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Effect Of Composition And Thickness Of Thermo-Gravimetric Analysis (TGA), Surface Morphology (SEM) And Dynamic Mechanical Analysis (DMA) Of Prosthetic Leg Socket Developed From Composite Of Woven Banana Fibre (WBF) Mat

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Abstract
This research work investigated the effect of composition and thickness of thermo-gravimetric analysis (TGA), surface morphology (SEM) and dynamic mechanical analysis (DMA) of prosthetic leg socket developed from composite of woven banana fibre mat reinforced epoxy resin. 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 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. Distill 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 0/90^o fibre mat. The woven banana fibre (WBF) mat was prepared according America Standard for Testing Materials (ASTM) standards and tested for thermo-gravimetric analysis (TGA), surface morphology (SEM) and dynamic mechanical analysis (DMA). The results showed that, thermal stability of the 3 layer woven banana fibre was more stable to a great extent, the surface morphology revealed an internal structure of micro cracks and while the dynamic mechanical test reported good energy dissipation capacity. From the aforementioned outcomes, woven banana fibre mat depicts high potentials for use as reinforcement in prosthetic leg socket.
Keywords: *Banana fibre, Epoxy resin, Composites, Physical properties, Leg socket.*

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I. Introduction

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 material 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 bio composites 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 the effect of composition and thickness of thermo-gravimetric analysis, surface morphology and dynamic mechanical investigations of prosthetic leg socket developed from composite of woven banana fibre for application in below the knee prosthetic leg socket.

II. Methodology

Materials

The materials and reagents used in this research include: banana fibres, 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.

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 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.

Distill 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 using a roller over the surface 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

Thermo-Gravimetric Analysis (TGA)

Figure 1A-1B show the results of the TGA analysis on woven banana fibre. This analysis was carried out to identify the thermal stability of the WBF.

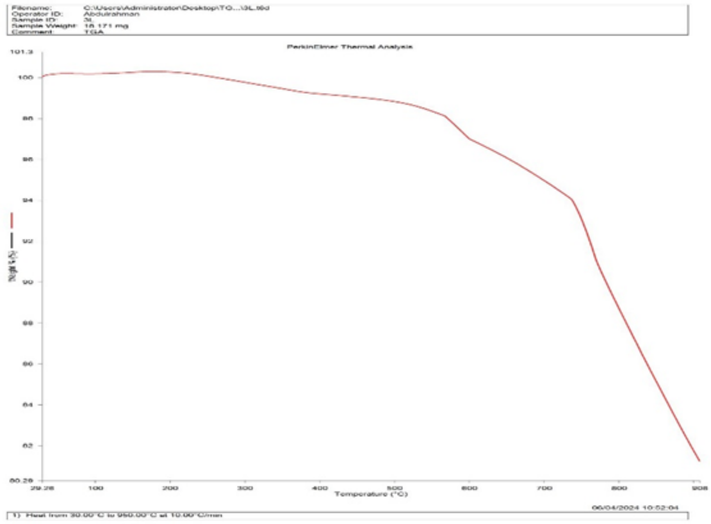


Figure 1(A): TGA Graph of 3LWBF mat Composite Sample

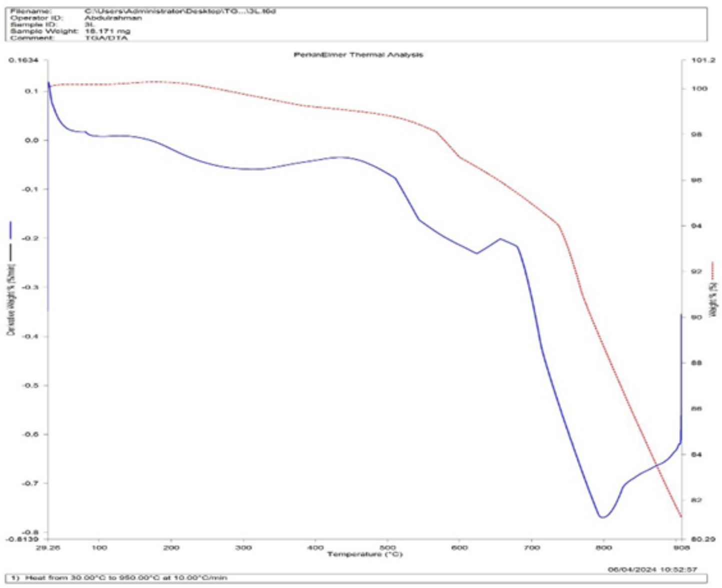


Figure 1(B): **TGA/DTA Graph of 3LWBF mat Composite Sample**

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. Figure 2 – 4 show the results of the SEM analysis on the specimens' samples

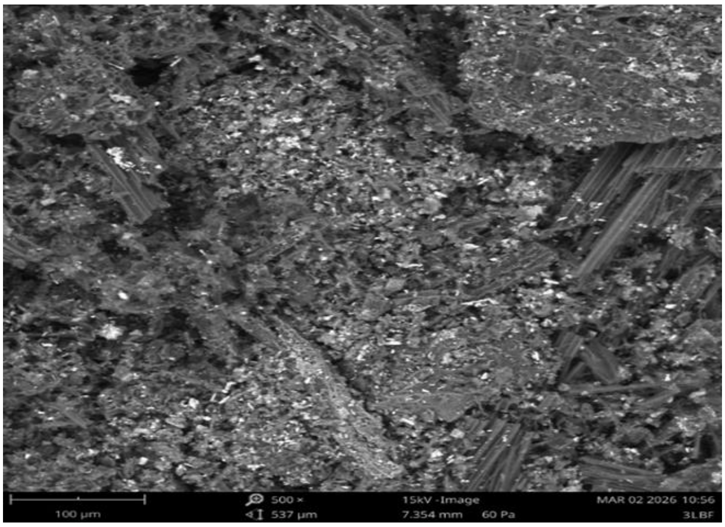


Fig. 2 SEM picture of woven banana composite with broken fibre with tapered ends

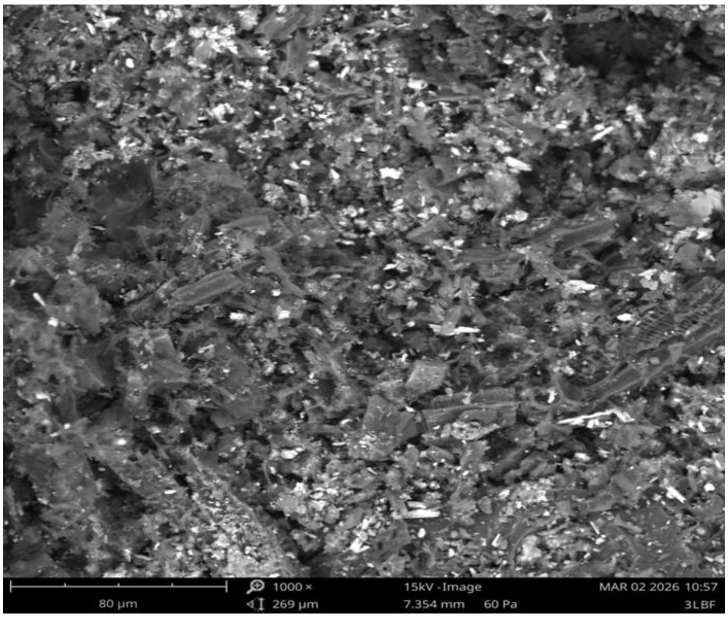


Fig. 3 SEM picture of woven banana composite with broken fibre with blunt ends

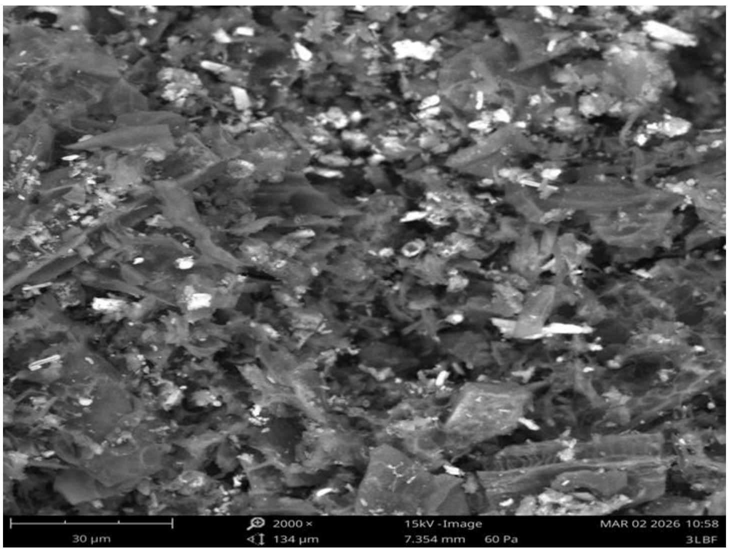
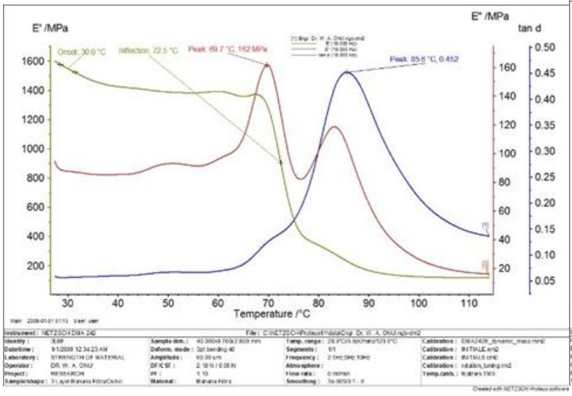
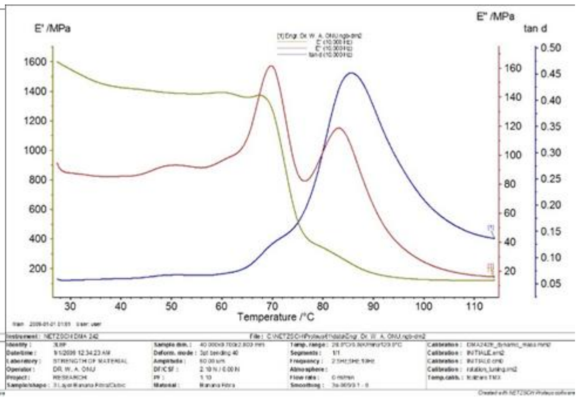


Fig. 4 SEM picture of woven banana composite with broken fibre with non-tapered ends

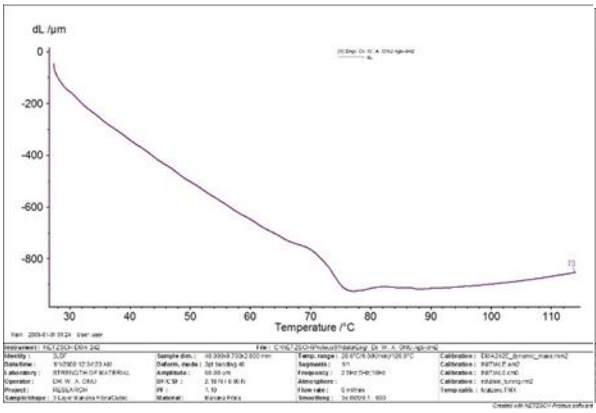
Dynamic Mechanical Analysis (DMA)

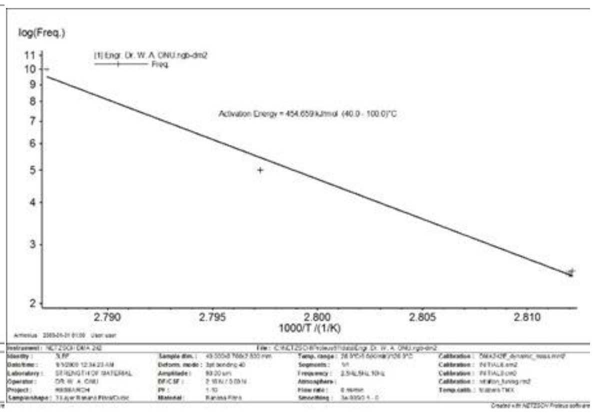
Dynamic mechanical analysis (DMA) is an effective tool used in studying the thermo-stable properties of materials. It allows the materials respond to temperature, stress, frequency and other properties which are studied and analyzed. DMA results are commonly presented in the form of a storage modulus (E'), a loss modulus (E') and a loss factor (tan d = E''/E'). Graph (a – j) show the typical DMA results of the 3 layer woven banana fibre – epoxy composite.



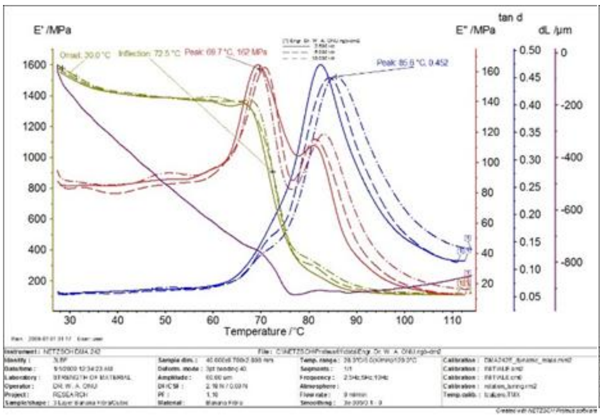


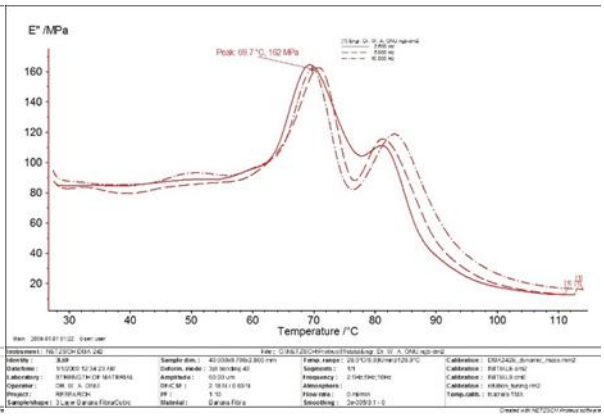
Graph (a). Storage modulus (E') vs Temperature. (b) E' vs Temperature of displacement of displacement curve. curve.



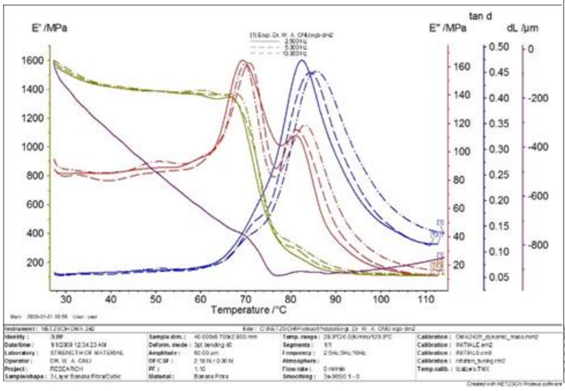


(c.) dL vs Temperature of displacement curve (d) log (freg) vs 1000T displacement curve

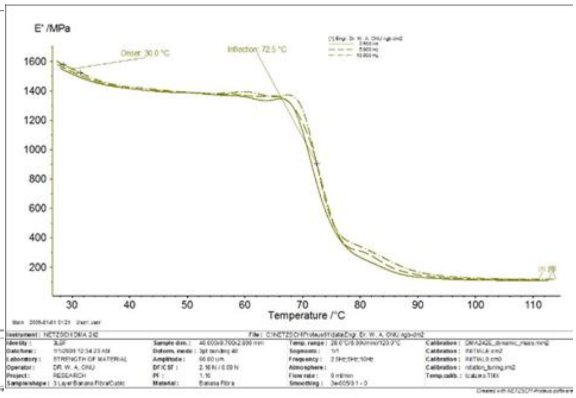




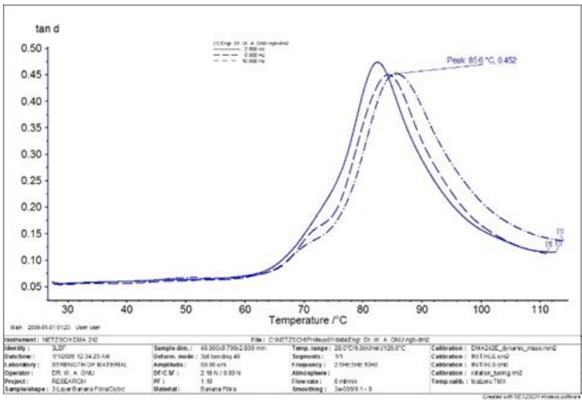
(e) E' vs Temperature of displacement curve. (f) E' vs Temperature of displacement curve



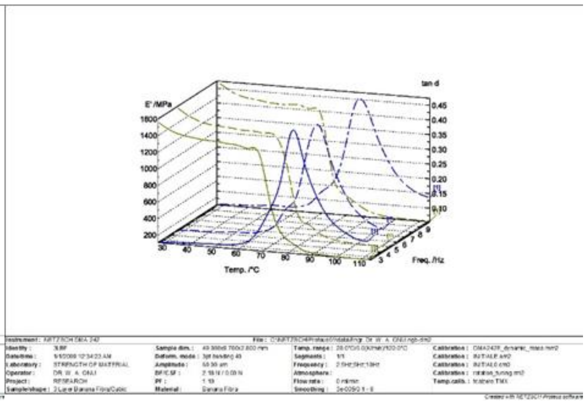
(g) E' vs Temperature displacement curve



(h) E' vs Temperature displacement curve



(i) Tan d vs Temperature displacement curve



(j) E' vs Temperature displacement curve

III. Result And Discussion

Thermo-Gravimetric Analysis Result

The thermal analysis of the 3 layers woven banana fibre reinforced epoxy resin composite was determined with the help of thermo-gravimetric analysis (TGA) and derivative thermo-gravimetry (DTG) as shown in Figure 1A – 1B, respectively. When a natural fibre is exposed to high heat conditions, thermal degradation occurs in the following sequences: hemicellulose, cellulose, lignin, wax and rest of the constituents. Degradation of 3 layers woven banana fibre ingredients was undertaken in four different steps. From Figure 1A, the initial degradation occurred at 100–200 °C with a loss of about 0.01%. At this temperature, moisture started to evaporate from the woven banana fibre. In the second stage of degradation, most of the cellulose and lignin contents got degraded and showed loss around 1.9 % which took place between 280 – 500°C. The third degradation was observed around (94 - 98 w %) recording a mass loss of about 4%. During the last stage of degradation, the cellulose degradation occurred from (82–93 w %) which coincided with the degradation of lignin as well as wax which left ash as residue. The thermal behaviour of the woven banana fibre mat reinforced epoxy composite is in agreement with Ogi, (2003) and Rami, *et al*., (2015) on the influence of thermal history on carbon fibre reinforced polymer laminates which a reduction in strength occurred due to higher degradation at the fibre/matrix interface. The energy required to start the woven banana fibre degradation is called kinetic activation energy (Ea). The TGA analysis elicits that the woven banana fibre mat is an appropriate substance that can be used as a better reinforcement for the production of prosthetic leg socket.

Surface Electron Microscopy Result

The view in SEM pictures clearly shows the fiber extension and breakage of fibers with extension due to stress. In all composites, a change in the microstructure was observed with fiber shrinkage, breakage, indicating the loss in strength when stress was applied (Fig. 2-4). 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 (Fig. 3). 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 (Fig. 2). 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.

Dynamic Mechanical Analysis Result

Dynamic mechanical analysis (DMA) is an effective tool used in studying the thermo-stable properties of materials. It allows the materials respond to temperature, stress, frequency and other properties which are studied and analysed. DMA results are commonly presented in the form of a storage modulus (E'), a loss modulus (E') and a loss factor (tan d = E''/E'). The storage modulus (E') describes the ability of a material to support a load which is the maximum energy stored by the material during one cycle of oscillation, it also gives information about the stiffness and load carrying capacity of composite materials. Graphs a, b, e, f, g, h and j represent the storage modulus (E') of all the composite samples tendered for the DMA test. According to these figures, an enhancement in storage modulus with fibre content was observed over the entire temperature range for all recoverable viscoelastic deformation. Graph c shows the loss modulus which is the amount of energy dissipated in form of heat by material during one cycle of sinusoidal load. The loss modulus increased as the temperature increased up to the glass transition temperature and suddenly decreased from the peak at different frequency. Graph i. shows the tan delta curve representing the dissipation of energy in the composite sample under cyclic load. The display of the graph revealed that the tan delta peak was increased due to less restriction in the movement of the polymer molecules caused by the presence of single fibre.

IV. Conclusions

In the work, effect of composition and thickness of thermo-gravimetric analysis (TGA), surface morphology (SEM) and dynamic mechanical analysis (DMA) of prosthetic leg socket developed from composite of 3 layer woven banana fibre mat reinforced epoxy resin was successfully carried out. The TGA, SEM and DMA of the composite as functions of fibre content were properly analyzed. Banana fibre has already proven to be an excellent alternative natural fibre in composite formation, as it is a resource with vast availability and fast growth with biodegradation. The 3 layer woven banana fibre not only improved the properties of the composite but also reduced its cost and make it eco friendly composite. Thus 3 layer woven banana fibre – epoxy resin has proved to be excellent for making cost effective composite materials. From the TGA test carried out on composite material by thermo-gravimetric analysis and derivative thermo-gravimetry (DTG) testing methods and by thoroughly evaluating the results obtained, it concludes that the 3 layer woven banana provides good thermal stability by making the composite a suitable replacement material in the manufacture of prosthetic leg socket and other applications

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.
Can also carry out scanning electron microscopy (SEM) analysis for this hybrid bio composites.

Aknowledgement

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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.