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# ANALYSIS OF MECHANICAL PROPERTIES OF BAMBOO FIBRE-REINFORCED BIO-COMPOSITES

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**Abstract**

*This research is based on studies of themechanical properties of bamboo fibre-reinforced polyethylene bio-composite. The extraction of bamboo fibre was carried out using a mechanical shredder. Some part of the fibre was treated and milled. The constituent materials were mixed in three different proportions of 80/20, 70/30 and 60/40 HDPE/bamboo fibre with respect to the volume for both treated and untreated fibres. The bio-composite samples were compounded with the aid of a two-roll milling machine at a temperature of 230 ºC for 10 min. The bio-composites were fabricated using the compression moulding technique. The tensile and flexural properties of the bio-composites were evaluated. The results showed that bio-composites fabricated with treated filler have improved mechanical properties (tensile strength and percentage elongation are 23.9, 12.9, 11.9 and 24, 14 and 12 respectively), as compared to those that were loaded with untreated filler (the tensile strength and percentage elongation are 19.4, 14.6, 7.1 and 18, 18 and 6 respectively). On the other hand, surface modification of bamboo fibre had a negative impact on the flexural properties of the bio-composites. Thus, untreated filler showed better flexural properties on the bio-composites than the treated.*

**Keywords:** High-density polyethylene, matrix, reinforcement, bio-composite

## INTRODUCTION

Over the past few decades, composites have increasingly become vital smart materials for new structures and infrastructures. Thus, they are now considered a better alternative in applications such as aerospace, civil engineering, transportation, packaging, sport and all other major industrial sectors. This is as a result of challenges associated with old technologies. For instance, experts in the pipeline industry have all agreed that future transmission pipelines will have to operate at higher pressure; hence alternative pipe other than the conventional steel pipe is required and this eventually lead to the discovery of Composite Reinforced Line Pipe (CRLP) (Mohipour *et al*., 2001). Composite is therefore defined as a combination of two or more distinct components (usually, the matrix and reinforcement) bonded by an interface.

A renewed interest in the use of renewable materials to replace the traditional fibre-reinforced composites (FRC) became necessary following ecological and environmental problems associated with the use of inorganic materials as reinforcements.

Composites can generally be classified into two - particle strengthened and fibre reinforced. In the former, the matrix bears the main load and any motion of dislocations in the matrix is intercepted by small

dispersed particles. In the latter, however, the fibres bear the main load, while the matrix is solely responsible for load distribution andit is transferred to the fibre (Akovali, 2001). *Fibres employed in fibre-reinforced composites are normally continuous or discontinuous. According to Bai (2003),* fibre-reinforced polymer (FRP) composites which are composed of fibres and matrices are of greater technological importance owing to their desirable properties such as high strength-to-weight ratios, durability, corrosion resistance, weather resistance, chemical resistance, lightweight and satisfactory fatigue life. They also have relatively low cost of production (Bai, 2003).

Bamboo like other natural fibres is made up of mainly cellulose and some lignin and is therefore called lignocellulosic fibre (Hassan *et al*., 2012). It is reported by Saravanan and Prakash (2008), as the fastest-growing woody plant on earth; since it can grow one-third faster than the fastest growing tree.It is widely used in composites due to its high mechanical strength, low density, availability, renewability and low cost (Ahmad and Kamke, 2005; Labasan*et al*., 2015)

Bamboo is a biodegradable cellulosic material that can be 100% biodegraded in soil by microorganism and sunshine. It is a renewable and naturally grown material which gives excellent environmental performance based on the Life Cycle Assessment (LCA) (Van der Lugt, *et al*., 2006). The fibre can be extracted directly from bamboo tree and is usually in three (3) forms – natural bamboo fibre, bamboo pulp fibre, and bamboo charcoal fibre (Zhang*et al*., 2014). In their work, Saravanan and Prakash (2008) stated that the fibre possesses antibacteria, bacteriostasis and deodorization properties with unusual breathability and coolness as a result of its high moisture absorption property. The properties of bamboo fibre are summarized in Table 1.

**Table 1**: Properties of Bamboo fibre

| Chemical composition | Value | Source |
|---|---|---|
| Cellulose (%) | 26 – 74 | (Mohanty *et al*., 2000; Hattallia *et al*., 2002; Hoareau *et al*., 2004; John and Anandjiwala, 2008; Li*et al*., 2010) |
| Lignin (%) | 10 – 31 | (Mohanty *et al*., 2000; Hattallia*et al*., 2002; Hoareau*et al*., 2004; John and Anandjiwala, 2008; Li *et al*., 2010) |
| Hemicellulose/pentosans (%) | 12.5 – 30 | (Mohanty *et al*., 2000; Hattallia*et al*., 2002; Hoareau*et al*., 2004; John and Anandjiwala, 2008; Li *et al*., 2010) |
| Pectin (%) | 0.37 | (Li *et al*., 2010) |
| Ash/aqueous extract (%) | 1.7 – 5 | (John and Anandjiwala, 2008; Li *et al*., 2010) |

| Physical property | Value | Source |
|---|---|---|
| Average length (mm) | 2.5 | (Faruk *et al*., 2012) |
| Length (mm) | 1.5 – 4 | (Rowell, 2008) |
| Diameter (μm) | 25 – 40 | (Faruk *et al*., 2012) |
| Width (mm) | 0.025 – 0.040 | (Li *et al*., 2010) |

| Mechanical property | Value | Source |
|---|---|---|

| | |
|---|---|
| Tensile strength (MPa) | 140 – 800 (Hattallia*et al*., 2002) |
| Young's modulus (GPa) | 11– 32(Hattallia*et al*., 2002) |
| Elongation at break (%) | 2.5 – 3.7 (Hattallia*et al*., 2002) |
| Density ($gcm^{-3}$) | 0.6 – 1.1 (Hattallia*et al*., 2002) |
| Elastic modulus (GPa) | 11 – 30(Mohanty et al., 2000; Hattallia*et al*., 2002) |
| Strain to failure (%) | 1.3 (Mohanty et l., 2000) |
| Moisture Content (wt.%) | 8.9 (John and Anandjiwala, 2008) |

Polyethene (also known as polyethylene) is reportedly the most produced and used thermoplastic resin worldwide. This success is recorded due to its light-weight, ease of processing, resistance to chemicals, low impact strength and good abrasion properties (Kingston*et al*., 2014). Polyethylene can be classified based on its density, molar mass and branching into – high density PE (HDPE), medium-density PE (MDPE), low-density PE (LDPE), linear low-density PE (LLDPE), very low-density PE (VLDPE) and cross-linked PE (XPE) (Kingston*et al*., 2014). . HDPE is the most widely used, accounting for 50% of PE demands; one-third by LLDPE, and the balance by LDPE (Peacock,2000). HDPE contains unbranched chains that are able to align and pack easily to give the highestdensity. This plastic is normally produced in three main forms – high density (HDPE, 0.940-0.965 g $cm^{-3}$), low density (LDPE, < 0.930 g $cm^{-3}$) and linear low density (LLDPE, 0.915–0.940 g $cm^{-3}$). They are non-degradable polymers because of their chemical and thermal stability.

**The properties of HDPE are presented in Table 2.**

**Table 2:** Properties of High Density polythene(Fung, 2009)

| **Property** | **Value** |
|---|---|
| Density ($gcm^{-3}$) | 0.48 – 1.46 |
| Melt flow index (g/10min) | 0.057 – 26 |
| Young's modulus ( GPa) | 0.8 – 1.0 |
| Max tensile strength (MPa) | 13.1 – 37.7 |
| Flexural modulus (GPa) | 0.5 – 1.65 |
| Elongation at break (%) | 25 – 2200 |

## EXPERIMENTAL

*Materials*

The bamboo plant used in this research was obtained from Kwagiri in Sanga Local Government Area of Kaduna State. It was about 3 years old and 17 metres in height and selected from non-polluted region. Bamboo fibres are extracted out of the culms of bamboo plants species Bambusa vulgaris, which is a widely spread bamboo plant in the rainforest areas of Nigeria, typically located in the Niger River Delta. The extraction was carried out using a conventional mechanical shredder by New Jersey (Machine capability, C.M. 98); milling was done using milling machine by Milling Agro production (NE 150); sieving was done using standard sieves (ASTM 460); compounding was done using two-roll milling machine (5189) and composite fabrication was done using compression moulding machine by Hydraulic press (1190) which were all procured from Nigeria Institute of Leather and Science

Technology (NILEST) polymer laboratories, Zaria. The extraction process was carried out with the bamboo in green state. Analytical grade NaOH pellet was also obtained from the Polymer Chemistry Laboratory, NILEST, Zaria. The tensile test was carried out with Monsanto tensometer (9875) at the Department of Mechanical Engineering Ahmadu Bello University (ABU), Zaria (Monsanto tensometer, Wiltshire, England). The flexural test was done with the aid of Universal testing machineat the Department of Mechanical Engineering, ABU, Zaria.

The matrix used in this research was a clean recycled high density polyethylene (HDPE) purchased from a commercial plastic store at the Central Market Kaduna. It was crushed and characterized.

*Methods*

1. Extraction and preparation of bamboo fibre

The extraction was carried out using a mechanical shredder from the Nigeria Institute of Leather and Science Technology (NILEST), Zaria. The bamboo culms were cleaned and introduced into the hopper of the shredder and crushed to smaller pieces to obtain the fibre. Surface modification of the fibre was achieved by treatment of some part of the crushed fibres with 1 wt. % of NaOH for 48 h at room temperature. This process is called mercerization. The fibre was cleaned by washing with distilled water and dried in an oven at 50 ºC until a constant mass value was obtained. In each case, both the treated and untreated fibres were further milled separately using the milling machine and sieved until particle size of 2500

**Table 3:** *Nomenclature for surface treatment*

| Nomenclature | Description |
|---|---|
| UT | Untreated |
| T | Treated |

1. Fabrication of biocomposite

The method of reinforcement used is incorporation of fibre in form of particulate filler into the polymer matrix. The constituent materials were mixed in three different volume ratios of 80/20, 70/30 and 60/40 HDPE/bamboo fibre respectively. The biocomposite samples were compounded with the aid of a two-roll milling machine at a temperature of 230 ºC for 10 min. The biocomposites were fabricated using the compression moulding technique. The compounded samples were placed in steel moulds of 100mm x 100mm with thickness of 3mm and then moulded at 230 ₦ for about seven min under an applied pressure of 0.2 kPa. The samples were air-dried and removed from moulds.

2. Mechanical characterisation

Two (2) mechanical properties of the biopolymers were studied. These are tensile and flexural properties.

The tensile test was performed using the Monsanto tensometer in accordance with standard procedure specified in the America Society for Testing and Materials, ASTM-D638. The test specimen size was 100mm x 15mm with thickness of 3mm and for each test specimen (treated and untreated biocomposites), two tests were carried out and the average value calculated. This test was carried out to evaluate the tensile strength at break, ultimate tensile strength, and young modulus of elasticity and percentage elongation of the fabricated biocomposite samples as given in the following equations:

$$\text{Tensile strength} = \frac{\text{Breaking force (N)}}{\text{Original cross sectional area (m}^2\text{)}} \quad \text{---------- 1}$$

Ultimate tensile strength (UTS):

$$\frac{\text{Force (N)}}{\text{Area (mm}^2\text{)}} = \frac{\text{F(N)}}{\text{A (mm}^2\text{)}} \quad \text{---------- 2}$$

Percentage elongation (strain elongation):

$$= \frac{DL}{L} \times 100 \quad \text{---------- 3}$$

Where:

$$DL = extension$$
$$L = original\ length$$

Young modulus:

$$E = \frac{UTS}{E} \quad \text{---------- 4}$$

Where:
E = strain elongation
UTS = ultimate tensile strength
The flexural test, which involves three-point static bending tests, was carried out with the use of a universal testing machine in accordance with the standard procedure as specified in ASTM -D6662. The purpose of this test is to determine the flexural properties of the produced biocomposites such as the modulus of rupture, the apparent modulus of elasticity, the stress at the proportional limit and the work at maximum load. A testing specimen size of 80 x 10 with a thickness of 4mm was used for both treated and untreated samples and the test was done at ambient temperature. Two tests were carried out and the average value calculated. The flexural strength (F.S.) of a specimen is determined using the following equation.

$$F.S = \frac{3PL}{2bt^2} \quad \text{---------- 5}$$

Where:
L is the span length of the sample; P is the load applied; b and t are the width and thickness of the specimen respectively.

*Results and Discussion*

**Table 4:** Tensile properties for treated and untreated biocomposites

| Sample Designation | Tensile strength ($N/mm^2$) (T) | Tensile strength ($N/mm^2$) (UT) | % Elongation (T) | % Elongation (UT) |
|---|---|---|---|---|
| Control | 40.3 | 16.3 | 55 | 19 |
| 80/20 | 23.9 | 19.4 | 24 | 18 |
| 70/30 | 12.9 | 14.6 | 12 | 18 |
| 60/40 | 11.9 | 7.1 | 14 | 6 |

As shown in Table 4, treatment with sodium hydroxide improves the mechanical properties of the materials. The tensile strength and percentage elongation of treated bamboo fibre biocomposite samples were higher than the untreated by a range of 18 – 50 %. This is because bamboo substituents, particularly lignin, hemicellulose and pectin are removed upon treatment with sodium hydroxide, leading to higher tensile strength and percentage elongation for the treated biocomposites.

This alkali treatment strengthened the fibre-matrix bonding. This is in agreement with (Abd-Hamid, 2012), who argued that the alkali treatment of the fibre leads to the removal of hydrogen bonding in cellulose hydroxyl groups of the bamboo (see scheme 1); hence, making them more reactive to the functional group of coupling agent, which eventually bonds the fibre to the polymer matrix. In addition, (John and Anandjiwala, 2008) emphasized that the treatment with NaOH increased the pore spaces, which in turn allowed the smallest pores in the bamboo to become widen.

Fibre – OH + NaOH Fibre – O-Na $+H_2O$

Scheme 1: Chemistry of alkali treatment of the fibre

As a result, increased swelling and a corresponding increase in strength of the treated bamboo fibre was recorded. This is a as a result of reduction in strain at failure and ductility of the fibre, leading to higher strength (Wong *et al*., 2010)

The flexural properties of the fabricated biocomposites improved greatly. The results indicated that the bending strength increases with increase in percentage loading of the fibre (see Table 5).

**Table 5:** *Flexural properties for treated and untreated biocomposites*

| Sample Designation | Modulus of Rupture ($N/mm^2$) (T) | Modulus of Rupture ($N/mm^2$) (UT) | Modulus of Elasticity ($N/mm^2$) (T) | Modulus of Elasticity ($N/mm^2$) (UT) |
|---|---|---|---|---|
| Control | 54.37 | 78.30 | 1200.75 | 1788.25 |
| 80/20 | 29.29 | 49.31 | 1023.61 | 1460.84 |
| 70/30 | 24.51 | 27.53 | 869.39 | 1423.54 |
| 60/40 | 15.55 | 24.37 | 856.89 | 1011.90 |

As for surface treatment of the bamboo fibre, biocomposites made from untreated bamboo fibres, however, showed higher flexural properties than those fabricated from treated bamboo. This is in agreement with (Bai, 2013), who emphasized that the treatment with NaOH solution results in dissolution of hemicellulose, lignin and pectin components of the bamboo, which eventually made the fibre more brittle and consequently decrease the mechanical resistance that is, flexural properties of the biocomposites.

The improved mechanical properties (see Tables 4 and 5) of the biocomposites are attributed to the strong bonding between fibre and polyethylene matrix, as a result of the chemical treatment of the bamboo fibre prior to composite formulation (Joseph *et al*., 1996).

It is evident from Table 5 below that the overall effect of mercerization is the reduction in interfacial tensions of the treated biocomposites; that is, the modulus of elasticity for untreated and treated biocomposites differs by up to 200 $N/mm^2$. This implies that the adhesion between the matrix and fibre is improved, since the general properties of the biocomposite depend on the interface between polymer

matrix and fibres. This is in agreement with (Li *et al*., 2010; Arrakhiz,*et al*., 2012). Moreover, the hydrophilic nature of bamboo fibre makes it incompatible with the polyethylene, being a hydrophobic polymeric matrix; thus, surface treatment of the fibre with sodium hydroxide (Figure 1) improves the mechanical interlocking with the polyethylene by removing lignin, hemicellulose and so on (see Figure 1) (Arrakhiz,*et al*., 2012).

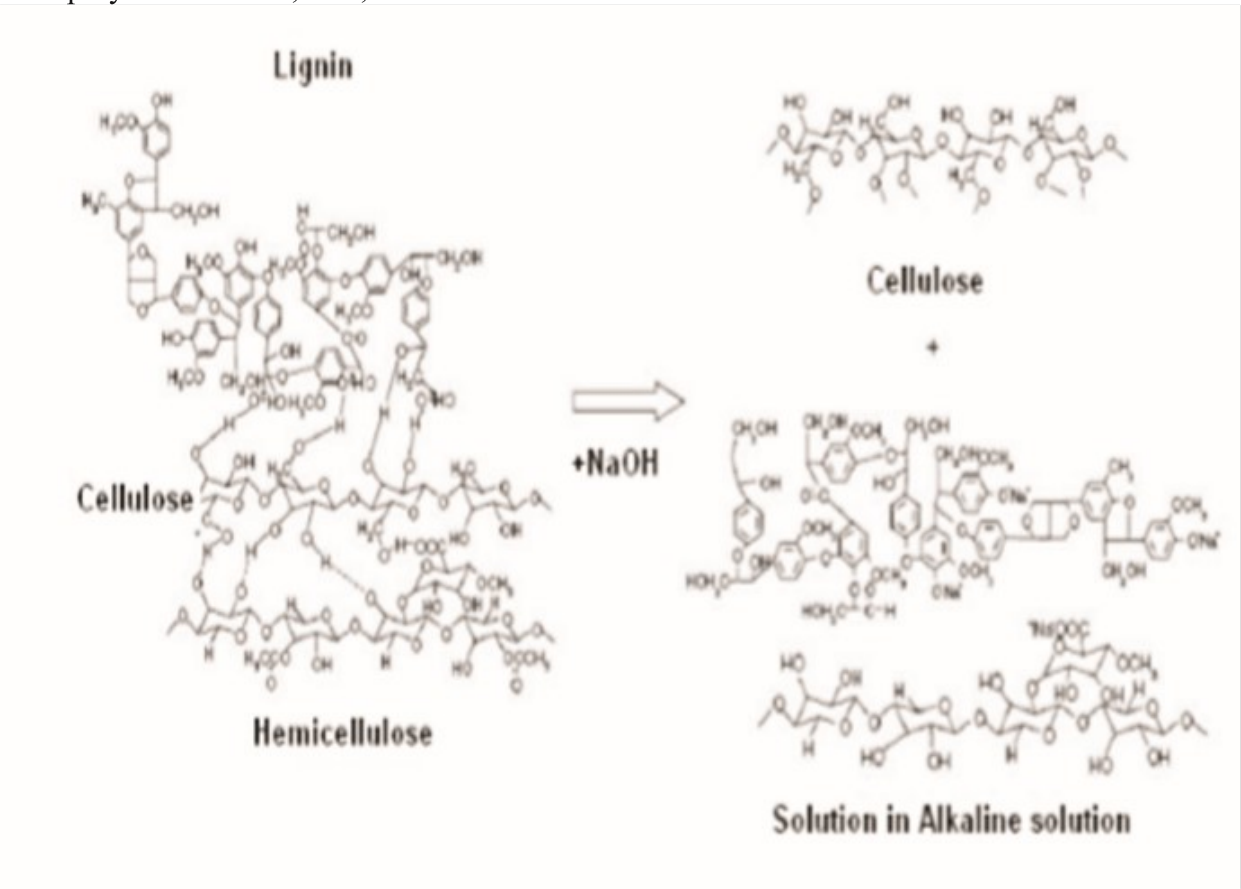


**Figure 1: Chemistry of alkali treatment of bamboo** (**Arrakhiz,***et al*., 2012)**.**

## Conclusion

From the results obtained, it was observed that the biocomposites fabricated with treated filler have improved tensile properties, as compared to those that were loaded with untreated filler. The tensile strength and percentage elongation for the treated biocomposite are 23.9, 12.9, 11.9 and 24, 14 and 12 respectively; while for the untreated, the tensile strength and percentage elongation are 19.4, 14.6, 7.1 and 18, 18 and 6 respectively. On the other hand, surface modification of bamboo fibre had a negative impact on the flexural properties of the bioicomposites. Thus, untreated filler showed better flexural properties on the biocomposites than the treated. The moduli of rupture and elasticity for the treated biocomposite are 29.29, 24.51, 15.55 and 1023.61, 869.39 and 856.89 respectively. For the treated, the moduli of rupture and elasticity are 49.31, 27.53, 24.37 and 1460.84, 1423.54 and 1011.90. Also, the results showed that varying the composition of filler / matrix has great effects on the mechanical properties of the biocomposites. Biocomposite fabricated with 80/20 composition showed better properties.

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