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Mechanical and electrical performance of *Roystonea regia*/glass fibre reinforced epoxy hybrid composites

GOVARDHAN GOUD* **and R N RAO**

Department of Mechanical Engineering, National Institute of Technology, Warangal 506 004, India

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Abstract. **The present paper investigates mechanical and electrical properties of *Roystonea regia*/glass fibre reinforced epoxy hybrid composites. Five varieties of hybrid composites have been prepared by varying the glass fibre loading. *Roystonea regia* (royal palm), a natural fibre was collected from the foliage of locally available royal palm tree through the process of water retting and mechanical extraction. *Roystonea regia*, *E*-glass short fibres were used together as reinforcement in epoxy matrix to form hybrid composites. It has been observed that tensile, flexural, impact and hardness properties of hybrid composites considerably increased with increase in glass fibre loading. But electrical conductivity and dielectric constant values decreased with increase in glass fibre content in the hybrid composites at all frequencies. Scanning electron microscopy of fractured hybrid composites has been carried out to study the fibre matrix adhesion.**

Keywords. ***Roystonea regia*** **natural fibre; glass fibre; epoxy; hybrid composites; mechanical properties; electrical properties.**

1. Introduction

Biocomposites are assuming much significance today due to growing environmental consciousness. Advantages of natural fibres over synthetic fibres such as glass and carbon are: low cost, low density, renewability, manufacturing ease and biodegradability. Natural fibres are being considered as potential reinforcement with both thermo plastic and thermoset matrices. Today natural fibre composites are widely used in automotive, furniture, construction fields. Natural fibre reinforced polyester composites are being used in engine and transmission covers of Mercedes-Benz buses. A good combination of mechanical properties and eco friendliness making natural fibre composites more attractive (Canter *et al* 2003). Jute, kenaf, flax, ramie and hemp are widely accepted for their good mechanical properties (Cicala *et al* 2009). Despite having several merits, natural fibre composites show lower modulus, lower strength and poor moisture resistance when compared with the composites reinforced with synthetic fibres such as glass and carbon. To overcome these limitations and to obtain great diversity of material properties, hybrid composites have been conceived wherein two or more fibres are reinforced in a single matrix (Li *et al* 2000). In hybrid composites higher performance of synthetic fibre and environmental advantages of natural fibres are combined. Glass fibres are widely used these days with polymer matrices due to their higher strength, light weight, dimensional stability, resistance to corrosion, electricity etc. Several investigators developed hybrid composites by reinforcing natural fibres with glass and reported improved properties. Hybrid effect of glass and OPEFB fibre was calculated by Srikala *et al* (2002) and the study revealed overall improvement in the performance after hybridization. Raghavendra Rao *et al* (2010) found superior flexural and compressive properties with bamboo/glass fibre reinforced hybrid composites. Tensile properties of ridge gourd reinforced phenolic composites increased after hybridizing with glass fibres (Varada Rajulu and Rama Devi 2007). Though considerable literature is available on electrical properties of natural fibre composites, literature available on electrical properties, particularly dielectric properties of hybrid composites is very limited. Paul *et al* (1997) investigated the electrical properties of low-density polyethylene composites reinforced with short sisal fibres and a comparative study on dielectric properties of flax, hemp and oil palm fibres was conducted by Shinoj *et al* (2010). Dynamic mechanical and dielectric behaviour of banana–glass hybrid fibre reinforced polyester composites was studied by Pothan *et al* (2010). Volume resistivity and loss factor of banana/glass fibre-reinforced phenol formaldehyde hybrid composites were investigated by Joseph and Thomas (2008). In the present study, mechanical and electrical properties of *Roystonea regia*/glass fibre reinforced epoxy composites were studied.

2. Materials and methods

2.1 *Specimen fabrication*

Roystonea regia fibre was extracted from locally available *Roystonea regia* tree. Glass fibre supplied by the local

*Author for correspondence (pgovardhan0@yahoo.com)

supplier was used along with the *Roystonea regia* fibre as the reinforcement in the hybrid composite. Matrix material used was epoxy resin (Lapox-12) and hardener k-6 supplied by Atul Limited, Gujarat, India.

To obtain *Roystonea regia* fibre, leaves and leaf stem from the foliage sheath of *Roystonea regia* tree are separated and the sheath is dried for three days in shade. In the next step it was immersed in water retting tank for three weeks followed by hand rubbing and rinsing in water till the unwanted greasy material was dissolved and fine fibre was extracted. Finally the extracted fibre was once again washed thoroughly in plenty of clean water to remove the surplus waste. The obtained fibre was dried under sun for one week. The average diameter of the *Roystonea regia* fibre used for the composite preparation was between 0·2 and 0·3 mm. Short *Roystonea* fibres of 5–8 mm length were obtained from the continuous fibres. Similarly glass fibres of size 5–8 mm length were obtained by cutting from the continuous fibre roving using electronic fibre cutting machine. Both *Roystonea regia* and glass fibres were dried in an oven at 80 °C for 24 h to remove surface moisture. Both types of short fibres were intimately mixed. The mould box was prepared with the dimensions of 200 (L) × 150 (W) × 3·0 (T) mm. Matrix was prepared by mixing the hardener to epoxy. The epoxy and hardener ratio was maintained at 10:1. Mould box was loaded with appropriate quantities of matrix and fibres in random orientation and finally the compression pressure of 170 KN was applied evenly to achieve a uniform thickness of 3 mm and cured for 24 h at room temperature. Five different types of samples are prepared. The sample designation and the content details are listed in table 1. The resultant material was randomly oriented *Roystonea regia*/glass fibre reinforced epoxy hybrid composite plate with dimensions 200 × 150 × 3 mm^3.

2.2 *Tensile testing*

Tensile testing was done with the help of INSTRON-3369 model Universal Testing Machine. The test was conducted as per ASTM D 3039–76 standards at a cross head speed of 10 mm/min. The temperature was conditioned at 22 °C with a humidity of 50 %. The specimen dimensions were 150 × 15 × 3 mm^3. In each case, five samples were tested and the average values were reported.

2.3 *Flexural testing*

Flexural testing was done as per ASTM D 5943–96 standards using three-point bending method at a crosshead speed of 5 mm/min and temperature of 22 °C with a humidity of 50 %. The specimen dimensions were 100 × 15 × 3 mm^3. The average of five samples was reported.

2.4 *Impact testing*

The impact testing was done as per ASTM D 256-88 by Izod impact machine with unnotched specimen. The specimen dimensions were 122 × 13 × 3 mm^3. In each case, five samples were tested and the average values were reported.

2.5 *Testing of electric properties*

To determine electric properties of the hybrid composites, specimens of 25 × 25 × 3 mm dimensions were prepared and tested with HIOKI 3531Z-impedence meter as per capacitance method at 0.5, 1, 2, 3, 4 and 5 MHZ frequencies.

3. Results and discussion

3.1 *Tensile tests*

Table 3 shows variation of tensile strength, tensile modulus and % elongation at break with glass fibre loading in hybrid composites. The total fibre loading (*Roystonea regia* and glass) of the composite was maintained at 20 wt%. All the tensile properties i.e. tensile strength, tensile modulus and % elongation at break, linearly increased with glass fibre loading in hybrid composites. This is due to the fact that the strength and modulus of glass fibre is much higher than the strength and modulus of natural fibre. In a hybrid composite, properties of the composite depend on the modulus and % elongation at break of the individual reinforcing fibres. Table 2 shows various physical and mechanical properties of *Roystonea regia* and glass fibres. Increased dispersion of fibres with increased glass fibre loading could be another reason for enhanced tensile properties. Scanning electron micrographs of tensile fractured 25 G and 75 G designated hybrid composites are shown in figures 1(a) and (b).

Table 1. Composition and designation of composites.

Designation	Epoxy (%wt.)	*Roystonea regia* (%wt.)	Glass (%wt.)
0G	80	20	0
25G	80	15	05
50G	80	10	10
75G	80	05	15
100G	80	0	20

Table 2. Physical and mechanical properties of *Roystonea regia* and glass fibres.

Properties	*Roystonea regia*	Glass
Density (g/cm^3)	0·825	2·14
Diameter (μm)	200–300	5–25
Tensile strength (MPa)	263	2500
Youngs modulus (GPa)	21	55
% Elongation	4·012	4·5

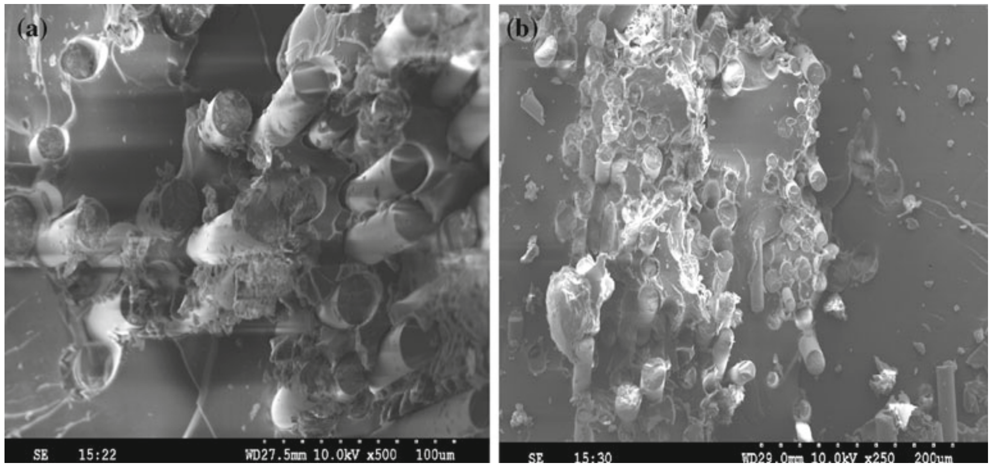

Figure 1. Scanning electron micrographs of tensile fractured surface of (**a**) 25G hybrid composite and (**b**) 75G hybrid composite.

Table 3. Variation of mechanical properties with weight percent *Roystonea*/glass fibre reinforced epoxy hybrid composites.

Hybrid designation	Tensile strength (MPa)	Tensile modulus (MPa)	% Elongation at break	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength (J/m)	Hardness (Shore *D*)
0G	28·86	2386·48	1·20	39·84	3845·81	124·23	72
25G	31·98	2416·42	1·28	40·12	3982·42	151·26	73
50G	33·43	2522·28	1·69	46·44	3996·25	158·43	75
75G	34·42	2644·32	2·11	48·66	4011·22	168·46	82
100G	36·42	2888·43	2·42	52·12	4126·18	169·33	83

3.2 *Flexural properties*

From table 3 it is evident that flexural strength and flexural modulus of hybrid composites increased with increase in glass fibre weight percentage. In flexural testing various mechanisms such as tension, compression, shearing take place simultaneously. With the addition of glass fibre shear resistance of the hybrid composite will increase (Mishra *et al* 2003) which will minimize shear failure. This will enhance the flexural properties.

3.3 *Impact strength*

The effect of glass fibre loading on impact strength of *Roystonea regia*/glass hybrid epoxy composites can be understood from table 3. The impact strength of 0 G composite i.e. composites only with *Roystonea regia* reinforcement (without glass fibre) is 124·23 J/m but 75 G composite i.e. hybrid composite with 15 %(wt.) glass fibre has shown impact strength of 168·46 J/m. The impact strength increased by 26 %. Fibres play a vital role in impact strength of the composites as they act as stress transferring medium and interacts with crack formation. With increase in glass fibre content, inter fibre interaction will increase the effective stress transfer between fibre and reinforcement. This contributes to increase in impact strength. The scanning electron microscopy of 25 G and 75 G composites are shown in figures 2(a) and (b).

3.4 *Hardness (Shore D)*

From table 3 it is clear that shore *D* values increased with increase in glass fibre content. This is due to the fact that hardness is density dependent and will increase with increase in density. The density of glass fibre is much higher than the density of *Roystonea regia* fibre. Hence increase in glass fibre loading would increase the hardness of the hybrid composite.

3.5 *Electrical properties*

Electrical conductivities of different hybrid composites at different frequencies are shown in figure 3. From the figure, conductivity increased with increase in frequency. This is mainly due to the additional contribution of finite-size clusters formed at higher frequencies. At excited frequencies, finite-size clusters (nano scale particles) bridge the gap

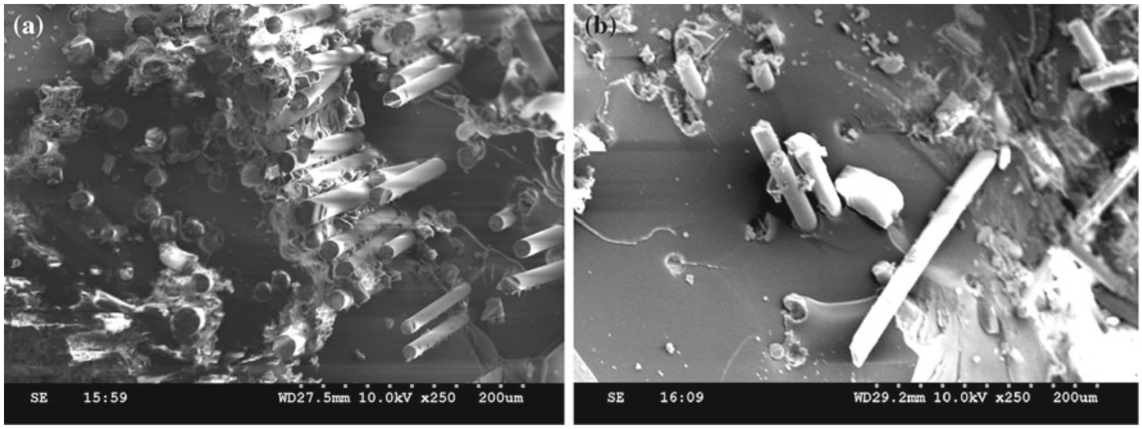

Figure 2. Scanning electron micrograph of impact fractured surface of (**a**) 25G hybrid composite and (**b**) 75G hybrid composite.

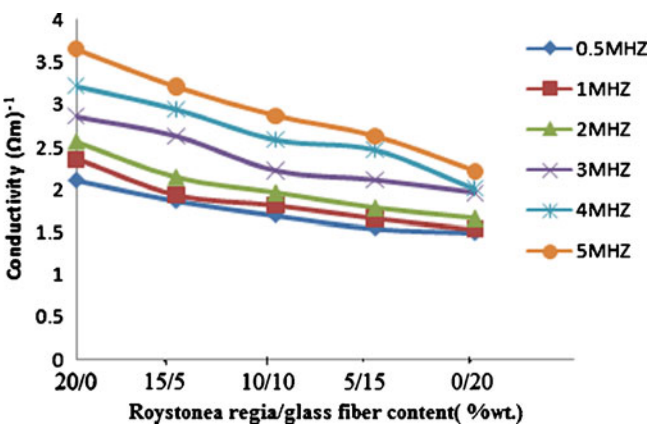

Figure 3. Variation of conductivity of hybrid composites at different frequencies as a function of *Roystonea regia*/glass fibre loading at total fibre content of 20 %.

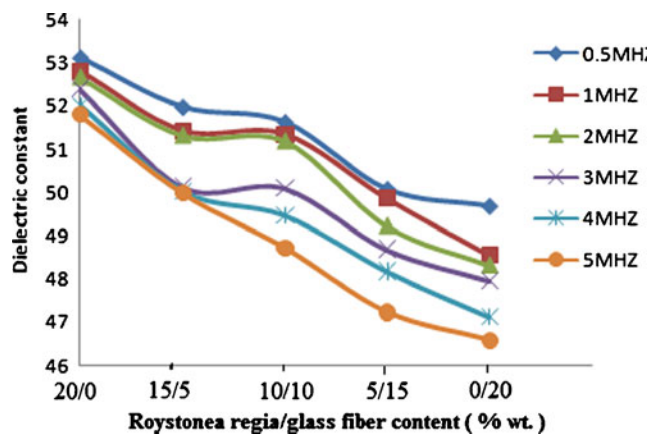

Figure 4. Variaton of dieletric constant of hybrid composites at different frequencies as a function of *Roystonea regia*/glass fibre loading at total fibre content of 20 %.

between atoms/molecules and condensed matter. This will result in the increased conductivity. Also from the figure it can be observed that electrical conductivity decreased with increase in glass fibre content in the hybrid composites. This is because the properties of hybrid composites mostly depend on the properties of its constituents. The electrical conductivity of glass fibre is lower than the conductivity of the *Roystonea regia* fibre. Because of the hydrophilic nature, natural fibres are more conductive.

Figure 4 shows dielectric constant decreasing with increase in frequency and glass fibre loading in hybrid composite. At higher frequencies the time available for orientation will be very little; hence proper orientation of the molecules is not possible. Reduced orientation of polarization is the main cause for the decrease in dielectric constant with increase in frequency. Dielectric constant is polarization dependent. Decrease in dielectric constant with increase in glass fibre loading is mainly due to the reduced presence of the polar groups. The *Roystonea regia* fibre is lingo cellulosic and hydrophilic in nature and consists of more polar groups. But glass fibre is hydrophobic and with the increase in glass fibre loading, there would be a corresponding decrease in natural fibre loading as the total weight of the reinforcement in hybrid composite is constant. With the decrease in natural fibre, presence of polar groups (polar water molecules) is reduced in the hybrid composite which results in lower dielectric constant values.

4. Conclusions

Replacing the *Roystonea regia* with glass fibre through hybridization leads to a considerable increase in tensile, flexural, impact and hardness properties. However, with the increase in glass fibre loading, electrical conductivity and dielectric constant values decreased at all frequencies. Hence it could be concluded that *Roystonea* and glass can be combined to produce hybrid composites to take full advantage of attractive mechanical properties along with low cost and eco-friendliness and these hybrid composites can be successfully employed in automotive and structural applications.

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