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Effect of Fibre Hybridization on Dynamic Mechanical Performance of Bagasse/Glass Fibre Hybrid Reinforced Epoxy Composite

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ABSTRACT

The dynamic mechanical analysis of sugarcane bagasse/glass fibre hybrid reinforced epoxy composite was investigated and compared with all glass reinforced counterpart. Bagasse fibre mats were produced and non-woven glass fibre mats obtained locally were used to produce the composites laminates at 45 % volume fraction at different layering arrangement using the compression moulding technique. The storage modulus (E'), loss modulus (E") and the mechanical damping factor (tan δ) of the composite were analysed at 1 Hz over heating temperature of between 33 to 200 ºC at 2 ºC/min heating rate. Results showed that the hybridization reduced the storage modulus and the damping factor irrespective of layering sequence. Also, hybridization shifted the glass temperature (T_g) slightly to a higher temperature, and glass reinforced composite had the highest storage modulus value of 8GPa whereas all bagasse reinforced composite exhibited the highest damping factor of 4.74×10^{-1}.

KEYWORDS

Storage modulus, Loss modulus, Composite, Dynamic mechanical analysis.

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INTRODUCTION

Since the middle of the 21st century, substantial advances have been made in the production and utilization of fibre-reinforced polymer composite (FRPC) [1]. This is because of its several advantageous properties compared to the classic monolithic metals, polymers and ceramics. Fibre-reinforced polymer composite usually have low densities, better strength and high corrosion resistance. They are low-cost and their properties can be tailored towards a specific application compared with the conventional materials [2]. A typical composite system consist of a discontinuous phase embedded in a continuous matrix. The discontinuous phase is the load bearing constituent and is usually harder while the continuous phase acts as the load transfer medium [3,4]. Recently, attention have shifted to hybridization of the reinforcing phase in the production of composites to exploit the advantages of hybrid structure such as mechanical damping, dimensional stability, *etc*. [5]. In this types of composite system, more than one type of fibre is used to reinforce a common matrix and the resulting property of composite shows a synergistic advantage of individual constituents.

Glass fibre is by far the predominant fibrous reinforcement used in the production of FRPC due to their availability, ease of production and high strength. However, there is often a considerable problem with the use of glass fibres as reinforcement of plastics these include; relatively high cost and density, non-recyclability, non-biodegradability, non-renewability and the added health risks due to its carcinogenic tendency [6,7]. Studies have shown that natural cellulose fibre from plant have proved to be a viable alternative to the synthetic glass fibres for polymer composite production. This is because plant fibres are low-cost, abundant and environment friendly as well as biodegradable [8,9]. They possess low density and poses no health risks during processing and handling compared to the synthetic fibres [10]. Plant fibres have also been reported to have high specific properties and exhibit reasonably good mechanical properties at compared with synthetic fibres *e.g.* glass [5]. One approach to confronting the problems posed by glass fibre is through hybridization to combine the advantages of cellulose and glass fibres in a synergistic manner.

Several researches reported the hybridization of reinforced phase of FRPC. Pandanattil and coworkers [11] assess the efficacy of glass/sisal fibre hybrid reinforcement as a potential choice for retrofitting of concrete structure. They highlighted that the inclusion of sisal fibres along with glass fibre was found to improve the energy absorption characteristics. Pandya *et al*. [12] carried out an experimental studies on the ballistic performance of symmetric hybrid composites using different layering sequence of the hybrid reinforcement. The result revealed that higher ballistic limiting velocity can be obtained by placing E-glass layer on the exterior and the carbon layer in the interior. Jawaid *et al.* [9] on the other hand studied the dynamic and thermal properties of oil palm empty fruit bunch (EFB)/woven jute fibre (Jw) reinforced epoxy hybrid bio-composites. Their study established that hybridization enhanced the dynamic mechanical and thermal properties of the bio composite. Dagwa *et al.* [13] evaluated the tensile and hardness properties of kaolin-sisal-epoxy composite at different proportion of the reinforcement. Their result showed that the addition of the sisal fibre positively affected the tensile and hardness properties while the increase in kaolin content resulted in a decrease in the tensile and hardness property of the composite. Unfortunately, the effect of sugarcane bagasse fibre hybridization with E-glass on dynamic mechanical parameters of epoxy composite have not yet been explored.

Sugarcane belongs to the grass family and primarily cultivated for its juice from which sugar is processed. The main by-product from sugarcane processing is the bagasse (cane fibre) which is obtained after the cane is crushed and the juice extracted. In northern Nigeria, sugarcane is a delicacy where people of all ages chew and extract the juice and simply throw away the fibre (bagasse) as waste. This waste litters lying everywhere and constitute a nuisance which raises public health concern. The cane fibre have been reported to have some desirable mechanical properties [14]. In this study, experimental investigation of the mechanical behaviour of sugarcane bagasse/glass fibre hybrid reinforced epoxy composite under dynamic loading was carried out.

EXPERIMENTAL

Sample preparation: Non-woven E-glass fibre mat was supplied by a commercial vendor with a density of 2.5g/cm^3. Waste bagasse obtained from dump sites after the juice have been extracted (Plate 1a) was sun-dried for three days and then grounded and sieved to particle size 1 mm (Plate 1b). The chemical composition of sugarcane bagasse is given in Table-1, however, this could vary with climatic and soil conditions. The sieved particulates were measured out and mixed with small quantity of epoxy resin to prepare the bagasse fibre mat using a three piece mould (Plate 1c). The mould was closed after filling with the mix and allowed to set at room temperature for 3 h under a compressive load of 50 kN. After curing the set bagasse mats were removed (Plate d). The hybrid composite was prepared by first mixing the epoxy and the resin in the ratio of 1:1 as follows: after preparing the mould which involved cleaning, placing the aluminium foil and applying wax on its inner surfaces, a light layer of the mixed epoxy resin was first applied and the mate was placed in the mould. A further coat of the epoxy was applied and then another mat was laid. The layering sequence

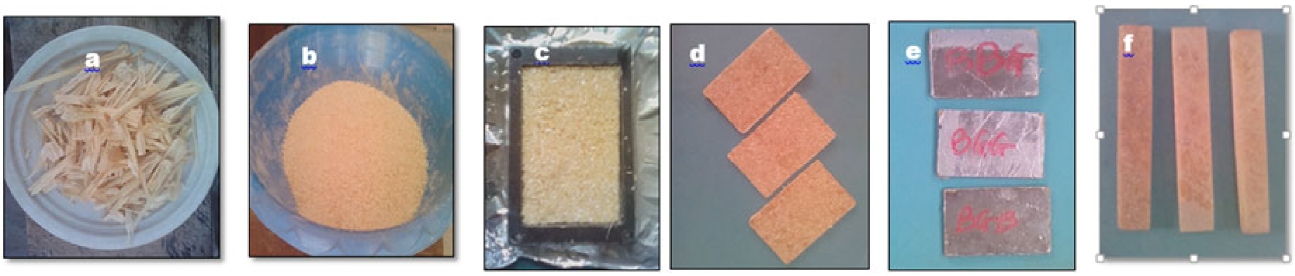

Plate 1: a- Raw Bagasse, b – grounded bagasse, c – Bagasse mat casting,
d – Bagasse mats, e – bagasse/epoxy composite samples, f – DMA test specimens

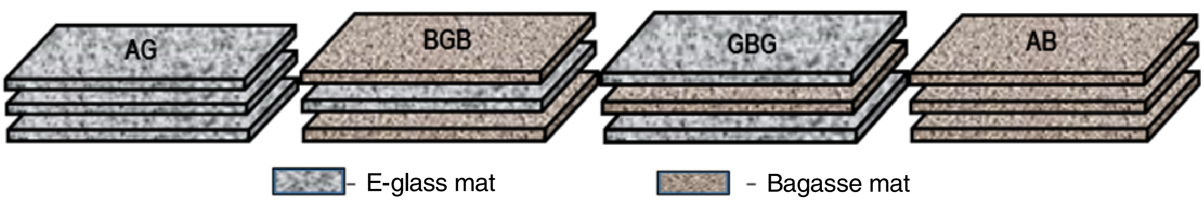

Fig. 1. Layering sequence model

of bagasse and E-glass mats are shown in Fig. 1. All the three mats were used as sample. The mould was then closed and subjected to a compressive load of 50 kN for 3 h at room temperature.

TABLE-1
CONSTITUENTS OF A TYPICAL SUGARCANE BAGASSE [Ref. 14]

S. No.	Constituent	Composition (%)
1	Cellulose	43.8
2	Hemicellulose	28.6
3	Lignin	23.5
4	Ash	1.3
5	Others	2.8

After curing, the samples were ejected (Plate 1e) from which the test specimens (Plate 1f) were cut out. Table-2 gives the designation of the interplay layering sequence used to produce the composite.

TABLE-2
FIBRE-MAT LAYERING SEQUENCE

S. No.	Designation	Fibre mat layering sequence
1	AG	All glass
2	AB	All bagasse
3	BGB	Bagasse-glass-bagasse
4	GBG	Glass-bagasse-glass

Dynamic analysis test: A NETZSCH DMA 242 dynamic mechanical analyzer was used for the evaluation of the storage modulus (E'), loss modulus (E") and the mechanical damping factor (tan δ) of composite samples produced. Three point bending mode used. The heating range was from room temperature 33 ºC to 200 ºC at a frequency of 1 Hz and heating rate of 2 ºK/min. The amplitude was set at 60 µm since all the samples have uniform thickness.

RESULTS AND DISCUSSION

Storage modulus (E'): The storage modulus is a measure of elastic energy stored in a material which can be recovered. It is used to evaluate the elastic behaviour of a materials subjected to sinusoidal loading [15,16]. In fibre reinforced polymer composite the storage and loss modulus behaviour is governed by matrix type, fibre loading, fibre length, fibre dispersion and fibre-matrix adhesion [17]. Fig. 2 showed that the hybridization of glass fibre with bagasse to reinforce epoxy reduced the storage modulus irrespective of the layering sequence of the fibre mats compared to all glass (AG) reinforced composite. Indeed hybridization reduced the glass transition temperature from 65 ºC for all glass reinforced epoxy composite to 50 ºC to the hybridized fibre composite.

Under this condition, the hybrid reinforcement might have enhanced the polymer molecular chain mobility. Also, due to the low frequency level (0.1 Hz), the molecules had enough time to undergo permanent deformation by rearrangement in an attempt to minimize localized stress, thus losing recoverable energy [2,18]. All bagasse (AB) composite displayed the least storage modulus value compared to the rest.

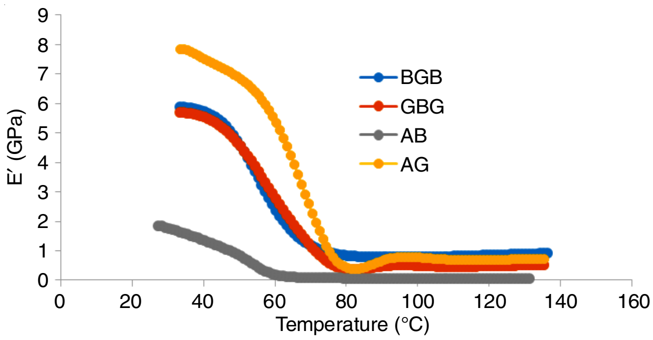

Fig. 2. Variation of storage modulus (E') as a function of temperature for AB, AG, BGB and GBG composites

Loss modulus (E''): The loss modulus is a measure of energy lost due to viscous flow of the polymer molecules in a material subjected to sinusoidal loading [5,15]. Normally, the loss modulus is dependent on the frictional resistance between the fibre reinforcement and the matrix. From Fig. 3, except for all bagasse (AB) composite, all modulus peaks can be observed to increase with temperature within the plastic region until it reaches a maximum and then decreases at higher temperatures in the rubbery region.

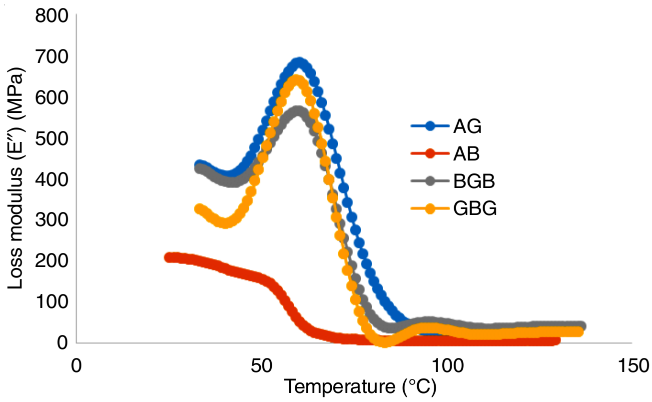

Fig. 3. Variation of loss modulus (E") as a function of temperature for AB, AG, BGB and GBG composites

In the loss modulus curve, the points of maximum peak correspond to maximum mechanical energy dissipation and coincide with glass transition temperature (T_g) of the material. AG composite is observed to present the highest loss modulus peak at a temperature of 62 ºC followed by GBG and BGB at temperatures of 61 ºC and 60 ºC, respectively. All bagasse (AB) composite on the other hand exhibited the least energy dissipation with a T_g at 53 ºC.

Damping factor (tan δ): The ratio of storage modulus (E') to loss modulus (E") of a material defines its index of mechanical damping or the tangent of the phase angle tan δ. It is a dimensionless parameter and a measure of the ability to dissipate energy through molecular movement when subjected to dynamic sinusoidal loading [5,19]. In fibre reinforced polymer composite the material damping behaviour is dependent on the friction between fibre and matrix, molecular movement in the polymer chain, fibre strength and the rate of crack propagation in composite system [5,15]. The height of tan δ is associated with the extent of energy dissipation as a result of polymer molecular chain movement. The variation in the damping factor measured over range of temperature shows that AB composite exhibited the highest damping peak (Fig. 4), this confirms the result in Fig. 2, whereby AB has the least storage modulus (E') value among all the composites.

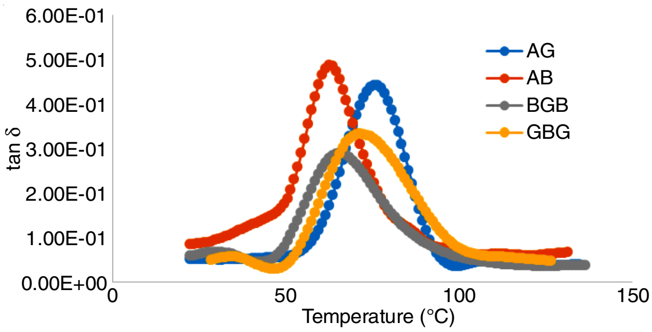

Fig. 4. Variation of damping factor (tan δ) as a function of temperature for AB, AG, BGB and GBG composites

Although AB composite displayed the highest damping performance, its damping peak occurred at 61 ºC compared with AG composite which is at 76 ºC. This suggests that the friction between the glass fibre and the epoxy matrix was more which impeded free movement of the polymer molecular chains [15]. Composites produced from hybrid reinforcement, on the other hand presented lower damping peaks, although the damping peak of GBG composite occurred at a slightly higher temperature, generally hybridization did not improved the damping factor values in all cases.

Conclusions

The effect of fibre hybridization on the dynamic mechanical analysis of bagasse/glass fibre hybrid reinforced epoxy composite compared with all the glass fibre reinforced composite have been investigated. Bagasse fibre mats were prepared from waste sugarcane bagasse and non-woven glass fibre mats were obtained from a commercial vendor to produce the composites using compression moulding technique. Based on the results obtained, the following conclusions can be made:

- Irrespective of fibre hybridization layering mat sequence, the storage and loss modulus was less than all the glass (AG) reinforced epoxy composites.
- Hybridization shifted T_g slightly to a higher temperature compared to all the glass reinforced composites.
- All glass (AG) composite showed the highest storage modulus value of 8 GPa whereas all bagasse reinforced composites exhibited the highest damping factor of 4.74×10^{-1}.

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