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Comparative Evaluation of Dynamic Mechanical Properties of Epoxy Composites Reinforced with Woven Fabrics from Sansevieria (*Sansevieria trifasciata*) Fibres and Banana (*Musa sapientum*) Fibres

Primerjalna ocena dinamičnih mehanskih lastnosti epoksi kompozitov, ojačenih s tkaninami iz vlaken sansevierije (Sansevieria trifasciata) in bananovca (Musa sapientum)

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Abstract
Globally, sustainable materials that are environmentally friendly and the path towards sustainable development are needed. Natural plant fibre utilization in various industries has seen a surge, especially in the automotive sector. Natural fibres such as from *Sansevieria* and banana pseudostem are readily available and have considerable mechanical properties that make them good candidates for reinforcement epoxy resins. The dynamic mechanical properties (DMA) of *Sansevieria* (*Sansevieria trifasciata*) and banana pseudostem (*Musa sapientum*) woven fibre epoxy composites are discussed. The results show that the optimum temperature range of application of the *Sansevieria* and banana epoxy composites is up to 50 °C. The glass transition temperature, Tg, obtained from the curves of mechanical damping factor (tan δ) was 100 °C and 120 °C for *Sansevieria* and banana fibre epoxy composites, respectively.
Keywords: DMA, Sansevieria trifasciata, banana fibre, Musa sapientum, epoxy composite

Izvleček
Trajnostni materiali, ki so okolju prijazni, in pot do trajnostnega razvoja sta potrebna v svetovnem merilu. Uporaba naravnih rastlinskih vlaken je doživela vzpon v različnih industrijah, še posebno v avtomobilski industriji. Naravna vlakna, kot so vlakna sansevierije in iz navideznega stebla bananovcev, so nam na voljo in imajo dobre mehanske lastnosti, ki jih uvrščajo med kandidate za ojačitev epoksi smol. Predstavljene so dinamične mehanske lastnosti epoksi kompozitov, ojačenih z vlakni sansevierije (Sansevierija trifasciata) in bananovca (Musa sapientum). Na podlagi rezultatov je bilo ugotovljeno, da je optimalna temperatura uporabe epoksi kompozitov, ojačenih s tkaninami iz vlaken sansivierije oziroma vlaken bananovca, do 50 °C. Temperatura steklastega prehoda, Tg, odčitana iz krivulje faktorja mehanskega dušenja (tan δ), je bila 100 °C za epoksi kompozit ojačen s tkanino iz vlaken sansevierije oziroma 120 °C za epoksi kompozit ojačen s tkanino iz vlaken bananovca.
Ključne besede: DMA, Sansevierija trifasciata, vlakna bananovca, Musa sapientum, epoksi kompozit

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1 Introduction

Globally, sustainable materials that are environmentally friendly and the path towards sustainable development is needed. Natural plant fibre utilization in various industries has seen a surge, especially in the automotive sector. According to the report [1] on Global Natural Fibre Composites Market 2014–2019: Trends, Forecast and Opportunity Analysis, showed that by 2016, the natural fibre composites market is expected to be worth US 531.2 million with an expected annual growth rate of 11% for the next five years [2]. Currently, natural fibres account to over 14% share of reinforcement materials; however, the share is projected to rise to 28% by 2020 amounting to about 830,000 tonnes of natural fibres [3]. Studies have been made of natural fibres and its composites, the most common kenaf, flax, jute, sisal, abaca to mention but a few have found their way in automotive applications [4–9] for components that don't need high mechanical strength.

Carbon and glass fibres whose feedstock is petroleum, is faced with challenges such as disposal concerns, dangerous toxic fumes and high energy demands, however, their performance in the automotive and aerospace industry is unparalleled. Unlike carbon and glass fibres, natural fibres are environmentally friendly [10], exhibit lower density [11], sustainable [12, 13] and some have closely comparable mechanical properties to those of carbon and glass [14].

Sansevieria trifasciata (Figure 1) is a species in the family of *Asparagaceae*. *Sansevieria trifasciata,* grows all over the world and in Africa there are many various species of *Sansevieria*.

Various species of banana (*Musa sapientum*) pseudostem fibre and sanseviera fibre have been studied elsewhere for reinforcement of composite structures. The mechanical properties of randomly oriented *Sansevieria* species such as *Sansevieria trifasciata*, *Sansevieria cylindrical*, *Sansevieria ehrenbergiiand*, *Sansevieria roxburghiana Schult*. have been investigated for the production of fibre and composites [15–19]. Banana pseudostem fibre was investigated as a filler for composite structures, it has been concluded that it posses, robust mechanical properties if applied as a filler in polymer resins [20].

The dynamic mechanical analysis (DMA) is an important tool to study the mechanical and the viscoelastic behavior of the material over a wide temperature range and frequencies [21]. In DMA, the material is subjected to a mechanical perturbation, then the resulting stress and strains are used to characterize the viscoelastic behavior of the material over a wide temperature range using either one or more frequency sweeps. Classical DMA outputs are storage modulus (E'), loss modulus (E") and mechanical damping factor (tan δ). The storage modulus shows how much energy a material can absorb, whereas the loss modulus shows how much energy the material releases. The mechanical damping factor can be utilized to show the impact resistance of the material.

Kumar et al., 2011 [17] studied the dynamic mechanical properties of short *Sanservieria cylindrica* epoxy composites and deduced that the introduction of *Sansevieria* fibre to epoxy polymer restricted the mobility of the polymer molecules. Paul et al., 2010 [22] showed that the DMA of banana fibre/PP commingled composites were found to depend on the banana fibre loading and the nature of the interface. The banana fibre reinforcement into the PP matrix positively influenced the storage and loss moduli and a decrease in the mechanical damping factor. Dynamic mechanical analysis of short randomly oriented intimately mixed banana/sisal hybrid fibre reinforced polyester composites was investigated by Idicula et al., 2006 [23]. The 40% volume fraction of fibres proved to be the optimum for increased storage and loss modulus.

In his study of DMA of woven banana/epoxy composite Venkateshwaran et al., 2012 [24] shows that plain, twill and basket weave patterns storage modulus decreases with an increase in the temperature. Further, it also indicates that the incorporation of fibres improves the storage modulus and decreases the damping factor. His work also showed that the storage modulus of all the patterns studied were above untreated jute/high density polyethylene and pineapple leaf fibre/polyester composite.

In our study, for the first time, is presented the dynamical mechanical analysis of epoxy composites reinforced with woven fabrics made from *Sansevieria trifasciata* fibres and banana pseudostem (*Musa sapientum*) fibres.

2 Materials and methods

2.1 Materials

Sansevieria and banana pseudostem fibre (Figure 1) were extracted using the hand extraction method.

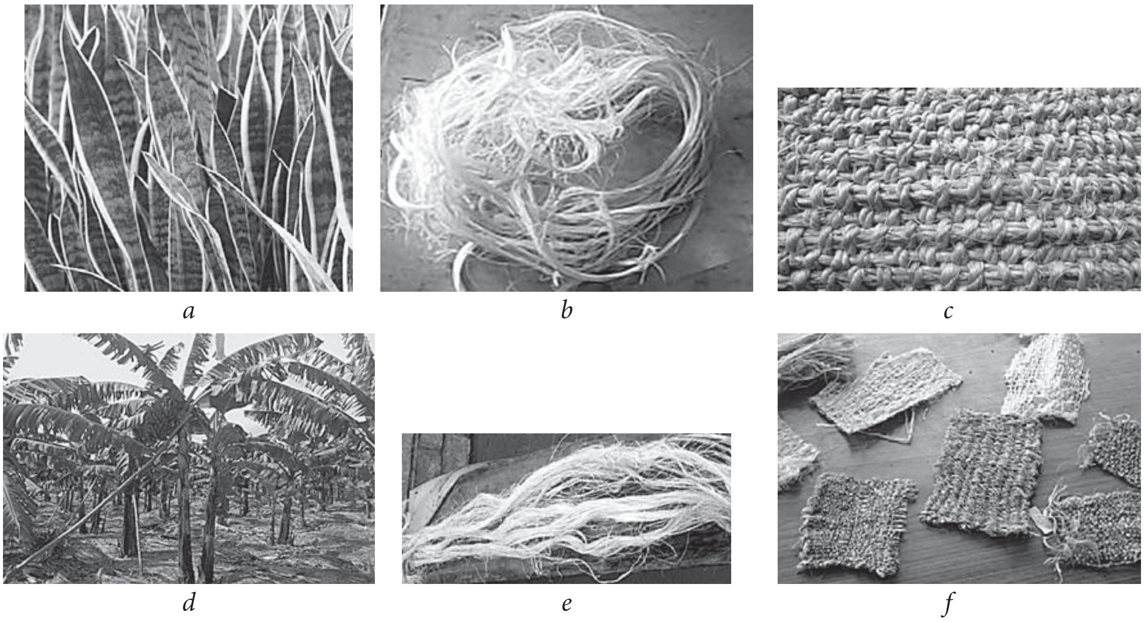

Figure 1: (a) Sansevieria trifasciata plant, (b) Sansevieria fibres, (c) woven fabric from Sansevieria fibres, (d) banana tree, (e) banana pseudostem fibres, (f) woven fabric from banana fibres

In order to make the fabric, fibre bundles were twisted and woven in plain weave patterns on a tapestry frame. Epoxy resin was supplied by Henkell, Uganda. The composites were fabricated using hand method and left to cure at room temperature.

2.2 Characterization methods

Morphology
The surface morphologies of the fabrics and fracture surfaces were investigated using a Vegas-Tescan Scanning Electron Microscope (SEM) with accelerating voltage of 20 kV.
The Digital camera Nikon DS-5M and Video microscope Navitar was used to examine the water immersed samples.

Fibre mechanical properties
Testing of mechanical properties of sansevieria fibres was done using an Eureka strength tester according to ASTM D 3822.

Dynamic mechanical properties
The DMA was carried out on a DMA 40XT machine. The samples with dimensions 56 mm x 13 mm x 2.5 mm were tested using three point bending mode at frequency of 1 Hz from room temperature to 150 °C at a heating rate of 3 °C/min.

3 Results and discussion

3.1 Morphology

Figure 2 shows the morphology of banana (*Musa sapientum*) pseudostem fibres and *Sansevieria trifasciata* fibres. Banana fibres are characterized by nodes

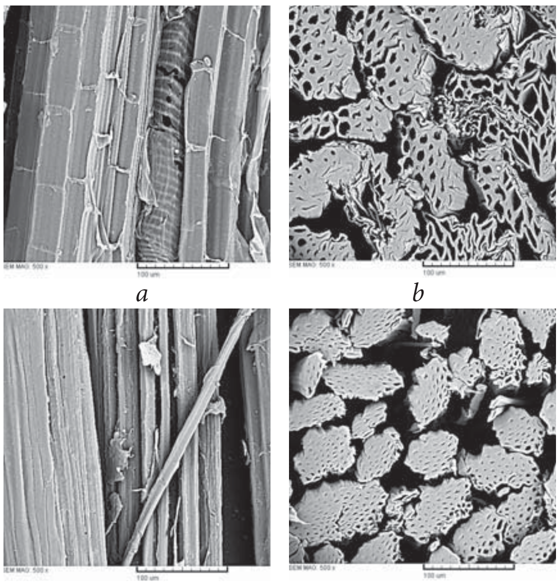

Figure 2: (a) Banana pseudostem fibres, (b) cross-section of banana tree fibres, (c) Sansevieria fibres, (d) cross-section of Sanseveria fibres

along their longitudinal surface. The cross section shows the fibres have slightly bigger lumens compared to *Sanseveria fibres*. SEM also shows that the fibres are covered with plant material on the surface. Because the fibres have lumen, the thermal insulation and acoustic properties of the fibres are enhanced.

3.2 Fibre mechanical properties

Sansevieria trifasciata fibre had an average tensile strength of 348.62 MPa and Young's modulus of 15.31 GPa. Elongation at break was 2.3% a value which is comparable to other researches elsewhere on leaf fibres. Banana pseudostem fibre had an average tensile strength of 941.05 MPa with percentage elongation at break of 1.6%. Since fibre strength translates into fabric strength, the strength of the fabric reinforced composite would increase relatively.

3.3 DMA

In order to assess the performance of structural applications, the dynamic mechanical properties help in material evaluation so as to understand the viscoeslastic behavior of the material against temperature, time and frequency. Three parameters storage modulus (E'), loss modulus (E") and damping factor (tan δ) were obtained over a temperature range from 27 °C to 150 °C.

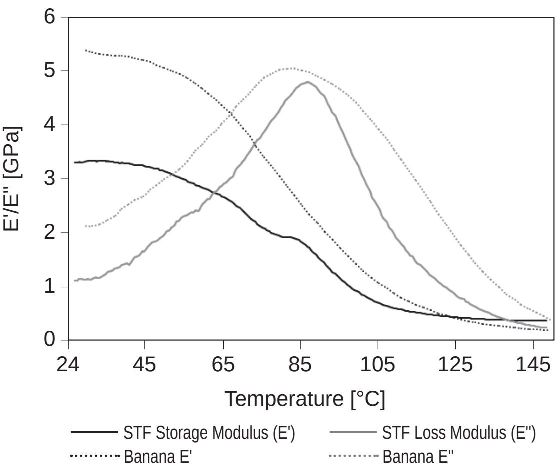

Figure 3: Behavior of composites storage and loss modulus of epoxy composites reinforced with a fabric from Sansevieria fibres (STF) and banana fibres (Banana)

The storage modulus shows the stiffness of the composites against temperature. It's observed that the storage modulus generally decreases with increasing temperature (Figure 3). The E' for banana woven epoxy composites at 27 °C was 5.4 GPa higher than that of Sansevieria composites which was 3.3 GPa at the same temperature.

The high value of storage modulus of banana pseudostem fibre epoxy composite is attributed to the natural strength of banana fibres and also the fibre morphology, which aided the fibre to matrix adhesion thereby reducing the mobility of the polymer chains.

A sudden fall of the modulus of the composites was observed at 50 °C which is marked by a sharp decrease in the storage modulus until to around 400 MPa at 120 °C. As the composite approaches the glass transition temperature, there's a sudden decrease in the storage modulus attributed to the free molecular movement of the polymer chains, however the gradual decrease of the storage modulus is observed more in the banana composites than *Sansevieria* due to a higher storage modulus.

The loss modulus curve shows how much energy is dissipated as heat by the developed composites. The polymer chain mobility increases with temperature until the glass transition region where the loss modulus rapidly falls. Above the glass transition, the composite's elasticity and viscous behavior greatly reduces because of the mobility of polymer molecules. It's observed that the loss modulus of banana epoxy composites was higher than that for *Sansevieria* composites. The variation of tan δ against temperature (Figure 4) aides in obtaining the glass transition temperature. The T_g obtained from the tan δ curve is higher than that obtained from the loss modulus curve. It's observed that the T_g obtained by the damping factor curve shows a value of 100 °C and 120 °C for *Sansevieria* and banana fibre epoxy composites respectively. This is the exact opposite of the glass transition temperature obtained from the loss modulus curve. Beyond the glass transition temperature, the material transitions from glass to rubbery state due to the mobility of polymer chains. The higher glass transition temperature of banana fibre epoxy composites is due to the thermal stability of banana fibres in comparision to sansevieria fibres, therefore more energy is needed for transition to rubbery state. The higher tan δ peak corresponds to high energy dissipation, whereas a shorter peak is equivalent to less energy dissipated. Pothan et al., 2003 [21] showed that weak fibre to matrix bond interfaces are sources of crack initiation; therefore higher energy is dissipated than strong interfaces. It's therefore observed that banana fibre woven composites exhibited weak fibre to matrix adhesion due to a higher tan δ peak, whereas *Sansevieria* composites showed strong fibre to matrix adhesion. The high tan δ peak also shows that banana fibre epoxy composites will be more viscous when loaded compared to *Sansevieria* composite.

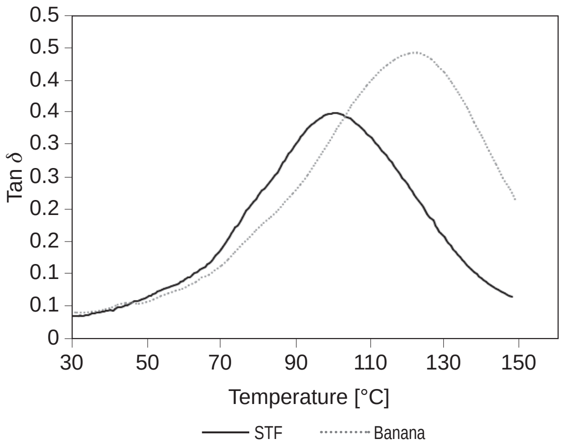

Figure 4: Effects of mechanical damping factor of epoxy composites reinforced with a fabric from Sansevieria fibres (STF) and banana fibres (Banana)

The dynamical mechanical properties have therefore shown that from 27 °C, the optimum temperature range of application of the *Sansevieria* and banana epoxy composites is up to 50 °C. Beyond 50 °C, the composites enter into a rubbery state and the performance is diminished.

4 Conclusions

The dynamical mechanical properties of *Sansevieria* and banana woven epoxy composites have been evaluated. Thermal stability was characterized by *Sansevieria trifasciata* woven epoxy composites and the mechanical damping factor, tan δ of 0.35 showed that *Sanseveria* epoxy composites had a stronger fibre to matrix interface compared with banana epoxy composite with tan δ of 0.44. Using the glass transition temperature obtained from the tan δ curve, banana epoxy composites exhibited the highest glass transition temperature, T_g of 120 °C compared to 100 °C of Sansevieria composites.

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