ISSN: 2186-8476, ISSN: 2186-8468 Print
Vol. 2. No. 1. March 2013

EFFECT OF FIBER LENGTH ON THE PHYSICAL AND MECHANICAL PROPERTIES OF RANDOM OREINTED, NONWOVEN SHORT BANANA (MUSA BALBISIANA) FIBRE /EPOXY COMPOSITE

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ABSTRACT

The effects of Banana fibre length on the physical and mechanical properties of banana fibre/epoxy composite were investigated. Five different samples were produced by varying the length of the fibre between 5mm and 25mm at 30% wt. fibre loading using the hand lay-up moulding technique. The mean density, percent moisture absorption, void content, tensile strength, tensile modulus, % elongation, compressive strength, impact energy, flexural strength and modulus of the composite were analysed. The results showed that the percent moisture absorption, void content and the compressive strength increased with increase fibre length while a decrease in density was observed. However, the tensile strength, tensile modulus and percent elongation had their highest values of 67.2 MPa, 653.07 MPa and 5.9% respectively at 15mm fibre length suggesting critical fibre length for effective and maximum stress transfer. The impact energy at failure, on the other hand, decreased with increase in fibre length from 80J to 40J for 5 mm and 25 mm fibre lengths respectively.

Keywords: Composites, Hand lay-up, Epoxy, Banana fibre, Mechanical property.

INTRODUCTION

The use of natural fibres for the reinforcement of composites has lately received increasing attention, by both academia and industries [1, 2]. This is being driven by environmental and economical reasons in addition to health concerns. Unlike the traditional glass, carbon, boron and kevler fibres, natural fibres are renewable and biodegradable: offer low density and cost in addition to being less abrasive to tooling; less irritating to the skin and respiratory system of humans processing the fibres; and have good thermal and acoustic properties [3, 4, 5, 6 & 7]. Furthermore, they can be formed into light weight composites, which are of special interest to the automotive and aerospace industries, since they lead to weight reductions and thus fuel saving [8].

In recent years, several green fibres such as hemp [2], jute [3], flax [9], kenaf [10] and coconut [11] have been used as reinforcement for plant fibre composites production with thermoplastic and thermosetting polymers as matrices [12 & 13]. This is because they are cheap, abundant, renewable, and biodegradable combined with good structural specific properties due to their low densities which makes them attractive for the automotive and packaging industries [14, 15]. Various researchers have worked on banana fibre polymer composites, for instance, Liu et al., [16] studied the properties of Banana fibre/high density polyethylene/nylon blend with particular interest on the effect of compatibilizing agent. The result was an improvement in moduli and a decline in impact toughness. Sapuan et al., [17] on the other hand studied the mechanical properties in the X and Y directions of random oriented woven banana fibre/epoxy composite, their result showed a significant difference in the composite property in both directions. Also, Rao et al. [18] studied the mechanical and

dielectric properties of vakka, sisal, bamboo and banana fibre reinforced polyester composite at different fibre loading. They found that the tensile and flexural properties increased with increasing fibre loading while the dielectric property declined with each fibre addition. Literature is deficient on the effects of fibre length on the properties of banana fibre/epoxy composite, hence this study is to explore this desideratum. The reason being that for every fibre reinforced polymer composite system, there exist a critical fibre length for maximum stress transfer at which the fibre develops a fully stressed conditions in the matrix [19]. Below this critical value the fibre may be strained above its limits due to the fact that only a fraction of its length is available for load bearing and above which it results in agglomeration, inefficient reinforcement and poor dispersion of the fibre in the matrix thus increasing fibre-fibre friction which acts as stress risers and crack initiation and propagation sites [20].

MATERIALS AND METHODS

Banana Fibre Extraction

Mature banana pseudo-stem was obtained from the farm, and was cut to a length of 50cm sliced longitudinally into four pieces and each was totally submerged in water for 15 days, after which the stems were removed from the water and were loosened by swishing back and forth in a pool of tap water. They were subsequently sun dried for eight hours and further loosened by manual combing. The extracted fibres were then treated with 5% sodium hydroxide (NaOH) solution for four (4) hours, under total immersion condition to avoid oxidation of the fibre, after which it was washed in overflowing tap water until neutral pH is attained [21]. The treated fibres were then dried in an oven for 24 hours at 105^{o}C to remove free water, and were subsequently cut into lengths of 5, 10, 15, 20 and 25mm and stored separately in an air tight container. The properties of the banana fibre used in this study is given in table 1.

Table 1. Properties of banana

Properties	*Banana fibre*
Cellulose (%)	62 – 64
Hemi cellulose (%)	19 [22]
Lignin (%)	5
Moisture content (%)	10 – 11.5
Density (g/cm^3)	1.35
Flexural modulus (GPa)	2 – 5
Microfibrillar angle	11[22]
Lumen size (mm)	5[22]
Tensile strength (MPa)	53.7
Young's modulus (GPa)	3.48

ISSN: 2186-8476, ISSN: 2186-8468 Print
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Epoxy Resin and Other Reagents

The epoxy resin (LY556), and hardener (HY591) used for this experiment were purchased from a chemical vendor in Jos metropolis, Plateau state, Nigeria in liquid form. The LY556 resin is a bi-functional epoxy resin i.e., diglycidyl ether of biphenyl-A (DGEBA), while HY951 is an aliphatic primary amine, viz., triethylene tetramine (TETA). Also, Petroleum jelly (debonding agent) was purchased locally from a chemical supplier in Zaria in their usual form.

Composite Production

The composite was made by hand lay-up moulding technique. The de-bonding agent was first applied on the inner surface of a three peice mild steel mould with dimensions 140mm x 80mm x 5mm followed by a pigmented gel coat using a spray gun to give high-quality surface finish. After about 20min, when the gel coat had become tacky, 20g of the fibres were manually laid in the mould randomly. The epoxy resin (mixed in the ratio of 3:2 with hardener) was applied by pouring into the prepared mould, and a hand roller was used to ensure thorough wetting of the reinforcement with the resin, and expel entrapped air. Layers of fibre and matrix formulation were added to obtain a thickness of 3mm. The mould was then closed and the set up was left to cure for 24hrs at room temperature under a load of 50N. The cured composite panels were ejected, trimmed and stored away for subsequent testing from which the test samples were cut out.

PHYSICAL PROPERTY TESTS

The moisture content, density and void content of the composite were determined as follows;

Moisture Absorption Test

The moisture content of the composite samples was determined by using the method of saturated moisture content based on thermo gravimetric principle. The samples were first dried in an oven for 12hrs at a temperature of 105^{o}C to ensure total moisture loss after which their masses were measured using balance (Mettler Toledo balance, Model XP603S). The dried samples were the soaked in distilled water at room temperature for 24hrs after which they were removed and droplets of water on their surfaces were mopped with cotton wool and their weights (M_{in}) measured. The samples were then returned to the oven preheated to 105^{o}C and were later removed at 1hr interval and weighed until constant weight (M_f) is attained. The percentage moisture absorption was determined from equation 1 [23];

$$Moisture\ Content = \frac{M_f - M_{in}}{M_{in}} \times 100\% \qquad 1$$

Where M_{in} - initial mass (g) and M_f - final mass (g)

Density Measurement

To determine the density, the samples were weighed using a precision balance (Mettler Toledo balance, Model XP603S with a precision of ±0.001g), while the dimensions of the samples were measured using a vernier caliper from which the voulumes were calculated. The density was then calculated from equation 2 as stated below;

$$Density\ (\rho) = \frac{m}{v} \qquad 2$$

Where m- mass of the composite (g) and v-volume of the composite (cm^3)

Determination Composite Void Content

The void content of the composite was determined from equation 3 as given by Mwaikambo and Ansel, [24];

$$V_p = 100 - M_d\left[\frac{r}{d_r} + \frac{g}{d_g}\right] \qquad 3$$

Where V_p - void content of the composite (%), M_d - measured density of the composite (g/cm3), r - resin content (weight %), d_r - resin density (g/cm3), d_g - fibre density (g/cm3) and g - fibre content (wt. %). Apparent fibre density was measured using Archimedes' method.

MECHANICAL PROPERTY TESTS

Tensile Test

The test was conducted according to ASTM D638 standard with a gauge length of 25mm, the test were carried out in Hounsfield tensometer Model H12 KW at a cross head speed of 1mm/min. The test piece was mounted and proper gripping was ensured, the test was done and results were recorded on five replicate samples.

Compressive Test

The test was carried out in accordance with ASTM D 695-02a on specimen with a configuration of 5x5x10mm. The test specimens were placed between the plates of the Houngsfield tensometer and compression force was applied. The compression test was carried out at 32^{o}C with 28 ± 2% relative humidity on five replicate samples for each test.

Impact Test

The impact strength of the composite panels was carried out using the izod impact testing machine according to ASTM D 256 standard. Samples were tested in replicates of five each at room temperature by a single swing of the pendulum hammer using ATS FAAR impact tester (Model no. 16.1, capacity of 25 joules). The specimen size was 65 x 12.5 x 3mm with depth under notch of 1.2mm.

Flexural Test

Three point bending test was performed in accordance with ASTM D790M test method I, procedure A to measure flexural properties of the composite samples. The samples measured 100x 8x5mm in length with a thickness respectively. In the test the outer rollers were 64mm apart at 0.5mm/min strain rate and five specimens were prepared each for each of the panels with 5, 10, 15, 20, and 25mm fibre lengths.

RESULTS AND DISCUSSION

Percentage Moisture Absorption And Density

Figure 1 shows the percentage of weight gain as a function of fibre length of banana fibre reinforced epoxy composites samples soaked in distilled water for 24hrs at room temperature. From the results of the experiment as depicted in Figure 1, the moisture content increased consistently from 8% for 5mm fibre length to 16% for 25mm fibre length with a corresponding increase in void content of the composite up to 1.43%. The increase in moisture absorption may be attributed to the inability of the matrix material to completely saturate the fibre at higher fibre length which likely facilitated moisture ingress. Therefore, it

ISSN: 2186-8476, ISSN: 2186-8468 Print
Vol. 2. No. 1. March 2013

can be suggested that short fibre composite are much suitable for applications where moisture is of concern.

Mylsamy and Rajendran [25] observed that more weight gain by plant fibre composites results in more water molecules getting interlocked in the composites. Thus chances are that the water molecules will attack the interface, resulting in debonding of the fibre and the matrix internally in the composite resulting in composite structural failure. Therefore, to reduce water absorption in composites, covalent bonding between fibres and matrix is introduced as exemplified in the work of Abdelmouleh et al., [26]. Hence with increase in porosity as observed here the likely hood of moisture gaining acess to the fibre/matrix interface is there, this may ultimately shorten composite service life. Also, a decrease in composite density from 1.47c/cm^3 to 1.36g/cm^3 for fibre lengths of 5mm and 25mm with increase moisture absorption was observed, suggesting the composite becomes less dense with increase fibre length.

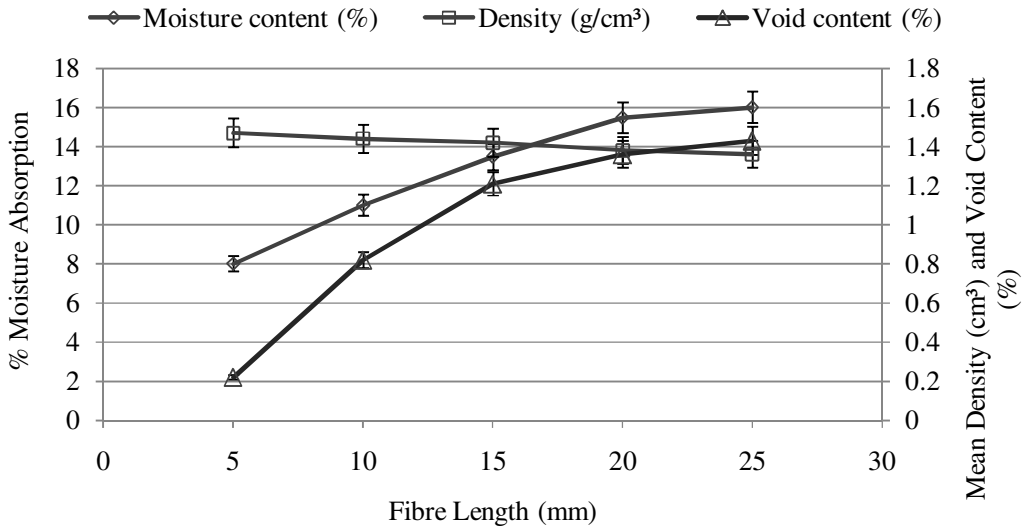

Figure 1. Composite percent Moisture absorption, Density and void content

This may be due to the tendency of longer fibre to entangle and agglomerate and increased fibre-fibre interaction leading to inefficient wetting[27]. This is also confirmed from the void content computed at various fibre lengths which increased from 0.22% to 1.43% at 5mm and 25mm fibre length respectively.

Mechanical Properties

The mechanical properties of natural fibre composite depend on many parameters such as fibre strength, modulus, fibre length and orientation, in addition, to the fibre matrix interfacial bond strength. Fibre matrix interface plays an important role in the composite properties. A good interfacial bond is required for effective stress transfer from the matrix to the fibre. In the present study, replicate banana fibre reinfnorced epoxy composite containing 30%wt of of 5mm, 10mm, 15mm, 20mm, 25mm, fibre length respectively were prepared in accordance with ASTM D638. The samples were tested in uniaxial loading and the composite properties were determined and the results presented in Figures 2 to 5. The dispersion and interfacial adhesion between the hydrophobic matrix and hydrophilic filler are critical factors in determining composite mechanical properties [28, 29].

Tensile Strength and Percent Elongation

Figure 2 graphically shows the results of tensile strength and percent elongation under tensile loading condition. As shown, the relationship between the two parameters with increased fibre length follows fairly the same pattern.

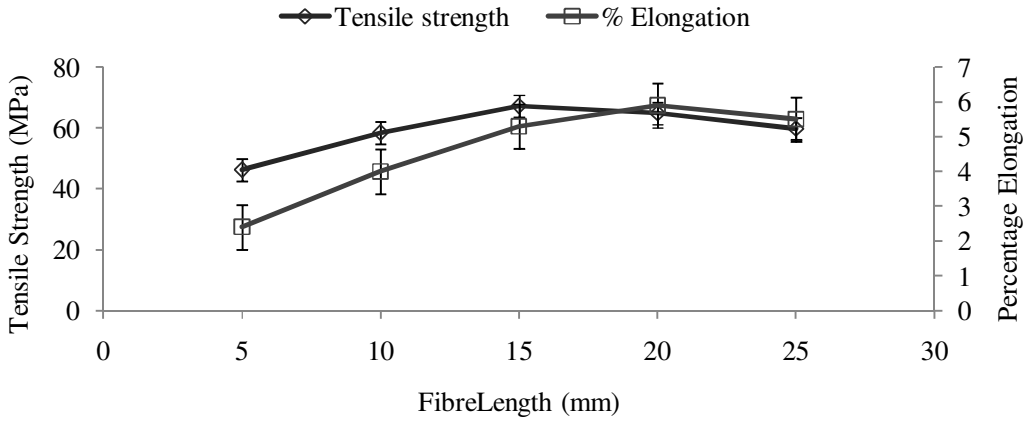

Figure 2. Effect of fibre length on mean Tensile strength and Mean % elongation

Mylsamy and Rajendran [25] in their paper observed that the elongation at break of short agave/epoxy composite increased consistently with fibre length between 3mm and10mm. This is in agreement with the result obtained whereby the percentage elongation increased from 2.4% to 5.7% with increased fibre length from 5mm to 15mm respectively. Subsequently, the tensile strength and % elongation decreases with increasing fibre length of up to 25mm. This could be attributed to improper fibre wetting due to increased fibre entanglement with length as well as the possibility of increasing fibre-rich and/or matrix-rich areas within the composite. Generally the tensile properties of composites are markedly improved by adding fibres to a polymer matrix since fibres have much higher strength and stiffness values than those of the matrices [13]. The effect of fibre length on the tensile properties of the banana fibre/epoxy composite was investigated and the tensile strength, tensile modulus and percentage elongation obtained. Mylsamy and Rajendran [25] opined that the tensile strength of the composite is influenced by the strength and modulus of the fibres.

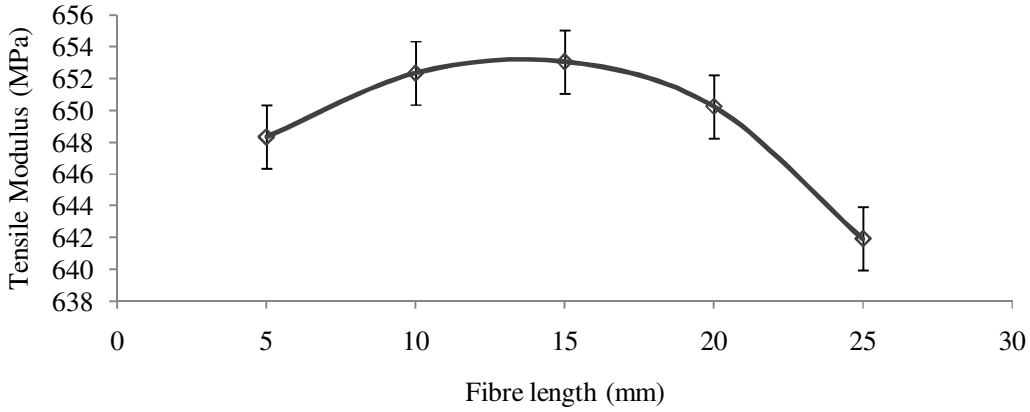

Figure 3. Effect of fibre length on mean Modulus of Elasticity

ISSN: 2186-8476, ISSN: 2186-8468 Print
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Young's Modulus

The young's modulus gives the relationship between stress and strain in a material which is a measure of the rigidity of a material [30]. Figure 3 gives the Young's modulus (YM) of the banana fibre/epoxy composite. It can be seen that the YM increases as the fibre length is increased and reached a maximum of 653.06MPa at 15mm fibre length, then falls to 641.93 MPa at 25mm fibre length. This may be attributed to the strong stress fields developed at the ends of the fibres in the composite beyond 15mm fibre length which made the composite samples less tough [26] and shorter fibre are said to move to optimized position in a composite than longer fibre [15].

Compressive strength

A Compression test is a method for determining the behaviour of materials under compressive load. During the test, the specimen is compressed, and deformation versus the applied load is recorded. In compression, it is usually known that the ultimate compressive strength of the composite is mainly dependent on the strength of the matrix and the extent of fibre/matrix adhesion [25 & 31]. The compressive strength of banana/fibre epoxy composite was enhanced with increasing the fibre length (Figure 4) with the highest compressive strength (212.56 MPa) achieved with fibre length of 25mm. This result is consistent with what El-Tayeb [31] and Mylsamy & Rajendran, [25] obtained in sugar cane fibre/polyester and short Agave fibre reinforced epoxy composites respectively. Bos et al., [1] on the other hand concluded that the compressive strength of the composites is influenced by the strength and modulus of the fibre. Composite specimens, usually under compression, fail by a combination of shear and compression. When fibre buckles, the matrix–fibre interface may fracture in shear and lead to ultimate failure [31].

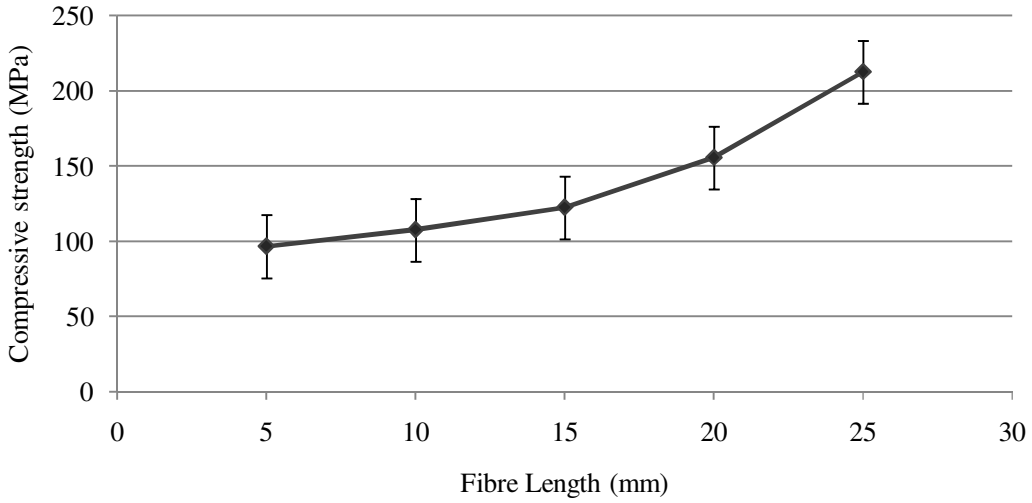

Figure 4. Effect of fibre length on mean Compressive Strength

Impact Energy

The total energy dissipated in the composite before final failure occurs is a measure of its impact resistance. The impact strength of composites is governed mainly by two factors: first, the capability of the filler to absorb energy that can stop crack propagation and second, poor interfacial bonding which induces micro-spaces between the filler and the matrix, resulting in easy crack propagation [28].

Also, Corrales et al. [32] in their study on chemical modification of jute fibre showed that the impact properties of short fibre reinforced composites depends on the interfacial properties of the matrix and fibres, aspect ratio, length, distribution and orientation of the fibre. Mylsamy and Rajendran, [25] had opined that the impact strength of plant fibre composites can only be improved by decreasing the fibre length and by increasing the friction stress between the fibre and the matrix.

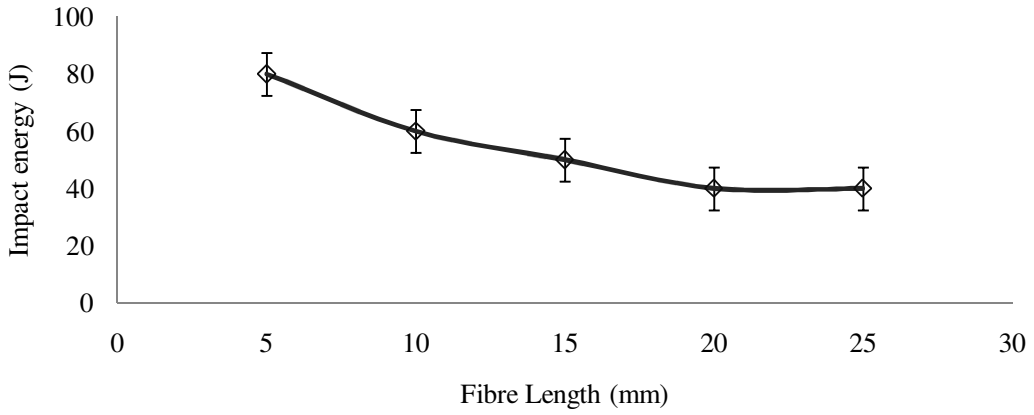

Figure 5. Effect of fibre length on mean Impact energy

Dhakal et al., [33] identified major micro failure mechanisms operating during impact loading of plant fibre composites to include initiation and propagation of matrix cracking, fibre–matrix debonding, fibre pullout and the fibre breakage. In the current study as presented in Figure 5, the impact strength decreases from 80J to 40J with an increase in fibre length upto 25mm which confirms Mylsamy and Rajendran [25] assertion.

Flexural Strength

As shown in Figure 6, the flexural strength and modulus of the composite increased proportionally with fibre length reaching a maximum of 90 MPa and 2.7 GPa respectively at 25mm fibre length. This result is in agreement with that obtained by Jang & Han [34] in functionally graded glass fibre mat reinforced poly (methyl methacrylate) compounds. Joseph et al, [35] attributed the increase in the flexural strength and modulus to the increasing fibre-to-fibre contact when the fibres were impregnated. This suggests that for applications where the flexural rigidity is required, composite fabricated from longer fibre length is desirable.

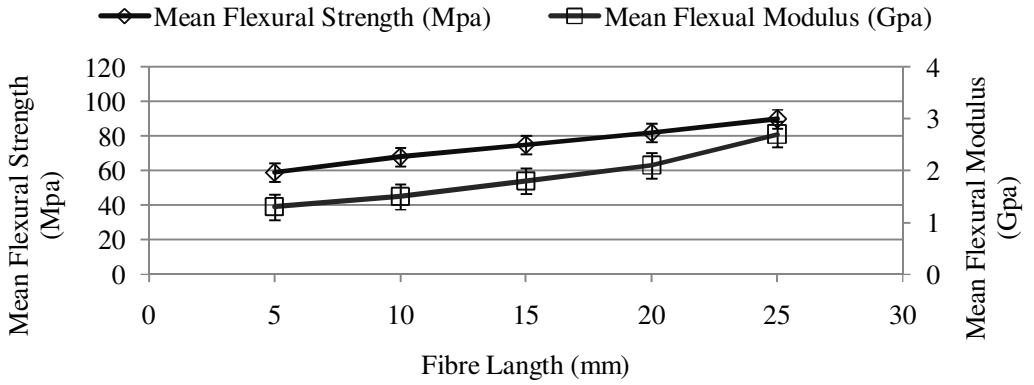

Figure 6. Effect of fibre length on Flexural strength and flexural modulus

ISSN: 2186-8476, ISSN: 2186-8468 Print
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CONCLUSIONS

From this study it has been demonstrated that the fibre length affects composite mechanical and physical properties with critical fibre length recorded at 15mm. Therefore the following conclusions can be drawn;

1. The percentage moisture absorption and void content increases with increase fibre length at constant fibre loading of 30%wt while there was a decline in composite density.
2. The tensile strength, tensile modulus and percentage elongation of the composite attained a maximum in composite fabricated from 15mm fibre length.
3. The compressive strength increases whereas the impact energy decreased with increasing fibre length.
4. The mean flexural strength and modulus of the composite increased with increasing fibre length up to 25mm.

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