Fabrication and Evaluation of some Mechanical and Electrical Properties of Jute-Biomass Based Hybrid Composites

N. M. Mehta, P. H. Parsania

Polymer Chemistry Division, Department of Chemistry, Saurashtra University, Rajkot-360 005, India

Received 31 March 2005; accepted 22 August 2005
DOI 10.1002/app.23014
Published online 23 January 2006 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: Hybrid composites based on bisphenol-C-formaldehyde resin and jute mat with rice, wheat, sugar cane, and jamun husks have been fabricated at 150°C under 30.4 MPa pressure for 2 h. The resin content in composites was 50% of fibers. Tensile strength, flexural strength, electric strength, and volume resistivity of hybrid composites have been evaluated and compared with those of jute-bisphenol-C-formaldehyde composites. It is observed that the tensile strength of composites is found to decrease by 53–72%, which is mainly due to random orientation of sandwiched fibers. Flexural strength has increased by 53–153% except jute–rice husk composite for which it is decreased by 26%. A little change in dielectric breakdown strength (1.89–2.11 kV/mm) is found but volume resistivity of Jute–wheat husk and Jute–jamun husk composites has improved by 437–197% and it is slightly decreased(2.3–25.2%) for the remaining two composites. Thus, hybrid composites possess good mechanical and electrical properties signifying their importance in low strength and light weight engineering applications as well as low cost housing units such as partition and hard boards. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 100: 1754–1758, 2006

Key words: hybrid composites; biomass; jute fibers; mechanical and electrical properties

INTRODUCTION

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 costs can be substantially reduced.

Among all reinforcing fibers, natural fibers[1–5] have gained their importance especially for low load bearing applications. Natural fiber reinforced polymer composites are superior over synthetic fiber reinforced composites in certain properties like enhanced biodegradability, combustibility, lightweight, ease of recyclability, etc. These advantages place the natural fibers composites among high performance composites having economical and environmental advantages, with good physical properties.[6,7]

Natural fiber-based composites are emerging as realistic alternatives to glass-reinforced composites in many applications especially as low cost, light weight and apparently environmentally superior alternatives to glass fibers in composites. There is an increased awareness world wide for the need to improve fire standards in areas of public risk such as transport. Fiber reinforced composites based on thermosetting polymeric resins offer many benefits over traditional materials but have typically suffered from poor fire performance.

Recently, research is being carried out world wide in producing low cost composites by using biomass or agricultural wastes in combination with jute fibers. Rice husk, wheat husk, cane sugar husk, etc. are biomass and are byproducts of the respective crop yields. Many investigators have utilized biomass for particle board,[8] medium density fiber board,[9] pulp,[10] and composites.[11–14]

Phenol–formaldehyde is one of the first synthetic resins used commercially in fabricating jute composites mainly because of its high heat resistance, low smoke emissions, excellent fire retardance properties, and compatibility with jute fibers; therefore, phenol–formaldehyde based jute composites are used as wood and ceramic substitutes. Today, when costs and performance are of prime importance for economics, phenolic resins are accepted in many high performance applications of composites.

Phenolic resins are well known for their excellent resistance to heat and combustion. However, as matrices for fiber reinforced composites, they suffer from inherent weakness and a need for extreme processing conditions. Fiber reinforced polymeric composites of-

Correspondence to: P. H. Parsania (phparsania@sancharnet.in).

fer many potential advantages over traditional materials such as steel and aluminum. Some benefits are low density, low thermal conductivity, excellent corrosion and chemical resistance, high strength to weight ratio, better design flexibility, cost effective production of complex 3D structures, excellent fatigue and impact properties, improved acoustic performance, radar/sonar transparency, low maintenance, etc.

The literature survey on hybrid composites based on bisphenol formaldehyde resins indicated that no work has been reported on bisphenol-C-formaldehyde based hybrid composites of jute and biomass husks. With a view to fabricate and investigate mechanical and electrical properties of hybrid composites, the present work deals with the fabrication and evaluation of some mechanical and electrical properties of jute-biomass based hybrid composites.

EXPERIMENTAL

Materials

Solvents and chemicals used were of laboratory grade and purified by appropriate methods prior to their use.[15] 1,1′-Bis(4-hydroxy phenyl) cyclohexane (Bisphenols-C),[16] and bisphenol-C-formaldehyde (BCF) resin[17] were synthesized and recrystallized/purified according to our recent publications. Woven jute fibers (Brown jute, *Corchorus capsularis*) used in the present study was collected from the Indian Jute Industries Research Association (IJIRA, Kolkata). The agro wastes such as rice husk (RH), wheat husk (WH), cane sugar husk (CH), and jamun flower husk (JH) were collected either from local markets or fields. Cane sugar fibers after extracting the juice was soaked in hot water for 1 h and then washed well with hot water till clear and transparent washing was obtained. All the agro waste fibers were dried either in open sunlight or in an oven at 50–60°C. Ordinary sieves were used to separate fibers of different sizes (2–3 mm RH, 6–8 mm WH/CH, and 1–2 mm JH).

Fabrication of BCF–jute composite

BCF (19.8 g) and 60% of jute fabric (15 × 15 cm^2, 32.8 g) was dissolved in 100 mL acetone and applied to the woven matrices with the help of a smooth brush. The prepregs were allowed to dry in sunlight. Eight such prepregs were stacked one over the other and subjected to a hydraulic pressure of 30.4 MPa at 150°C for 2 h and at room temperature for 12 h. Silicon spray was used as a mold releasing agent. The composite was hereafter designated as BCF–jute composite.

Fabrication of hybrid composites

A matrix material (BCF) used in the fabrication of hybrid composites was 50% of jute mats (15 × 15 cm^2, 5.5 g) and biomass (RH, WH, CH, and JH). Thus, 20.5 g (for WH)/25.5 g (for RH, CH, and JH composites) BCF was dissolved in 100 mL acetone and applied to the jute mats with the help of a smooth brush and the remaining solution was mixed with 30 g (WH)/40 g (RH, CH, and JH) biomass. The solvent was allowed to evaporate at room temperature for about 15 min. Resin coated biomass was sandwiched uniformly between two resin coated jute mats and was placed between two stainless steel plates and subjected to a hydraulic pressure of 30.4 MPa at 150°C for 2 h. Silicon spray was used as a mold releasing agent. The hybrid composites were hereafter designated as BCF–jute–RH, BCF–jute–WH, BCF–jute–CH, and BCF–jute–JH.

Measurements

The tensile strength (IS: 11,298-Pt-2–87) and flexural strength (ASTM D 790–92), electric strength(IEC-243-Pt-1–88), and volume resistivity (ASTM D 257–92) measurements were made on a Universal tensile testing machine (model No. 1185) at a speed of 50 mm/min, a high voltage tester (Automatic Electric, Mumbai) in air at 27°C by using 25/75-mm brass electrodes, and a Hewlett–Packard high resistance meter at 500 V DC after charging for 60 s, respectively.

RESULTS AND DISCUSSION

A composite is susceptible to failure due to three entities, namely reinforcement, the matrix, and the interface. The failure of one initiates the failure of the others. To increase the potential application area of natural fiber composites, it is essential to concentrate on fiber modification, compatibility of resin, and coupling agents.

The mechanical properties of natural fiber composites depend upon a number of parameters, namely fiber strength, modulus, fiber length and orientation, fiber matrix interfacial bond strength, fillers, compatibilizers and impact modifier, and fiber content.[18,19] Fiber-matrix interface plays an important role in the composite properties. A good interfacial bond is required for effective stress transfer from the matrix to the fiber, whereby maximum utilization of the fiber strength in the composite is achieved.

Among thermoset composites, phenolic composites possess versatile strength and modulus over other resins like epoxy and unsaturated polyester resins because fiber–matrix interfacial bond strength increases in the order PF > epoxy > polyester. Lignin rich fiber composites show better resistance to weathering as compared to cellulose fiber composites. Lignin has lower affinity towards moisture and acts as a protective barrier for cellulose microfibrils from moisture absorption.

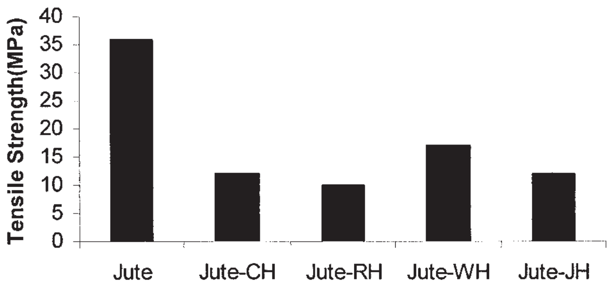


Figure 1 Comparative tensile strength of jute, jute–CH, jute–RH, jute–WH, and jute–JH composites.

Tensile properties

Tensile properties of materials are most widely used for defining the quality characteristics of polymeric materials. They are very useful for the purpose of engineering design and understanding the characteristics of the materials. For tensile testing, the samples can be prepared by different ways, namely molding, compression molding, and punching. In the present case, the samples are prepared by the punching technique according to IS: 11,298-Pt-2–87. The load value (W) at any point on the load extension curve, the tensile strength (σ) can be determined by dividing it by the predetermined original crosssectional area (A):

$$\sigma = W/A \tag{1}$$

A comparative tensile strength (T_S) of hybrid composites along with BCF–jute composite[20] is presented in Figure 1. The performance of composites depends on the selection of the constituent materials especially, matrix materials and fiber loading. It is expected that increasing fiber loading increases strength, which means effective stress transfer between reinforcement and the matrix. Jute fibers are mainly made up of cellulose, polyols, and lignin. Jute fibers are hygroscopic and possess low wettability with hydrophobic resins and weak interfacial bond strength mainly due to hydroxyl groups of cellulose and lignin.[21] Biomass mainly consists of cellulose and lignin but to a lesser extent as compared with jute. Jute is richer in lignin as compared with biomass and hence has lower affinity towards moisture. The tensile strength of the hybrid composites: BCF–jute–WH (17 MPa), BCF–jute–CH (12 MPa), BCF–jute–JH (12 MPa), and BCF–jute–RH (10 MPa) has decreased by 53–72% as compared to BCF–jute (36 MPa) composite.[20] The decrease in tensile strength is mainly due to random orientation of sandwiched fibers indicating discontinuous stress transfer upon hybridization. BCF–jute–WH composite has almost twice the tensile strength as compared with BCF–jute–CH, BCF–jute–JH, and BCF–jute–RH hybrid composites. Out of the four biomass fibers selected, WH is to be found more effective in stress transfer as compared with the remaining three husks. Thus, orientation of fiber, nature of fiber, and nature of supporting mat for sandwiching biomass husk are very important in determining tensile properties of fabricated hybrid composites.

Flexural strength

Flexural strength is the resistance of material under the bending mode. In a pure bending mode, a rectangular beam made of homogeneous material undergoes maximum tensile stress on one surface through the thickness to maximum compressive stress on the other. If the tensile and compressive moduli are equal, the stress becomes zero at the midpoint of the thickness where tension reaches zero before compression starts building up at the midpoint.

Flexural properties are useful in quality control and classification of the material with respect to bending strength and stiffness. These properties depend upon various factors such as the type and amount of the additives which can soften or reinforce the material. For the same material, results will be different if the sample is prepared by molding or machining. Increase in temperature decreases strength and modulus. Surface roughness, sinks, voids, and any other kinds of imperfection, anisotropy, accurate measurements of dimensions, etc. also affect flexural properties. In the present case flexural strength of the composites was determined according to ASTM D 790–92:

$$\text{Flexural strength, MPa} = 1.5\, FL/wt^2 \tag{2}$$

where F is the breaking load, L is the span length (50 mm), w is the width and t is the thickness of the specimen in mm.

Comparative flexural strength of BCF–jute (19 MPa) and hybrid composites: BCF–jute–CH (48 MPa), BCF–jute–JH (41 MPa), BCF–jute–WH (29 MPa), and BCF–jute–RH (14 MPa) is shown in Figure 2. From Figure 2 it is clear that the flexural strength of BCF–jute–WH (52.6%), BCF–jute–JH (94.5%), and BCF–jute–

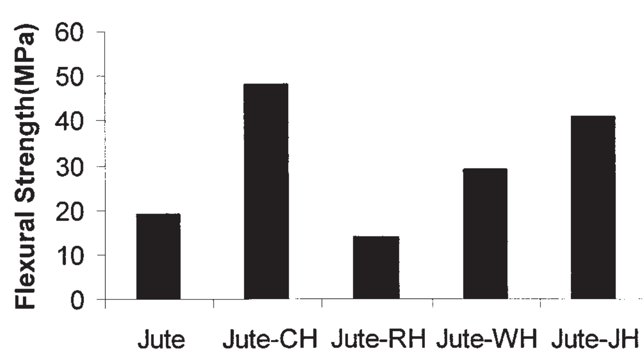
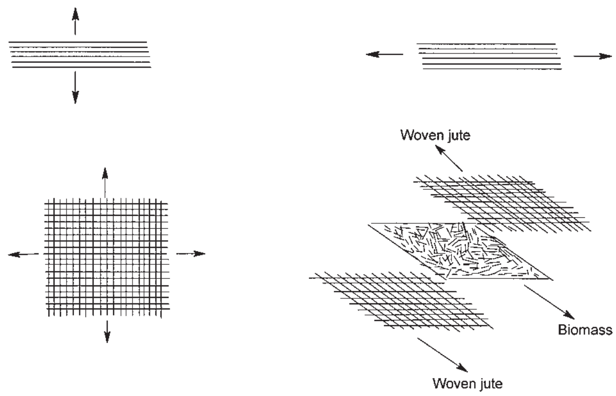


Figure 2 Comparative flexural strength of jute, jute–CH, jute–RH, jute–WH, and jute–JH composites.



Scheme 1

CH(152.6%) has increased to a greater extent upon hybridization, while for BCF–jute–RH (26.3%) it has decreased. Flexural strength depends on matrix material, and under tension the strength of the composite is almost entirely provided by the reinforcement. The increase in the flexural strength indicates increase in resistance to shearing. The flexural property of hybrid fiber reinforced plastics is dependent not only on the hybrid composition but also on the arrangement of the material layers. The decrease in the flexural strength is the evidence of reduction in the stiffness of the material. Thus, tensile strength has decreased but the flexural strength has improved by 53–153% except in BCF–jute–RH composite.

The performance and durability of composites depend upon the strength and stiffness of the fibers, the strength and stability of matrix and the interfacial bond strength between fiber and matrix. In hybrid composites, the fibers are not lined up in any direction as shown in Scheme 1. They are just a tangled mass. The composites can be made stronger by lining up all the fibers in the same direction (Scheme 1). Oriented fibers are strong when pulled in the direction of the fiber but they are weak at right angles to the fiber's direction. The woven fibers give a composite good strength in many directions. Under tension, the strength of the composite is entirely provided by the reinforcement. The increase in flexural strength of hybrid composites is due to tangled biomass, which increases the stiffness. The lowering in tensile strength of hybrid composites is mainly due to random orientation of biomass fibers, indicating discontinuous stress transfer in the direction of stress application. Under identical conditions except the nature of husks selected, hybrid composites except BCF–jute–RH possess excellent flexural strength as compared with BCF–jute composite.

Electric strength and volume resistivity

Synthetic organic polymers are well known for their electrical insulation characteristics and offer a wide

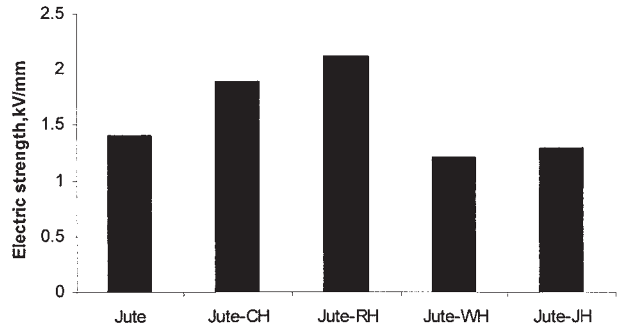


Figure 3 Comparative electric strength of jute, jute–CH, jute–RH, jute–WH, and jute–JH composites.

choice of mechanical properties in combinations ranging from flexible to very rigid and strong. Polymers can be tailored to obtain specific properties in combinations. In the present case, dielectric breakdown strength and volume resistivity of the composites are determined according to IEC: 243(Pt. I)1988 and ASTM D 257–92 methods:

$$\text{Electric strength, } V/\text{mm} = V/t \tag{3}$$

where V is the puncture voltage and t is the thickness of the specimen in mm.

$$\text{Volume resistivity, } \Omega\,\text{cm} = R_v A/t \tag{4}$$

where R_v is the volume resistance in ohms, A is the area of electrodes (19.6 cm^2) and t is the thickness of the specimen in cm.

Comparative dielectric breakdown strength and volume resistivity of hybrid composites along with BCF–jute composite[20] are shown in Figures 3 and 4, respectively. From Figure 3, it is clear that there is not much change in dielectric breakdown strength between BCF–jute composite (1.41 kV/mm) and hybrid composites: BCF–jute–CH (1.89 kV/mm), BCF–jute–RH (2.11 kV/mm) BCF–jute–WH (1.21 kV/mm) and BCF–jute–JH (1.29 kV/mm), but volume resistiv-

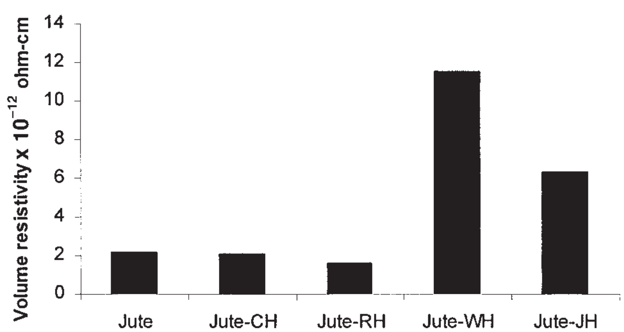


Figure 4 Comparative volume resistivity of jute, jute–CH, jute–RH, jute–WH, and jute–JH composites.

ity of BCF–jute–WH (1.15×10^{13} Ω cm) and BCF–jute–JH (6.35×10^{12} Ω cm) composites has increased by 437.4% and 196.7%, respectively, as compared to BCF–jute (2.14×10^{12} Ω cm) composite, while for BCF–jute–CH (2.09×10^{12} Ω cm) and BCF–jute–RH (1.60×10^{12} Ω cm) it is decreased by 2.3–25.2%. Dielectric breakdown voltage of the material decreases with increase in electrode area and the results are affected by geometry and the material of the electrodes. Factors like sample thickness, temperature, humidity, time of voltage application, extent of ageing, and frequency of current inversely affect the breakdown strength.

Volume resistivity data are useful for comparing the relative insulation quality of material selection, evaluating the effects of material composition and environment, and for material specification. The values are also useful to some extent for designers. Volume resistivity is susceptible to humidity, impurities, degree of resin cure, temperature, and nature of polymers. In the present case, BCF–jute–WH and BCF–jute–JH composites possess superior volume resistivity as compared to BCF–jute–RH and BCF–jute–CH composites.

CONCLUSIONS

The tensile strength of hybrid composites has decreased by 53–72% due to random orientation of sandwiched fibers. The flexural strength of hybrid composites has increased by 53–153% except BCF–jute–RH composite for which it has decreased by 26%. Not much difference in dielectric breakdown strength between hybrid composites (1.21–2.11 kV/mm) and BCF–jute (1.41 kV/mm) composite is observed but volume resistivity of hybrid composites especially for BCF–jute–WH and BCF–jute–JH has increased by 197–437%. On the basis of the observed fact, it is concluded that hybrid composites may be suitable for partition and hard boards, for low load bearing housing units, and also for other applications

The authors are thankful to Professor H. H. Parekh, Head of the Department of Chemistry, for facilities, and the Director, IJIRA, Kolkata, for providing brown jute, and the Director, ERDA, Vadodara, for testing of the composites.

References

1. Schmidt, R. G.; Frazier, C. E. Adhesion and Adhesives 1998, 18, 139.
2. Gibson, R. F. Principles of Composites Materials Mechanics; McGraw Hill: New York, 1998.
3. Hyer M. W. Stress Analysis of Fiber Reinforced Composite Materials; McGraw Hill: New York, 1998.
4. Gassan, J.; Gutowski, V. S.; Compos Sci Technol 2000, 60, 2857.
5. Bledzki, A. K.; Reimance, S.; Gassan, J. J Appl Polym Sci 1996, 59, 1329.
6. Sreekala, M. S.; Kumaran, M. G.; Seena, J.; Maya, J. Appl Compos Mater 2000, 7, 295.
7. Bledzki, A. K.; Gassan, J. Prog Polym Sci 1999, 22, 221.
8. Harun, J.; Idris, H.; Mohd, Y. N. Y.; Kasim, J. In Utilization of Oil Palm Tree. Oil Palm Residues: Mohmad, A. L.; Abdul Aziz, A.; Khoo, K. C. Mohd Yunus, N. Y.; Md. Tahir, P.; Abbod, F.; Mohd. Yusof, M. N.; Husin, M., Eds.; Oil Palm Tree Utilization Committee (OPTUC), 1997, 89–95.
9. Chooi, S. Y.; Chan, K. W. In Utilization of Oil Palm Tree. Oil Palm Residues: Progress towards Commercialization; Harun, J.; Mohmad, A. L.; Abdul Aziz, A.; Khoo, K. C.; Mohd, Y. N. Y.; Tahir, P.; Abbod, F.; Mohd Yusof, M. N.; Husin, M., Eds.; Oil Palm Tree Utilization Committee (OPTUC), 1997, 96–105.
10. Mott, L.; Sule, A.; Suleman, A.; Mathews, R. In Utilization of Oil Palm Tree. Oil Palm Residues: Progress towards Commercialization; Harun, J.; Mohmod, A. L.; Abdul Aziz, A.; Khoo, K. C.; Mohd, Y. N. Y.; Tahir, P. Md.; Abood, F.; Mohd, Y. M. N.; Husin, M., Eds.; Oil Palm Tree Utilization Committee (OPTUC), 1997, 131–140.
11. Mohd, I. Z. A.; Aminullah, A.; Ismail, H.; Rozman, H. D. J Appl Polym Sci 1998, 68, 2189.
12. Abdul Khalil, H. P. S.; Ismail, H.; Ahmed, M. N.; Ariffrin, A.; Husan, K. Polym Int 2001, 50, 396.
13. Abdul Khalil, H. P. S.; Rozman, H. D.; Ismail, H.; Ahmed, M. N. Polym Plast Technol Eng 2000, 39, 757.
14. Ismail, H.; Mohd, I. Z. A. Polym Plast Technol Eng 2001, 40, 103.
15. Weisberger, A.; Proskauer, E. S. Techniques of Organic Solvents: Interscience: New York, 1955.
16. Garchar, H. H.; Parsania, P. H. Asian J Chem 1994, 6, 87.
17. Sanariya, M. R.; Parsania, P. H. Int J Polym Mater 2000, 17, 261.
18. Miwa, M.; Horiba, N. J Mater Sci 1994, 29, 973.
19. Youngquist, J. A.; Krzysik, A. M.; English, B. W.; Spelter, H. N.; Chow, P. In the Use of Recycled Wood and Paper in Building Applications; Proceedings of the 1996 Symposium Sponsored by the U.S. Department of Agriculture Forest Service, Forest Product Society, 1996, 123–134.
20. Mehta, N. M.; Mavani, S. I.; Parsania, P. H. Int J Polym Mater 2005, 22, 205.
21. Gassan, J.; Bledzki, A. K. Composites 1997, 28, 1001.