thermoplastics. Composite Part A: Applied Science and Manufacturing, 37:1660-1671.

Facca, A. G., Kortschot, M. T. and Yan, N. (2007). Predicting the tensile strength of natural fiber reinforced thermoplastics. Journal of Composites Science and Technology, 67:2454-2466.

Faruk, O., Bledzki, A. K., Fink, H. and Sain, M. (2014). Progress report on natural Fiber reinforced composites. Macromolecular Materials and Engineering, 299:9-26.

Fornes, T. and Paul, D. (2003). Modelling properties of nylon 6/clay nanocomposites using composite theories. Polymer, 44:4993-5013.

Huang, J. and Young, W. (2019). The mechanical, hygral, and interfacial strength of continuous bamboo fiber reinforced epoxy composites. Composite Part B: Engineering, 166:272-283.

Izani, N., Tahir, P. M., Khairun, M. and Uyup, A. (2013). Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers, Composite Part B Engineering 45(1): 1251-1257.

Jiang, L., Chen, F., Qian, J., Huang, J., Wolcott, M., Liu, L, and Zhang, J., (2010). Reinforcing and Toughening Effects of Bamboo Pulp Fiber on Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) Fiber Composites. Industrial & Engineering Chemistry Research 49:572-577.

Kalaprasad, G., Joseph, K., Thomas, S. and Pavithran, C. (1997). Theoretical modelling of tensile properties of short sisal fiber-reinforced low-density polyethylene composites. Journal of Materials Science, 32:4261-4267.

Khan, Z., Yousif, B.F. and Islam, M. (2017). Fracture behaviour of bamboo fiber reinforced epoxy composites, Composite Part B: Engineering, 116:186-199.

Kim, D.H., Na, S.K. and Park, J.S. (2003). Preparation and characterization of modified starch-based plastic film reinforced with short pulp fibre. II Mechanical properties. Journal of Applied Polymer Science, 88:2108-2117.

Koronis, G., Silva, A. and Foong, S. (2017). Predicting the flexural performance of woven flax reinforced epoxy composites using design of experiments. Material Today Communication 13:317-324.

Li, X., Tabil G. L. and Panigrahi, S. (2007). Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a Review. Journal of Polymer and Environment 15:25-33.

Manalo, A. C., Wani, E., Azwa, N., and Karunasena, W. (2015). Effects of alkali treatment and elevated temperature on the mechanical properties of bamboo fibre polyester composites. Composite Part B: Engineering, 80:73-83.

Ni, W., Wang, B., Wang, H. and Zhang, Y. (2006). Fabrication and Properties of Carbon Nanotube and Poly(vinyl alcohol) Composites. Journal of Macromolecular Science, Part B: Physics, 45-659-664.

Ofem, M. I. (2018). Deformation of micro-fibrillated chitin film and composites. Journal of Material Science, 53:8666-8675.

Okubo, K., T. Fujii, T., and Thostenson, E. T. (2009). Thostenson, Multi-scale hybrid biocomposite :processing and mechanical characterization of bamboo fiber reinforced PLA with microfibrillated cellulose, Composite Part A: Applied Science and Manufacturing, 40:469-475.

Osorio, L., Trujillo, E., Van-Vuure, A. W. and Verpoest, I.

(2011). Morphological aspects and mechanical properties of single bamboo fibers and flexural characterization of bamboo/epoxy composites. Journal of Reinforced Plastic Composite 30:396-408.

Prasob, P. A. and Sasikumar, M. (2019). Viscoelastic and mechanical behaviour of reduced graphene oxide and zirconium dioxide filled jute/epoxy composites at different temperature conditions. Material Today Communication 19:252–261.

Rao, K. M. M. and Rao, K. M. (2007). Extraction and tensile properties of natural fibers : vakka, date and bamboo. Composite Structures 77-288-295.

Reddy, K., Maheswari, C., Shukla, M., Song, J. and Rajulu, A. (2013). Tensile and structural characterization of alkali treated Borassus fruit fine fibers. Composite Part B: Engineering, 44:433-438.

Saba, N., Paridah, M. T. and Jawaid, M. (2015). Mechanical properties of kenaf fibre reinforced polymer composite: A review. Construction and Building Materials, 76:87-96.

Sen, T. and Reddy, H. N. J. (2011). Application of sisal, bamboo, coir and jute natural composites in structural upgradation. International Journal of Innovation, Management and Technology 2:186-191.

Senthilkumar, K. Saba, N. R. N., Jawaid, M. C. M. and Siengchin, S. (2019). Effect of alkali treatment on mechanical and morphological properties of pineapple leaf fibre/ polyester composites, Journal of Polymer and Environment, 27:1191-120.

Shindea, S. S., Salveb, A. V. and Kulkarnic, S. (2017). Theoretical modeling of mechanical properties of woven jute fibre reinforced polyurethane composites. Materials Today: Proceedings, 4:1683-1690.

Sydenstricker, T. H., Mochnaz, S. and Amico, S. C. (2003). Pull-out and other evaluations in sisal-reinforced polyester biocomposites. Polymer Testing, 22:375-380.

Wang H, Sheng K C, Chen J, Mao, H. L. and Qian X. Q. (2010). Mechanical and thermal properties of sodium silicate treated moso bamboo particles reinforced PVC composites. Science China Technological Science, 53 (11):2932−2935.

Wegst, U. and Ashby, M. (2004). The mechanical efficiency of natural materials. Philos. Magazine 84:2167-2186.

Zakikhani, P., Zahari, R., Sultan, M. T. H. and Majid, D. L. (2014). Extraction and preparation of bamboo fibre-reinforced composites, Materials and Design, 63:820-828

Zhang, K., Wang, F., Liang, W., Wang, Z., Duan, Z. and Yang, B. (2018). Thermal and mechanical properties of bamboo Fiber reinforced epoxy composites. Polymers (Basel), 10(6):608,