Mechanical and electrical properties of Jute-Biomass-Styrenated Methacrylate Epoxy Resin sandwich composites

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Sandwich composites of jute-biomass (banana, sugarcane, coir, wheat husk and groundnut)–styrenated methacrylate epoxy resin of 1,1'-bis(4-hydroxyphenyl)cyclohexane have been fabricated by compression molding technique at 110°C and 2 Bar pressure for 5 h. J-EBCMASt, J-B-EBCMASt, J-SC-EBCMASt, J-CO-EBCMASt, J-W-EBCMASt and J-GN-EBCMASt showed respectively tensile strength of 34.5, 17.1, 11.4, 11.9, 20.7 and 13.1 MPa, and flexural strength of 32.3, 21.6, 28.3, 11.2, 52.1 and 22.1 MPa, electric strength of 1.6, 1.2, 1.5, 1.3, 1.3 and 1.4 kV/mm and volume resistivity of 5.9 x 10^12, 2.5 x 10^12, 4.7 x 10^12, 5.3 x 10^12, 3.2 x 10^12 and 2.3 x 10^12 ohm cm. Considerably lower mechanical and electrical properties of sandwich composites are due to different nature of biomass and random orientation. The composites may be useful for low load bearing housing and electrical applications.

Keywords: Styrenated vinyl ester, Biofibers, Sandwich composites, Mechanical and electrical properties.

Introduction
Recent research and development in natural fiber reinforced composites as potential structural material has attracted the attention of material scientists all over the world because of their low cost, easy availability, light weight, renewable and biodegradable in nature, low density and high specific strength make them the most suitable candidates for low load bearing applications. Various items have been made from jute fiber based composites. Natural fiber reinforced composites offer many advantages over the traditional construction materials namely steel and aluminum in respect of low density, low thermal conductivity, excellent corrosion and chemical resistance, high strength to weight ratio, better design flexibility, excellent fatigue and impact properties, improved acoustical performance and low maintenance. Hybrid composites are materials made by combining two or more different types of fibers in a common matrix. They offer a range of properties that cannot be obtained with a single kind of reinforcement. By careful selection of reinforcing fibers, the material cost can be reduced substantially. The mechanical performance of composites is mainly dependent upon the properties of the matrix, reinforcement and the interactions between matrix and reinforcing agent. Natural fibers have already been recognized for their role in composites and can be advantageously utilized for the development of environment friendly composite materials with good physical properties. Low cost hybrid composites are produced by the use of biomass or agro waste in combination with jute. Banana fiber, sugarcane husk, coir fiber, wheat husk and groundnut shell, rice husk, etc. are by products from the crops. Considerable work has been carried out on utilization of biomass for particle board, medium density board, pulp and composites. The incentives of utilizing agro waste in the fabrication of composites are their low density, less abrasiveness to equipment, low cost, etc. The main drawback of natural fibers in producing good composites is their compatibility with fillers and resins. Studies on the characteristics of natural fiber–polymer composites containing nano fillers appear to be limited. To the best of our knowledge no work has been reported on jute-biomass-vinyl ester resin sandwich composites of methacrylate epoxy resin of 1,1’-bis(4-hydroxy phenyl)cyclohexane, which encouraged us to investigate present work. In this paper we have reported synthesis of methacrylate epoxy resin of 1,1’-bis(4-hydroxy phenyl)cyclohexane (EBCMA) and utilized it for the fabrication of jute-biomass sandwich composites and evaluated their mechanical and electrical properties.

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Materials and techniques

Solvents and chemicals used were of laboratory grade and purified prior to their use. Woven jute fabric (Brown jute, Corchorus capsularis) used in the present study was collected from local market (Rajkot). The agro wastes such as banana fiber, sugarcane husk, coir fiber, wheat husk and groundnut shells were obtained from the local farms/market. Epoxy resin of 1,1’-bis(4-hydroxyphenyl)cyclohexane (EBC) (EEW= 809) was synthesized and purified according to our previous publication. Styrene (Sisco Chem, Mumbai), triethylamine (Spectrochem, Mumbai), hydroquinone (Sisco Chem, Mumbai), methyl ethyl ketone peroxide (MEKP) and 6% cobalt naphthenate (free samples from EPP Composites, Rajkot) were used as received.

Synthesis of vinyl ester

Into a 2L round-bottomed flask containing 400 g EBC, 500 mL 1,4-dioxane, 160 mL methacrylic acid, 5 g hydroquinone and 20 mL triethylamine was placed in an oil bath. The reaction mass was refluxed for 2.5 h for desired acid value (< 2) and cooled to room temperature. Semisolid epoxy methacrylate was isolated from cold water, filtered, washed well with sodium bicarbonate solution and distilled water till unreacted acid was removed completely and dried at 50°C in an oven. The resin is soluble in chloroform, acetone, 1,4-dioxane, dimethylformamide, dimethylacetamide, etc. The resin was purified three times dissolving in 1,4dioxane and precipitating in large excess of water. Hereafter resin is designated as EBCMA and was styrenated by dissolving 500 g EBCMA and 220 mL (40 % w/w) styrene in chloroform. Hereafter styrenated EBCMA is designated as EBCMASt.

Fabrication of composites

Hand layup compression molding was followed for the preparation of jut-biomass sandwich composites. Jute to biomass ratio was kept 1:2 w/w and 100 % matrix material of reinforcing fibers. Required quantity (Table 1) of EBCMASt was transferred into a 500 mL beaker and 1% (total mass of matrix material) each of methyl ethyl ketone peroxide (initiator) and cobalt naphthenate (promoter) were mixed well. The resultant solution was applied to two 21cm X 21cm jute fabric by a smooth brush and remaining resin solution was mixed with biomass at room temperature. Resin impregnated jute sheets and biomass filler were allowed to dry at room temperature for about 15 min. Resin coated filler was uniformly sandwiched between two resin coated jute sheets and placed between two preheated stainless steel plates and pressed under hydraulic pressure. Silicone spray was used as a mold releasing agent. The temperature was increased slowly to 110°C with decreasing pressure to 2 Bar and kept for 5h, cooled to room temperature, the resultant composite sheet was peeled and edges were machined as per the requirement of the test methods. Hereafter jute-biomass composites are designated as J-B-EBCMASt, J-SC-EBCMASt, J-CO-EBCMASt, J-WH-EBCMASt and J-GN-EBCMASt.

Measurements

The tensile strength (ISO/R 527-1996 Type-I), flexural strength (ASTM-D-790-2003), electric strength (IEC-60243-Pt-1-1998) and volume resistivity (ASTM-D-257-2007) measurements were made on a Shimadzu autograph universal tensile testing machine, Model No. AG-X series at a speed of 10mm/min, a high voltage tester (Automatic Electric-Mumbai) in air at 27°C by using 25/75mm brass electrodes and a Hewlett Packard high resistance meter in air at 25°C.
after charging for 60 sec at 500 V DC applied voltage, respectively. Replicate measurements (3-5) were carried out on each sample and average values were considered.

**Results and Discussion**

The mechanical performance and durability of composite materials are mainly governed by three factors, namely reinforcement, the matrix, and interfacial bond strength. Strength, stiffness, and stability of fibers and matrix are very important for long term service of composites. Natural fibers are hygroscopic and possess low wettability with hydrophobic matrix material and therefore it is necessary to concentrate on fiber modification, compatibility of resin and coupling agents. Tensile properties of materials are most widely useful for engineering design and understanding quality characteristics of polymeric materials. The tensile strength ($\sigma$) of the composites was determined according to eq. 1:

$$\sigma = \frac{W}{A}$$  \hspace{1cm} (1)

Where $W$ = the load value at break and $A$ = original cross-sectional area of the sample.

Flexural properties are useful for quality control and classification of materials with respect to bending strength and stiffness. Flexural strength of the composites was determined according to eq. 2:

$$\text{Flexural strength} = \left(\frac{1.5FL}{wt^2}\right)$$  \hspace{1cm} (2)

Where $F$ = breaking load, $L$ = span length (50 mm), $w$ = sample width (mm), and $t$ = sample thickness (mm).

Tensile and flexural strengths of J-EBCMAS, J-B-EBCMAS, J-SC-EBCMAS, J-CO-EBCMAS, J-WH-EBCMAS and J-GN-EBCMAS are presented in Fig.1. The % change in above mentioned properties with respect to J-EBCMAS is reported in Table 2. From Fig. 1, it is clear that as compared to J-EBCMAS, sandwich composites showed considerably low tensile strength (11-21 MPa) and flexural strength (11-28 MPa) except J-WH-EBCMAS (52.1 MPa). Tensile properties of the composites depend upon various factors such as nature of the reinforcement, and matrix, fiber strength, modulus, fiber length, fillers, compatibilizers and impact modifiers, fiber content, degree of crosslinking, orientation, the presence of soft and hard segments, fiber loading, interfacial adhesion, etc.23-28 Good interfacial bond strength is necessary for effective stress transfer from matrix to fiber in the composite. Lignocellulose fibers have better resistance to weathering and moisture uptake. Flexural property depends upon various factors such as type and amount of additives, which can soften or reinforce the material, method of sample preparation e.g., molding or machining, temperature, surface roughness, sinks, voids, and other imperfections, anisotropy, and accuracy in measured dimensions. In sandwich composites biomass fibers are not lined up in any direction but they are just tangled mass. The composites can be made stronger by lining up all the fibers in the same direction. Oriented fibers are strong, when pulled in fiber direction but they are weak at right angles to the fiber direction. The woven fibers give a composite good strength in many directions. Under tension, the strength of the composite is entirely due to reinforcement. Volume resistivity and electric strength data are very useful for comparing relative insulation quality of material selection, to evaluate the effects of material composition and environment and for material selection. They are useful to material scientists to design specific properties in combination.
Electric strength and volume resistivity of composites were determined according to eqs. (3) and (4), respectively:

Electric strength = \( \frac{V}{t} \) … (3)

Where \( V \) = puncture voltage (volts) and \( t \) = sample thickness (mm)

Volume resistivity = \( \frac{(R_v A)}{t} \) … (4)

Where \( R_v \) = volume resistance (ohms), \( A \) = area of electrodes, and \( t \) = sample thickness (cm). Electric strength and volume resistivity of above mentioned composites are presented in Figs. 2 and 3, respectively. From Figs. 2 and 3, it is clear that both electric strength (1.2 - 1.5 kVmm\(^{-1}\)) and volume resistivity (2.3x10\(^{12}\) – 5.3x10\(^{12}\) ohm cm) of the sandwich composites are considerably lower than that of J-EBCMASt. The % change in these properties with respect to J-EBCMASt is reported in Table 2. Electrical properties of the polymeric composites are affected by several factors namely humidity, impurities, degree of resin cure, temperature, nature of polymers, nature of fillers and additives, geometry, electrode area, and electrode material, sample thickness, time of voltage application, current frequency, and extent of aging. The decrease of 40-67% tensile strength, 12-65% flexural strength, 6-19% electric strength and 10-92 % volume resistivity are mainly due to different nature and random orientation of biomass resulting into discontinuous stress transfer and also interfacial adhesion between matrix and reinforcing materials besides other above mentioned factors. In present investigation sandwich composites resulted into lowering in mechanical and electrical properties and may be useful for low load bearing housing and electrical applications.

Conclusions
Vinyl ester is highly soluble in common solvents. Composites are prepared by compression molding technique. In compliance to J-EBCMASt all the sandwich composites showed lower mechanical and electrical properties due to random orientation of the biomass and relatively poor interfacial adhesion as well as different nature of the biomass and the resin. The sandwich composites are only sustainable to low load bearing housing application and also for electrical appliances.

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References