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Effect Of Mechanical Properties And Microstructural Analysis Of Below The Knee Prosthetic Leg Socket Developed From Woven Banana Fibre (WBF)

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Abstract:
The present work investigated the effect of mechanical properties and microstructural analysis of below the knee prosthetic leg socket developed from woven banana fibre (WBF) with varied fibre content that were prepared using hand lay-up technique using L-12 epoxy resin and k-6 hardener. Composite materials are one of the emerging fields in polymer science that are gaining attention for application in various sectors, such as health, building, aeronautic and automotive. The banana fibre used in this study was extracted by removing the bark of a banana stem, followed by manually peeling off the fibre from the bark using the hand stripping method. The extracted fibre was sun dried for 72 hours and then treated with 0.1 mol of NaOH solution for 2 hours. Distilled water was used in neutralization procedure to remove the alkali from the surface of the fibre and then allowed to air dry for 24 hours to remove all moisture prior to weaving and lamination. The fibre was hand woven into bidirectional 0/90º fibre mat. The woven banana fibre (WBF) mat was prepared according America Standard for Testing Materials (ASTM) standards and tested for mechanical tensile strength, fatigue limit, compressive strength and microstructural behavior. The results thus obtained signified the mechanical tensile strength, fatigue limit, compressive strength got improved in the woven banana fibre mat composite with increased laminates from 1LWBF – 3LWBF, thus acting as a positive reinforcement in providing extra strength and minimal internal micro cracks in the scanning electron microscopy analysis. From the aforementioned outcomes, the 3 layer woven banana fibre (3LWBF) composite sample depicts high potentials for use as reinforcement in prosthetic leg socket.
Keywords: *Banana fibre, Epoxy resin, Composites, Reinforcement, Leg socket*

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I. Introduction

Composites are materials made up of two or more component parts differing in physical and chemical properties, bonded together to form an amalgamated material. Composites are made of matrix and fibre, where matrix surrounds fibres to form a compact material. Natural based fibres are materials that biodegrade rapidly and are non-toxic for human beings and environment. They possess suitable properties like renewability, environmentally friendly, biodegradability, non-toxicity, accessibility, low density, easy processing, recyclability, resistance to corrosion and low cost. The demand for natural based fibres is increasing daily where it is now widely researched as possible alternative materials to synthetic fibre reinforcements (McCarthy *et al*., 2009).

Rosalam, and Vershiys (2012) revealed that using natural fibre-based bio composites, such as the natural based reinforced plastic have the same and even more desirable properties of light weight, high level of degradability, eco-friendly and cost efficient than the conventional materials of glass/carbon fibres. The results of the study were based on the compatibility of the properties of existing and proposed materials which showed great potentials for alternative use.

Andrew *et al*., (2012) reported that the combinations of plant resin and either banana or ramie fibres gave high tensile strengths. However, the conventional composite material for socket with plant resin and ramie fibre failed at a similar loading, exceeding the ISO 10328 standard. Both wall thickness and fibre-matrix adhesion play significant role in socket strength.

According to Me, and Tsiokos (2012), Kenaf natural based fibre can be processed into yarn and converted into bicomposites of high impact strength to replace the fibre-glass as one of the layer in prosthetic socket fabrication. Kramer, and Davenport, (2015) reported that, the superior strength and ductility results revealed during fibre loading test carried out using bamboo natural reinforced fibre composite in accordance with ASTM (2004) can replace the cotton and nylon composites currently used in the manufacture of orthopedic and prosthetic devices.

Renewable and biodegradable natural based bio-composites fibres have become the need of today due to strong environmental concerns, cost efficiency and growing regulations on contamination and pollution of the environment by synthetic based materials. There have been lots of interests in research for adequate and more environmental friendly natural based bio-composite materials for prostheses which is as a result of increase in amputation cases resulting from wars, diseases, auto-crashes (Seymour, *et al.,* 2010).

The word prosthesis is referring to a device that replaces an absent or affected part of the human body. Orthopedic prosthesis is used to partially or totally replace a segment of a missing or deficient limb and the main objective is to provide ambulation to amputees (Edwards, 2018).

Despite some important recent advances in prosthetics, several amputees still reject their prostheses or show low satisfaction level mainly due to socket-related issues, such as poor comfort, reduced biomechanical functionality and hampered control (Dillingham *et al*., 2001). In addition, skin lesions occur in the 63-82% of lower limb amputees, thus causing prosthesis abandon rate of about 25-57% (Meulenbelt, and Daniel, 2009). However, this study focuses on effect of mechanical properties and microstructural analysis of below the knee prosthetic leg socket developed from woven banana fibre (WBF) for application in below the knee prosthetic leg socket.

II. Materials And Methodology

Materials

The materials and reagents used in this research include: banana fibre, epoxy resin, methyl ethyl ketone peroxide, sodium hydroxide, cobalt, hardener, plaster of paris (POP) bandage, POP powder, laminating leather (Polvinyl acetate, PVA), and digital weighing scale. The banana fiber was locally sourced in Efekwo-Otukpa village, Ogbadibo Local Government Area, Benue state. The chemicals were obtained from Chika Chemicals Company Nig. Ltd, Lagos.

The instruments and equipment used are listed in Table 1. They are: Scanning electron microscope (SEM), Istron Universal Testing Machine (UTM), Fatigue testing machine and a universal digital testing equipment for compression test.

Preparation of Woven Banana Fibre (Hand knitting technique)

Banana stem was cut from the plant harvested from a plantation in Makurdi, Benue State. The fibre was extracted by removing the bark from the stem, followed by manually peeling off the fibre from the bark using the hand stripping method (Paramasivam, *et al*., 2020).

The extracted fibre was sun dried for 72 hours until all the moisture was removed from the fibre and then treated with 0.1 mol of NaOH solution for 2 hours. Bar and Almeida, (2013) reported that surface chemical treatment has a significant role in determining the crystallinity of the banana fibre.

Distilled water was used in neutralization procedure to remove the alkali from the surface of the fibre. After being neutralized, the fibre was air dried for 24 hours to remove all moisture prior to weaving and lamination (Begum and Islam, 2013). The fibre was then woven into bidirectional 0/90^o fibre mat. Plates 2a-2d present photographs of banana stem, strips from banana stem, extracted banana fibre and hand-woven banana fibre.

(a) (b) (c) (d)

Plate 1: (a) Banana stem, (b) Strips from banana stem, (c) Extracted banana fibre (d) Banana fibre in mat form

Preparation of Composite (Hand lay-up technique)

The composites were fabricated by hand lay-up process. The fibre mat was hand woven from banana fibre. The mould used for fabricating the composites was made from aluminum material with a debonding agent applied on the inner side. The inner cavity dimension of the mould is 180mm x 130mm x 8mm thick. For the single composite, the fibre mat was neatly cut into the mould size, mounted on the base plate of the mould which was placed on the table, and then it was completely filled with the epoxy resin. Epoxy hardener was the catalyst mixed with epoxy resin to give effective binding. The epoxy resin applied was distributed to the entire surface by means of a roller and the air gaps formed during fabrication were removed by gently squeezing using a roller until the matrix was set properly under the pressure of 6MPa. The setup was left to cure for 24 hours at room temperature. The same process was repeated for the 2 layers woven banana fibre mat (2LWBF) and 3 layers woven banana fibre (3LWBF) mat.

Table 1: Composition of Woven Banana Fibre (WBF) Mat and Epoxy Composite

WBF Mat No. of Layers	Epoxy resin (g)	Epoxy hardener (g)
1	193.2	96.6
2	186.4	93.2
3	179.8	89.9

III. Results

Mechanical tensile strength test

The mechanical tensile strength properties were obtained using an electromechanical Instron Universal Testing Machine (UTM). The graphs (Fig.1- 3) present the results obtained with a grip displacement rate of 2000mm/min.

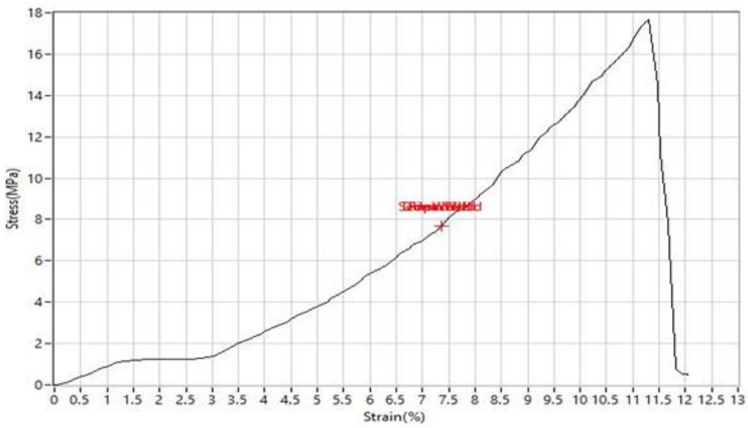

Fig. 1: Stress vs Strain Graph of Tensile Strength for 1LWBF

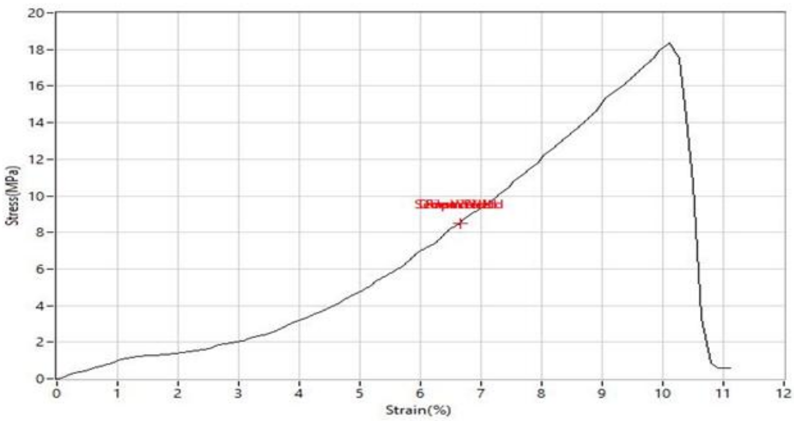

Fig 2: **Stress vs Strain Graph of Tensile Strength for 2 LWBF**

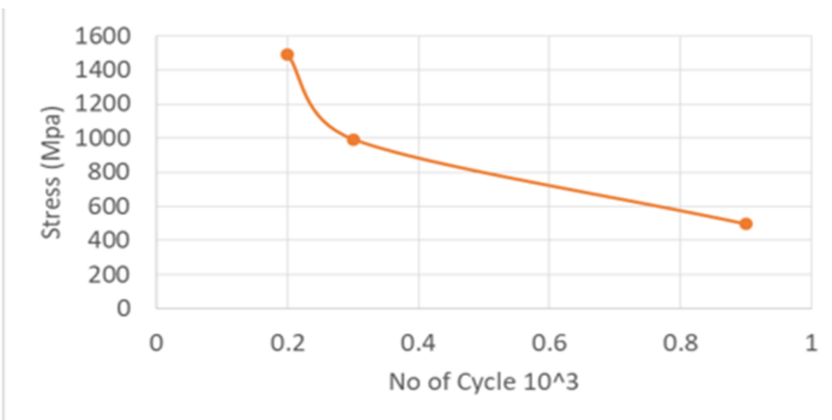

Fig 3: Stress vs Strain Graph of Tensile Strength for 3LWBF

Fatigue test

The specimens used in the fatigue tests were prepared in the form of I layer woven banana fibre mat (1LWBF) and 3 layers of woven banana fibre (3LWBF). During the fatigue tests, the temperature rise at three points on the surface of the specimens was measured using thermocouples and recorded in a computer. Periodically the procedures were stopped and a static loading test carried out. The stiffness modulus was derived from the stress-strain curves obtained.

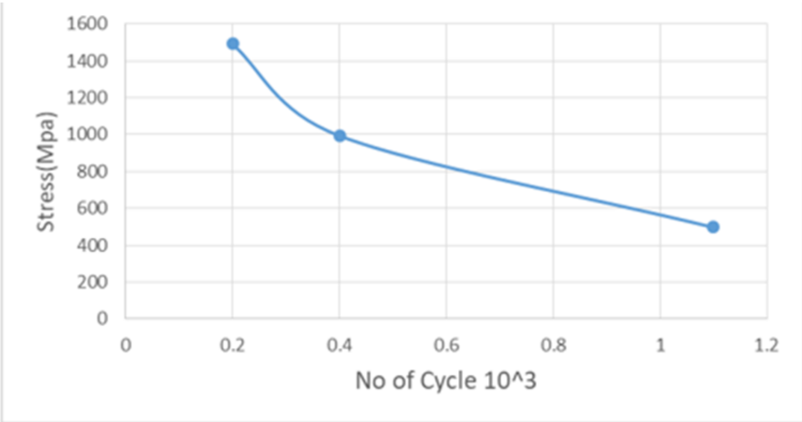

Fig. 3: S-N Fatigue Test Curve for 1LWBF

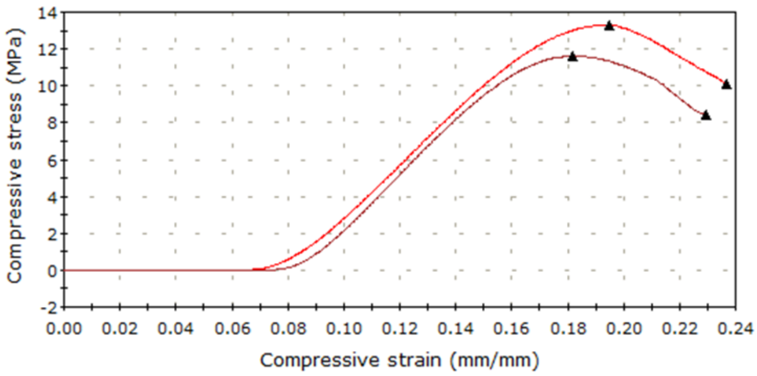

Fig. 4: S-N Fatigue Test Curve for 3LWBF

Compressive Test

Compressive strength is required by the composite material so as to receive a compressive load of the weight and the dynamic movement of the prosthetic leg socket. For each sample, two moduli were determined, one for the front and one for the backside. These were averaged to determine the compression modulus and strain for the composite. The graphs of Fig. 5 – 7 present the compressive test result of the specimen samples (1LWBF, 2LWBF and 3LWBF).

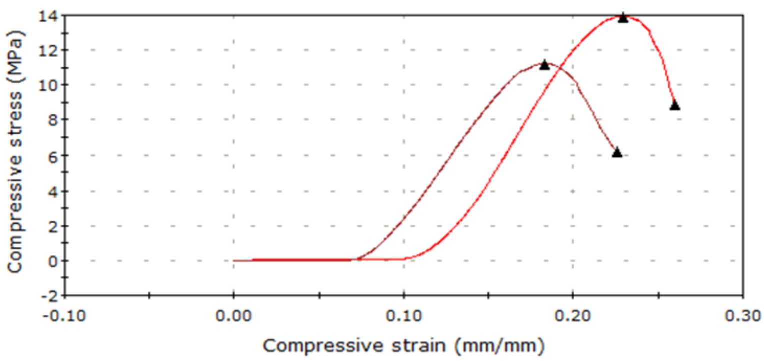

Fig. 5: Compressive Stress vs Strain Curve for 1LWBF Composite Sample

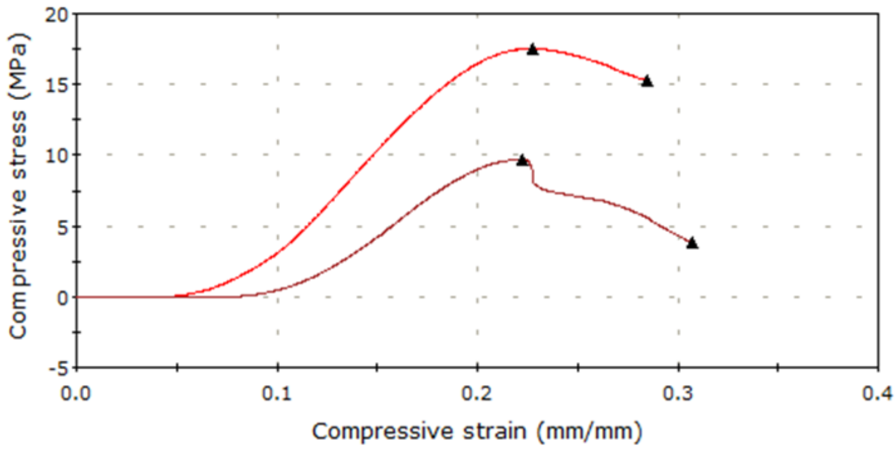

Fig. 6: Compressive Stress vs Strain Curve for 2LWBF Composite Sample

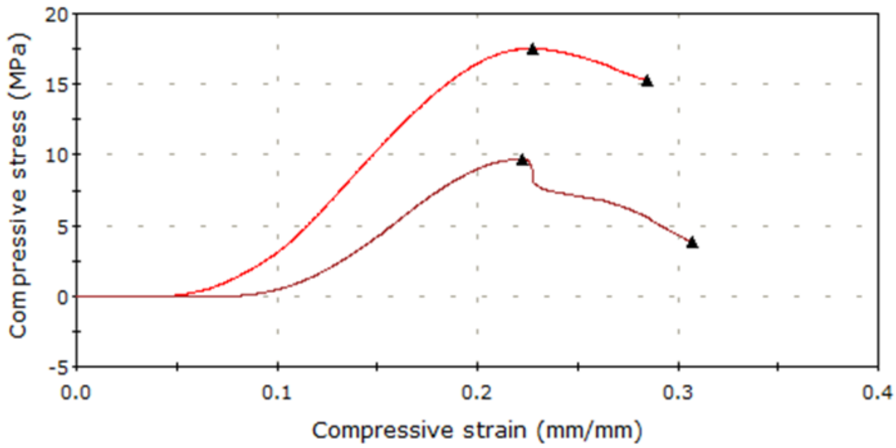

Fig. 7: Compressive Stress vs Strain Curve for 3LWBF Composite Sample

Surface Electron Microscopy (SEM)

The surfaces of the 3 layer woven banana fibre – epoxy composite specimens were inspected by using a scanning electron microscope JEOL.JSM-6480LV. The specimen surfaces were first cleaned carefully, air dried and then coated with 100A thick gold film with vacuum evaporation to enhance the conductivity of specimen sample. The samples were then placed in JEOL sputtering unit and SEM was observed at 20kv. The scanning electron microscope was used to observe the internal cracks, fractured surfaces and internal structure of the tested samples. Figure 8 – 10 show the results of the SEM analysis on the specimens' samples

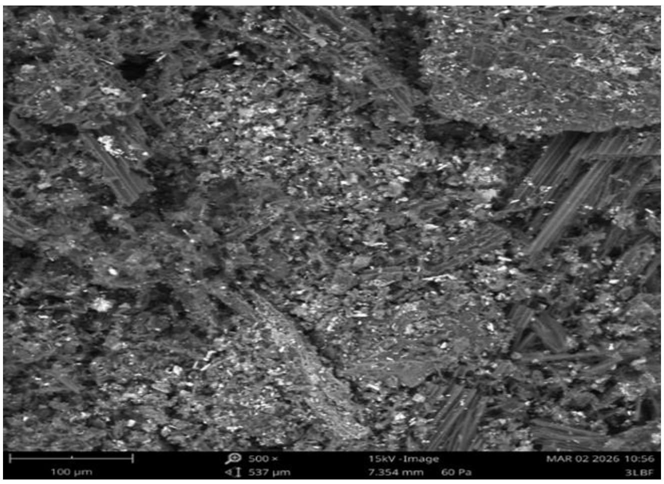

Fig. 8 SEM picture of woven banana composite with broken fibre with tapered ends

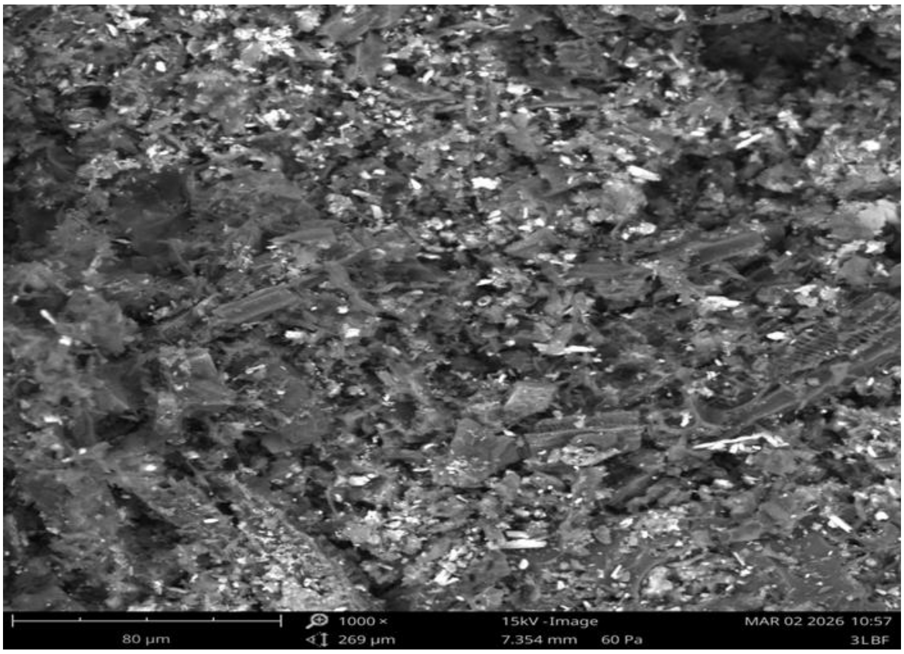

Fig. 9 SEM picture of woven banana composite with broken fibre with blunt ends

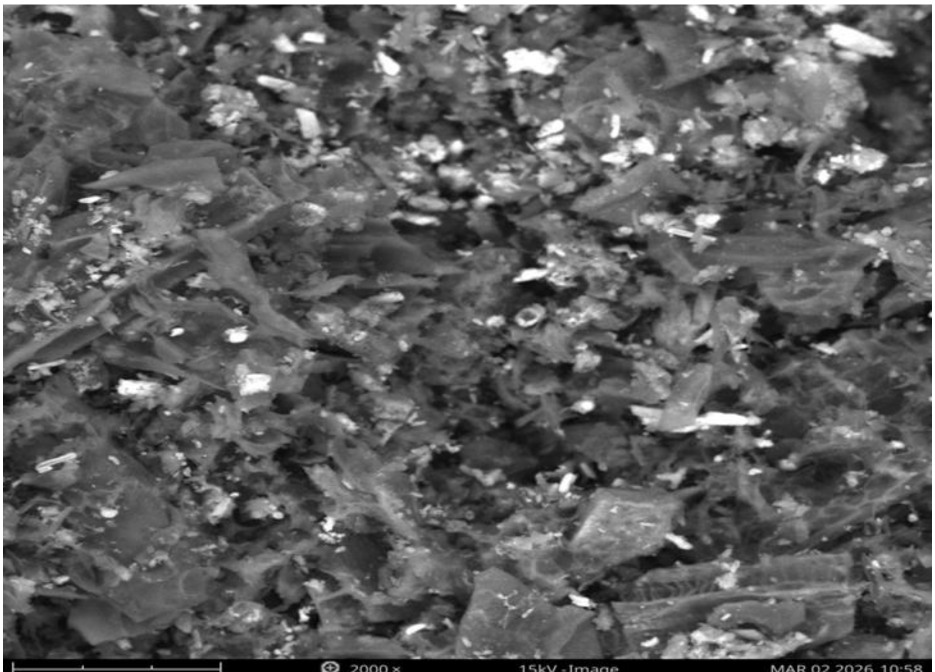

Fig. 10 SEM picture of woven banana composite with broken fibre with non-tapered ends

IV. Discussion

Mechanical Tensile Strength Test Result

It is well known that fibre strength is mainly responsible for strength properties of the composite (s). Therefore, the variation in tensile strength of the composite with various fibre loading is obvious. The stress/strain graphs of Fig. 5 – 7, the pattern revealed that tensile strength varied from 0.1 – 6.2, 0.0 – 17.8, 0.0 – 18.4MPa respectively. The tensile strength was observed to increase with the stacking of woven banana fibre mat. However, beyond the maximum points of 6.2, 17.8 and 18.4MPa, sudden decrease was observed. This confirmed that when composite materials attain ultimate tensile strength, fracture normally occurs due to the presence of lignin in the fibres, resulting in brittle fraction.

Fatigue Test Result

Most fatigue lifetime testing has been on round cross-section specimens to the ASTM E466 standard than using other shapes and conditions. The fatigue test results of the s-n curves for the two specimen samples in this study, where nearly linear in the low stress level. The stiffness modulus was calculated by linear regression of the curves in the nearly linear region. The two types of laminates (1LWBF and 3LWBF) were tested in load amplitude control. During all the fatigue tests the temperature rise at three points on the surface of the specimens were measured and periodically the static stiffness modulus was obtained (as described earlier). For analysis purposes, similar results were obtained for both laminates where the rise of temperature followed the same pattern of both load amplitude. The maximum temperature in both laminates occurred at failure. A linear relationship is observed for both laminates. However, the fatigue strength is strongly influenced by the layer design.

Compressive Test Result

Fig. 5 – 7 represent the graphical results of compressive test carried out on 1LWBF, 2LWBF and 3LWBF respectively showing two moduli, one for the front and one for back end. All averaged to give the following mean maximum compressive strength of 13.61611MPa, 13.20563MPa and 12.60349MPa respectively.

Microstructural Test Result

The microstructural test was carried out using the scanning electron microscopy (SEM) and the results revealed the SEM pictures clearly showing the fiber extensions due to stress and breakage of fiber. In all the composites, a change in the microstructure was observed with fiber shrinkage, breakage, indicating the loss in strength when stress was applied on the specimen samples (Fig. 8-10). The non-hybridized banana-epoxy composite upon induction of load stress showed higher tendency fiber shrinkage, fibre breakage and spontaneous formation of micro-cracks. The fibre breakage was rapid with blunt ends in Fig. 9. The delaminating with crack propagation due to the micro-crack formation and interfacial bonding failure observed in the woven banana fibre epoxy non-hybridized composites and the rate of crack propagation increased frequently by decreasing the integrity of the structure. However the break formation was gradual and not sudden, which can be observed in the SEM pictures, where the breakage was rapid with tapering ends in Fig. 8. Formation of severe cracks due to the inter-laminar failure revealed higher misalignment of woven banana fibre-epoxy composites suggesting the superiority of hybrid composites.

V. Conclusion

In the study, effect of mechanical properties and microstructural analysis of below the knee prosthetic leg socket developed from woven banana fibre (WBF) was successfully carried out. Banana fiber has already proven to be an excellent alternative natural fiber in composite formation, as it is a resource with vast availability and good biodegradable status. Thus, banana fibre in woven form in combination with epoxy resin has proved in this work, to be excellent for making cost effective composite materials for the health industry, aeronautic and automotive sectors. From the tensile strength test, fatigue test, compressive test and microstructural test carried out on composite materials according to ASTM standards and by thoroughly evaluating the results obtained, it concludes that the 3LWBF mat provides the optimum properties making the specimen sample cheaper, biodegradable and best alternative for use in the manufacture of prosthetic leg socket.

Therefore, it is conclusive from the above results that the woven banana fibre mat exhibited better properties and can conveniently be a suitable sustainable replacement material for certain synthetic polymer composites applied in the manufacture of prosthetic leg socket and other applications**.**

Applications

- Aviation and aerospace: Banana fibre has been extensively used in aviation and aerospace for primary airframe construction and other applications such as, luggage racks, instrument enclosures, bulkheads and, storage bins.
- Medical: Because of its low porosity, non-staining and hard wearing finish, banana fibre is widely suited to medical applications such as prostheses etc.
- Automobiles: Banana fibre has been extensively used for automobile parts like body panels, seat, for improving the composites properties, the fibers were treated with various chemicals and matrix blend with suitable chemical for making the banana fibre composites. This may improve the mechanical, thermal, tribological properties of the banana composites cover plates, door panels, bumpers and engine cover.
- Home and furniture: Roof sheets, bathtub furniture, windows, sun shade, shoe racks, book racks, tea tables, spa tubs etc.

Scope For Future Work

Similarly, various other natural reinforcing materials could be used to mix with banana fibre to form better hybrid composite which has better mechanical properties and as well as cost effectiveness.

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Conflict Of Interest

None declared

References

[1]. Andrew, S Sewell, T, Noroozi, S., Vinney, J, And Amali, R. (2012). Improvements In The Accuracy Of An Inverse Problem Engine's Output For The Prediction Of Below-Knee Prosthetic Socket Interfacial Loads. Engineering Applications Of Artificial Intelligence, 23(6):1000-1011.

[2]. Bar, T.A And Almeida (2013). "Breathable Liner For Transradial Prostheses," In Myoelectric Controls/Powered Prosthetics Symposium Fredericton.

[3]. Begun, R.J. And Hamzat, N.M. (2013). Orthoses And Prosthetics As Ambulation Devices. Biomedics And Physio Jour. ABS Publication. Vol.12. Pp. 453-574.

[4]. Dillingham, T. B. And Laszczak, P. (2001). "Development And Validation Of A 3D-Printed Interfacial Stress Sensor For Prosthetic Applications," Med. Eng. Phys., 37(1):132–137.

[5]. Edwards, M. L. (2018). Lower Limb Prosthetics. In: Olson DA, Deruyter F, Editors. Technologies For Mobility And Locomotion. St. Louis: Mosby, Inc; P. 297-310.

[6]. Kramer, A.T. And Davenport, B.R. (2015). Selection And Evaluation Of Natural Fibres. A Literature Review. International Journal Of Innovative Sciences, Engineering And Technology. Vol. 4 (18) 122-134.

[7]. Mccarthy, J. C., Bono, J. V., And O'Donnell, P. J. (2009). Custom And Modular Components In Primary Total Hip Replacement. Clinical Orthopaedics And Related Research (344), 162 171.

[8]. Me, D. And Tsiokos, A. (2012). "Fiber Optic-Based Pressure Sensing Surface For Skin Health Management In Prosthetic And Rehabilitation Interventions," Biomed. Eng. - Tech. Appl.

[9]. Meulenbelt, H. E. And Daniel, B. T. (2009). "Determinants Of Skin Problems Of The Stump In Lower Limb Amputees," Arch. Phys. Med. Rehabil., Vol. 90, No. 1, Pp. 74–81.

[10]. Ogi A.T. (2003). Mechanical Properties Of Pineapple Leaf Fiber Reinforced Polymer Composites For Application As A Prosthetic Socket. Journal Of Engineering And Technology (Research Gate).

[11]. Paramasivam, L. A., Sabu, T. And Neelakantan, N. R. (2020). "Short Banana Fibre Study. Work Presented At EU Engineering Conference Session Aberdeen, UK,

[12]. Rami, S., Linga, R., And Shetty, P.B. (2015). Mechanical Properties Of Short Banana Fiber Reinforced Natural Rubber Composites. International Journal Of Innovative Research In Science, Engineering And Technology, 2(5), 1653-1655.

[13]. Rosalam, J. And Versluys, R. (2012). "Prosthetic Feet: State-Of-The-Art Review And The Importance Of Mimicking Human Ankle–Foot Biomechanics," Disabil. Rehabil. Assist. Technol., 4(2):65–75.

[14]. Seymour, J., Taya, M., And Saito, M. (2010). Optimization Of Mass-Produced Trans-Tibial Prosthesis Made Of Pultruded Fiber Reinforced Plastic.