

Mechanical Properties of Banana Pseudo Stem Fibre Reinforced Epoxy Composite as a Replacement for Transtibial Prosthetic Socket

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Abstract: Using natural plant fibres as reinforcement in polymers has earned relevance in recent years due to their eco-friendly nature. Thus, an investigation was undertaken on banana pseudo stem, a natural fibre abundantly available in Nigeria. Banana pseudo stem fibres are not only strong and lightweight, but also relatively inexpensive for they are often considered as waste. The purpose of this study is to establish the tensile, flexural, and hardness properties of banana pseudo stem reinforced in epoxy composite materials. This is projected to serve as a replacement to the currently used synthetic glass fibre transtibial prosthetic socket. The resin used was epoxy (TKL 121). Composite samples, after treatment of the continuous fibres with 5 % NaOH and 2 % ascectic acid solution, were prepared manually using hand-lay-up method with the fibre ratio of 0, 20, 30, 40 and 50 %. The results of 30 % glass fibre polyester composite (GFPC) were compared with those of banana pseudo stem epoxy composite (BPEC) produced in this study. The tensile, hardness and impact tests of BPEC at 40 % fibre content were 64.23 ± 4.11 MPa, 63.31 ± 0.03 MPa, 55.23 ± 0.20 BHR, respectively. These were slightly lower than those of the glass fibre composite, which are respectively 65.72 ± 3.30 MPa, 66.10 ± 1.88 MPa, and 61.05 ± 1.77 BHR. Consequently, BPEC can further be developed to serve as a potential replacement for glass fibre composite in prosthetic socket application using standard production procedure.

Keywords: Banana pseudo stem fibre, chemical treatment, prosthetic socket, Epoxy and biomaterials

1. Introduction

Natural plant fibres such as pineapple leaf, cotton, rice, bamboo, sisal, and banana pseudo stem are abundantly available in most parts of Nigeria and their sources are renewable. Synthetic materials that are mostly used for reinforcement such as glass fibre, aramid, keplar and silicon are expensive because they are imported and also non-biodegradable since they are sourced from "non-renewable" petroleum products. These materials are less biocompatible, not environmentally friendly, and are as well having poor resistance to solvents and poor bonding to resins (Agustinus et al., 2009; Daniel et al., 2001). Although the strength of natural fibres is less than that of the synthetic ones, natural fibres can easily be recycled, more environmentally safe, potentially abundant and can be obtained at low or no cost (Ramachandran et al., 2010; Mkwaikanbo, 2006). Thus, natural fibres could be used in order to mitigate the problem of greenhouse effect through the production of green composite (Ramkrishna et al., 2001; Navdeep et al., 2012).

Banana is the most important harvest crop in the world (FAO, 2005). In 2007, more than 100 million tons of banana and plantain were produced (Danladi et al., 2014; IITA, 2015). Nigeria is the largest producer of banana in Africa after Uganda, Rwanda and Ghana. This

indicates that banana pseudo stems is readily available, and the stems currently categorised as biomass waste are usually left decomposed or buried after harvest. In order to maximise the benefit of our large production of banana, it is very critical to start processing the pseudo stem to fibres, which can then be utilised for composite production. As a bio-material, banana pseudo stem fibre has good mechanical properties and meets the required recommended qualities for prosthetic socket materials. Some of these qualities include good specific strength, light weight, availability, environmentally friendliness, renewability, cost effectiveness, biocompatibility, comfortableness, and good interfacial bonding with resin (Taylor et al., 1992; Horne et al., 2009; Michelle et al., 2009).

Basic requirement of prosthesis are biocompatibility, light weight, high tensile and flexural strength, good hardness, durability and ease of fabrication. These properties are required to ensure the durability and user's safety under a dynamic load (Philip et al., 2005). Although traditional materials such as wood, leather, metal, and cloth (fabrics) still play some roles in prosthesis fabrication, light materials like titanium, aluminium alloys and polymers are usually employed. Polymers used are nylon, polyester, urethane,

polyethylene, polypropylene, acrylics, polyurethane and epoxy while reinforcing fibres used include fibre glass, nylon, Dacron, carbon, and Kevlar (Quigley, 2002; Uellendahl, 1998; Artificial Limb, 2015). The polymers are used to bond fabrics used as reinforcement together.

In this study, banana pseudo stem epoxy composites (BPEC) were developed to serve as replacement for the glass fibre polyester prosthetic socket. Above knee prosthetic socket is currently being produced by most teaching hospitals in Nigeria using fibreglass materials. Using natural fibre will reduce the high cost associated with the procurement of fibreglass used in prosthetic socket production. This prosthetic socket requires periodical replacement due to increase in body weight, growth, wears and diseases, and thus mostly not affordable for low income users, mostly found in the developing countries such as Nigeria.

The aim of this study is to extract fibres from banana pseudo stems and use it as reinforcement for production of fibre reinforced epoxy composites, which can be utilised for the production of prosthetic sockets using hand lay-up method. Banana pseudo stem epoxy composites (BPEC) will be used as alternative materials to substitute the glass fibre reinforced polyester composite (GFPC). Hence, the tensile strength, flexural strength, and hardness values of the fabricated BPEC with 20-50 % fibre content will be compared with the imported GFPC with 30 % glass fibre content.

2. Materials and Methods

Banana pseudo stems (Figure 1) were locally sourced at Oko-Oba village, near Ibadan, Oyo State, Nigeria. Polyester resin (methyl 2-methylpropenoate resin), 2 % cobalt naphthenate catalyst, and Methyl ethyl ketone peroxide (MEKP) hardener were supplied by the chemical Bond Limited in Ojota, Lagos, Nigeria. Sodium hydroxide (NaOH), acetic acid, Epoxy TKL-121 (a Bisphenol resin derived from organic compounds containing Bisphenol A and di-glycidyl-ethers, BADGE) and hardener DETA (Diethylenetriamine) were also supplied by the same company. The glass fibre, polyvinyl acetate used as the mould releasing agent, and ethanol used as a cleaning/washing agent were sourced at a chemical store, in Lagos State, Nigeria.

2.1 Materials Preparation

A low cost steel roller machine developed for Banana pseudo stem fibre extraction by Nigeria Forest Research Institute of Nigeria (NFRIN), Ibadan was used for the banana pseudo stem fibre extraction. Unlike manual extraction, the machine provides clean working environment for the workers and reduces drudgery. The machine has a rigid frame on which the roller rotates. The roller, driven by 1 hp horizontal single phase electric motor with blunt edge, is made of horizontal bars (Sudhakar et al., 2003). The banana pseudo stems were

fed into the machine by adjusting the guiding roller, while the fibres were separated from the waterproof pseudo stem pulp matrix. Thereafter, these fibres were later retted with 0.01 M of NaOH and the banana pseudo stem was observed to be properly softened and released from the fibres after the 14th day. At this stage, banana pseudo stem fibres were extracted. The dried fibres were then immersed in 5 % NaOH solution for 1 hour before thoroughly washed under running water. This was then followed by treating with 2 % acetic acid to make the fibres stronger and avoid decay. The extracted banana pseudo stem fibres, as shown in Figure 2, were sun dried and subsequently oven dried for 4 hrs at 85 °C to remove free water content following the method described by Sumaila1 et al. (2013).



Figure 1. Banana pseudo stems



Figure 2. Samples of extracted fibres obtained from banana pseudo stems

2.2 Fabrication of Composites

Continuous banana pseudo stem fibres with symmetrical orientations were used for the composite fabrication. A 150 x 150 x 3 mm glass mould, polished with polyvinyl acetate as mould releasing agent, was used for the composite fabrication. Epoxy resin and hardener were mixed in a ratio of 1:1 while GFPC was prepared with 2 % cobalt naphthenate catalyst and unsaturated polyester resin to hardener ratio 10:1. BPEC samples were prepared using manual hand lay-up method with 0, 20, 30, 40 and

50 wt. % fibre loading. Meanwhile GFPC was fabricated using 30 % fibre glass. Pressure was added during the lamination to reduced void. To remove the entrapped air and void, a load of 15 kg was placed on the mould for 24 hrs after pressing with a sliding roller at laboratory temperature and relative humidity of 26 ± 2 °C and 59 ± 1.5 %, respectively.

2.3 Mechanical properties of the Specimens

The composites in the form of plates were cut into standard configurations according to ASTM D 3039 for tensile test, ASTM D 790 for flexural, and ASTM E10 for hardness test (ASTM, 2016a, b and c). Universal Testing Machine (Instron 5567) was used. Averages of five samples were tested for each formulation, and the calculated standard deviations were recorded.

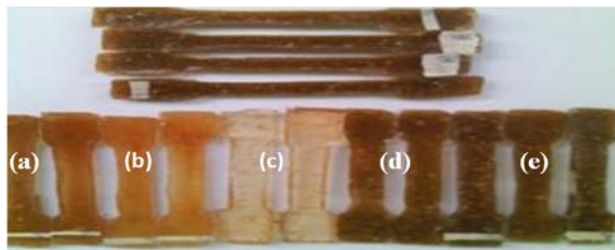


Figure 3. Tensile test Composite samples with varying fibre compositions in wt. %: (a) 30, (b) 20, (c) 0, (d) 40, and (e) 50

(a) Determination of Tensile Properties

The tensile test was performed on all the composite samples according to ASTM D 3039 (ASTM, 2016a). Universal Testing Machine (Instron 5567) was used at cross-head speed of 5 mm/min. Various composite samples at different fibre ratios, as shown in Figure 3, were loaded to failure. With tensile testing, ultimate tensile strength and Young's modulus were derived.

(b) Determination of Flexural Strength

The specimen was prepared as per ASTM D 790 (ASTM, 2016b), the test speed was maintained at a crosshead of 1.7 mm/min. Composite specimens were prepared with dimension of 120 mm × 10 mm × 4 mm (length x width x thickness) for flexural testing. Universal Testing Machine (Instron 5567) was used. In each case of the compositions,

five samples were taken, loaded to failure and average values were reported.

(c) Determination of Hardness

Hardness test was conducted on Brinell hardness machine and the specimens were prepared as per ASTM E10 (ASTM, 2016c). A load of 100 kg was applied on the specimen for 30 sec using 1.6 mm diameter ball indenter and the indentation diameter was measured. Hardness was measured at three different locations of the specimen and the average value was calculated including their standard deviations. The indentation was measured and hardness was calculated using Equation [1] (Sudeep et al., 2014).

$$BHN = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]} \quad (1)$$

Where, P - Load applied to the specimen. A - Area of the indentation (mm), D - Diameter of the ball indenter (mm) and d - Diameter of the indentation (mm).

3. Results and Discussion

Table 1 shows the mechanical properties of banana pseudo stem epoxy and glass fibre composite. These properties, that is, tensile modulus, tensile strength, elongation at break, flexural strength and hardness are directly related to prosthetic socket.

3.1 Tensile properties

High Young's Modulus and tensile strength guarantee a total contact socket and yield a superior comfort degree for prosthetic socket users. This condition should be considered in selecting socket materials. Traditional sockets are usually made from rigid materials although some prefer a flexible socket (high Young's Modulus) supported by rigid frame as it provides better comfort during walking and sitting (Maleque et al., 2007).

Table 2 represents the result obtained from the tensile strength and Young's modulus of banana pseudo stem epoxy and glass fibre polyester composites, respectively. Both tensile strength and Young's modulus as shown in Table 1, increased with addition of fibre and 50 % fibre loading induced the highest value for BPEC. The tensile properties of BPEC were compared with FGPC fabricated at 30 % glass fibre. It was observed that Young's modulus of glass fibre was higher than all fibre compositions of BPEC.

Table 1. Mechanical properties of fibres*

Composite	Fibre ratio	Tensile strength (MPa)	Young's modulus (GPa)	Flexural strength (MPa)	Hardness (HBR)
Banana pseudo stem	0	14.30±2.21	2.43±0.19	29.21±1.14	37.98±0.12
	20	22.74±4.10	3.79±0.08	44.21±0.21	42.66±0.60
	30	49.82±3.73	5.22±0.13	55.77±0.21	46.17±0.33
	40	65.93±4.11	5.88±1.00	72.31±0.03	55.23±0.20
	50	70.05±3.67	6.21±0.20	77.02±0.11	63.28±1.03
Glass fibre	30	65.72±3.30	7.33±3.22	66.10±1.88	61.05±1.77

*Mechanical properties values are means of 5 replications plus and minus standard deviation.

Table 2. Tensile strength and Young's Modulus of socket materials

Strength Range	Fibre Types	UTS Range (MPa)	Young's Modulus (GPa)
Low	Perlon, nylon, cotton, nyglass, spectralon.	18 – 42	1.8 – 5.1
Middle	Glass	67 – 109	5.0 – 17.3
	Rattan Epoxy	66.25 ± 0.81	8.68 ± 0.68
	Ramie Epoxy	86 ± 6.07	9.40 ± 0.68
	Ramie Polyester	67 ± 5.11	7.45 ± 0.57
	Bamboo Epoxy	78.09 ± 1.97	8.96 ± 0.33
	Pineapple Epoxy	77.47 ± 3.85	7.93 ± 0.11
	GFPC	65.72 ± 3.30	7.33 ± 3.22
High	BPEC	69.44 ± 4.11	6.87 ± 1.21
	Carbon	236 – 249	20.6 – 25.5

Sources: Philip et al., (2005) and Augustinus et al., (2010)

However, tensile strength of BPEC at 40 and 50 wt. % were greater than GFPC with 0.3 % and 6.12 %, respectively. Moreover, various factors have been reported to govern the strength and performance of composite materials. The adhesion at interface between the resin and fibre, and the mechanical properties of the resin and fibre, greatly affect composite performance. Other factors are the fibre length, orientation and ratio of the fibre to resin (Philip et al., 2005).

For BPEC, from among the factors that probably enhanced superior tensile strength of BPEC than GFPC, was good interface between the resin and fibre. A combination of banana pseudo stem fibre and epoxy matrix treated with sodium hydroxide (alkali) and acetic acid gave a stronger bounding. Thus, the active site of banana pseudo stem increased with the elimination of lignin, and the fibre was less damageable with a large load. Therefore, this led to higher storage modulus values due to increased cross linking and formation of a strong fibre/matrix interface (Timothy et al., 2007). Also, continuous banana pseudo stem fibre was used for fabrication in this study, and improved strength was observed with addition of fibre. Increase in fibre length and fibre content was reported to improve the tensile strength and flexural strength of composite (Mkwaikanbo, 2006; Oyewo, 2015).

Processing techniques also affect the performance of composite (Irawan et al., 2012). In this study, BPEC was fabricated using hand-lay-up method. Fibre ratios 0, 20, 30 and 40 wt. % were easy to fabricate, whereas, 50 wt. % BPEC was difficult to fabricate. The difficulty in 50 wt. % fibre loading was due to insufficient epoxy matrix resin to hold banana pseudo stem fibre firmly. Hence, voids, brittleness and deformities were observed in the resultant composites. For this reason, values from 40 wt. % were preferred to higher values of 50 wt. % of BPEC, and thus, comparison with other studies was done with this 40 wt. % fibre loading.

Compared with other works as shown in Table 2, for instance, the values of BPEC of this study were lower than Ramie Epoxy composite (REC) manufactured with filament winding method. Filament winding process yielded more accuracy by ensuring strong bond between ramie fibre and epoxy resin. However, with manual hand-

lay-up method, attainment of uniform thickness is difficult and the presence of voids may not be totally eliminated (Hariprasad et al., 2013).

Table 2 compares the results of this study with some related benchmark literatures in prosthetics and orthotics. With regards to strength, Philips et al., (2005) classified materials used in prosthetic and orthotics into low, middle and high strength range categories. The stipulated middle composite materials must have the tensile strength ranges between 67- 109 MPa and elastic modulus of 5.0-17.3 GPa. This shows that BPEC with 65.93 ± 4.11 MPa and 5.88 ± 1.00 GPa fall conveniently into the middle strength bio-materials. Other studies (such as Augustinus et al., (2010), Oyewo, (2015), and Irawan et al., (2012)) also agreed with this classification. However, GFPC values were below BPEC and recommended middle strength bio material ranges.

3.2 Flexural strength

Flexural property is very useful in prosthetic socket as the materials involved must be able to resist deformation under loads. Some of the required properties of materials used in prosthetic socket are: ability to receive dynamic loads, light weight, elastic and strong (Maleque et al., 2007). Table 3 represents the flexural strength of banana pseudo stem epoxy composite and glass fibre polyester. The flexural strength at 0, 20, 30, 40, and 50 % were 29.21 ± 1.14, 44.21 ± 0.21, 55.77 ± 0.21, 72.31 ± 0.03 and 77.02 ± 0.11 MPa, respectively. This indicates an increment of 33.92 %, 20.73 %, 22.87 %, and 6.12 %. In contrast, the flexural strength of glass fibre composite at 30 % was 66.10 ± 1.88 MPa. This shows that BPEC at 40 and 50 wt. % are higher than GFPC.

With the above values, it was observed that banana pseudo stem with epoxy resin had higher strength and elasticity than polyester and glass fibre combination. A probable reason for the lower strength of glass fibre composite is due to the hard and brittleness of polyester upon solidification which may control the reinforced materials. The higher flexural values induced by BPEC over GFPC were probably attributed to the use of chemical surface treatment of banana pseudo stem. Alkali treatment has been reported to enhance the flexural properties of composites (Mkwaikanbo, 2006).

Table 3. Flexural strength of prosthetic socket materials

Socket materials	Flexural strength (MPa)	Reference
Ramie Epoxy	103 ± 15.62	Irawan et al. (2012)
Ramie Polyester	84.8 ± 6.93	Irawan et al. (2012)
Pineapple Polyester	53.02 ± 1.20	Oyewo (2015)
Pineapple Epoxy	81.27 ± 1.27	Oyewo (2015)
Glass Polyester fibre (GPFC)	66.10 ± 1.88	Present study
Banana pseudo stem (BPEC)	72.31 ± 0.03	Present study

Compared with values shown in previous literature in Table 3, the results of BPEC were greater than pineapple leaf polyester and glass fibre polyester. However, BPEC was less superior to pineapple epoxy, ramie epoxy and polyester composites. Process of fabrication, chemical surface treatment, fibre orientation, and fibre contents determine the strength of composites (Bobbyester et al., 2015). Filament winding method used for ramie composite is stronger than hand lay-up method. Also, fibre treated with alkali, as done in this study, and thereafter reinforced with silane coupling agent as carried out for ramie composite gave better flexural strength than those without silane treatment.

3.3 Hardness

Hardness is closely related to strength. It is the ability of a material to withstand scratching, abrasion, indentation, or penetration (Sudeep et al., 2014). To withstand body weight, higher hardness is required for materials used in prosthetic socket. As shown in Table 1, the hardness of BPEC increased with addition of fibre. The reason for higher hardness of BPEC is probably due to the action of epoxy resin transmitting applied stress to the fibres which resulted in higher strength (Begum et al., 2013).

Glass fibre composite produced with 30 % fibre loading gave the hardness value of 61.05 ± 1.77 HBR. This value was found to be higher than 0, 10, 20, 30 and 40 % fibre loading of BPEP. However, the values of BPEC induced by 50 % fibre loading values were higher than glass fibre polyester composites. With this observation, it shows that hardness value equivalent – and even greater – than glass fibre composite can be obtained from banana pseudo stem composites. This is achievable by simply increasing the banana pseudo stem fibre content. This is also in agreement with Begum et al. (2013). Belgum et al. (2013) and Bobbyester et al. (2015) reported that same level of tensile strength and hardness could be achieved, especially at low strength application, for glass fibre composite as well as natural plant composite, but the required fibre content for the purpose is much higher for the latter composition than in the former. Improvement in hardness of the composites has been reported to be influenced by interfacial bonding, uniform dispersion and good bonding strength between filler and matrix component in composites (Hariprasad et al., 2013). Hence, as reiterated by Sudeep et al. (2014) and Bobbyester et al. (2015), hardness is directly proportional

to the fibre content. This study through the experimental results, also agrees that filler content is a function of hardness.

4. Conclusion

The use of glass fibre in polyester matrix and banana pseudo stem fibre as reinforcement in epoxy matrix brought about improvement in the mechanical properties. Thus, the effect of the investigation of the addition of these fibres brought about the following promising outcomes.

- 1) There was improvement in the mechanical properties of the reinforced epoxy composites up to 50 wt. % banana pseudo stem fibre loading.
- 2) 40 % fibre loading banana pseudo stem composite was the best and preferred to higher values of 50 % fibre loading.
- 3) Banana pseudo stem composite had superior mechanical strength than glass fibre composite, as banana pseudo stem fibre at 40 and 50 % fibre loading were higher than 30 % glass fibre loading.

Consequently, banana pseudo stem epoxy composite (BPEC), having better strength than glass fibre polyester composite, can further be developed as a potential replacement for fibreglass polyester prosthetic socket.

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