Scholarly Journal of Engineering Research Vol. 2(1), pp. 21-29, May 2013
Available online at http:// www.scholarly-journals.com/SJER
ISSN 2276-8955 © 2013 Scholarly-Journals

Full Length Research Paper

Hardness, tensile properties and morphology of blend hybrid biocomposites

G. Venkatesha Prasanna[1]* and K. Venkata Subbaiah[2]

[1]Department of Mechanical Engineering, Bellari Institute of Technology and Management Bellary-583104, India.
[2]Department of Mechanical Engineering, Andhra University College of Engineering, Visakhapatnam-530003, India.

Accepted 2 April, 2013

In the present, work intercross linked networks of unsaturated polyester (UP), toughened epoxy blends were developed and this blend was used as matrix. The palmyra-banana fibers reinforced into this matrix blend and the matrix blend hybrid biocomposites were fabricated by hand lay-up technique. The objective of work is to optimize the process for the production of high performance, low cost and less weight natural fibers reinforced blend hybrid biocomposite for the automotive and transportation industry applications. The variation of hardness and tensile properties of 10, 20 and 30% volume content of untreated and treated palmyra-banana fibers reinforced blend hybrid biocomposites were studied. The effect of % of fiber content with and without alkali treatment on mechanical properties was investigated. The mechanical test results clearly showed that these properties were found to be higher when alkali treated banana-palmyra fibers were used in the matrix blend composites. The mechanical properties were optimally increased at 20% volume content of alkali treated banana-palmyra fibers when compared with 10 and 30% volume content of treated fibers and 10, 20 and 30% volume content of untreated fibers reinforced composites. In the case of morphological features, results clearly showed that when matrix was reinforced with fibers of different % volume content, morphological changes took place depending on the % volume content of fibers and the surface modifications by alkali treatment. The morphology of fractured surface indicates good bonding between matrix and fiber reinforcement.

Key words: Natural fibers, Blend, Alkali treatment, Morphology, Mechanical properties, hybrid biocomposites.

INTRODUCTION

Polymer composite materials are being used in aerospace, automotive, marine, infrastructure, military, leisure boats, aircraft industry and sport equipment. Present day industry takes an interest in environment friendly polymer composite materials, due to economic and ecological reasons (Sapuan et al., 2006; Edeerozey et al., 2007; Kaith et al., 2008).

Clay reinforced by straw was the first known composite material in human history used in building construction developed by the ancient Egyptians approximately 3,000 years ago. In the present age, the main focus area is in identifying a biocomposite which is lighter in weight, biodegradable, ecofriendly, cost effective, performance oriented, excellent mechanical strength, high corrosion resistance, dimensionally stable and also suitable for several applications. The polymer blend offers adjusting the cost performance balance, tailoring the technology to make the products for specific end use applications, enhancing resin's performance and improving properties like solvent resistance and impact strength etc.

The present worldwide market volume for polymer blends would be more than 700,000 metric tons per year. Majority of engineering composite materials consists of epoxy matrix reinforced with different natural and synthetic fiber materials. Epoxy is the versatile and widely accepted matrix material for the fabrication of advanced composites, missile equipments and in different applications because of its excellent bonding, mechanical, thermal, chemical and dielectrical characteristics. The toughness of epoxy has been increased by blending with suitable polymers and elastomers. Hence, suitable polymeric material is

*Corresponding author. E-mail: gvpsagar4@gmail.com

required to improve the impact strength, stress-strain properties by retaining stiffness, glass transition temperature and thermal stability of epoxy resin.

Among the various polymer blends, modification of epoxy with polyester was found to be suitable combination (Harani et al., 1999; Varada et al., 2003; Li and Sain, 2003). Because the unsaturated polyester offers very good mechanical, thermal, corrosion resistant properties and low cost when compared to epoxy. The blending technique was used effectively to overcome the inferior properties of both components. Miscible polymer blends produced a new improved material from less superior individual components.

Natural fibers are renewable and obtained from natural resources possessing several advantages. Natural fiber reinforced composites have considerable potential to replace conventional materials like metals and synthetic fibers in structural and semi-structural applications, especially, in the furniture industry (Mohanty et al., 2001). The matrix, often a polymeric material, surrounds the reinforcement and keeps it in place. The reinforcing fibers are chosen to improve the properties of the matrix, for example, stiffness and strength.

As compared to traditional synthetic fibers, natural fibers are able to impart the polymer composites with properties like low cost, non-abrasive effect, low health hazards, low specific gravity, enhanced mechanical properties, biodegradability, low density, high toughness, non corrosive, ease of processing, high degree of flexibility, good acoustic and thermal insulation, good calorific value, less machine wear and good availability (Kaith et al., 2008; Jawaid et al., 2010).

The banana fibers obtained from the dried stalks of banana trees find applications in automotive and transportation industries. Banana fibers are eco-friendly, inexpensive, possess good specific strength, light weight and lower density compared to glass fiber (Babu et al., 2006). Palmyra fibers are obtained from (borassus flabellifer) palmyra trees. These are not only cheaper but also possessed high specific strength, modulus, low specific weight, low density, good resistance to friction and heat and will withstand many chemicals and solvents (Udaya et al., 2007). Although, the properties of natural fibers vary with their source and treatment, alkali treatments have been proven effective in removing impurities from fibers and improving mechanical properties (Noorunisa et al., 2007; Singha and Thakur, 2009).

In the present work, six different samples were prepared in which three untreated samples and treated composite samples were used as a function of variation of % fiber content. The mechanical tests like tensile and hardness were conducted on the untreated and alkali treated palmyra-banana fibers reinforced hybrid biocomposites. The morphology of fractured surface indicates good bonding between matrix and fiber reinforcement.

MATERIALS AND METHODS

The two resins namely epoxy araldite LY 556 as resin, hardener HY 951 supplied by Ciba-Geigy of India Ltd., unsaturated polyester resin supplied by M/S Rishab polymers, (Hyderabad, A.P., India), with methyl ethyl ketone peroxide as catalyst and cobalt naphthenate as accelerator were used as matrix. The banana fiber with density of 1.35 gm/cc, thickness 0.3 mm and palmyra fiber with density of 0.78 gm/cc and thickness 0.4 mm (Kakinada, A.P.) were reinforced into the matrix blend.

Fabrication of blended hybrid biocomposites

The mould cavity was coated with a thin layer of aqueous solution of poly vinyl alcohol (PVA) which acts as a good releasing agent. Furthermore, a thin coating of hard wax was laid over it and finally, another thin layer of PVA was coated. The hand lay-up technique was used to impregnate the composite structures. Each coat was allowed to dry for 20 min at room temperature.

The blend was made from the epoxy resin and hardener taken in the ratio of 100 and 10 parts by weight and unsaturated polyester resin and styrene were mixed in the ratio 100: 25 parts by weight respectively, later, 1 wt. % methyl ethyl ketone peroxide catalyst and 1 wt. % cobalt naphthenate accelerator were added and mixed thoroughly. Then, the epoxy and unsaturated polyester resins were taken in the required proportions to get the required matrix blend.

Firstly, 3 and 10 mm thick matrix plates were made by loading the mould with the epoxy and unsaturated resins blend, then, the 3 and 10 mm thick fibers reinforced matrix blend hybrid biocomposite plates were made by loading the mould with matrix blend and untreated and treated banana-palmyra fibers and air bubbles were removed carefully with roller. For the taken composition of blend, the fiber content varied. The closed mold was kept under pressure for 24 h at room temperature. To ensure complete curing, composite samples were post cured at 80°C for 2 h by keeping them in a vacuum oven. After curing, the composites were removed from the mould box and cut into specimens. Composites with 0, 10, 20 and 30% by volume of untreated and treated samples were prepared.

Mechanical analysis of polymer composite samples

Tensile properties

The tensile property of treated and untreated samples of pseudo-stem banana and palmyra
fibers reinforced matrix blend hybrid biocomposites was measured using M/S Instron 3369 Model computerized UTM. The cross head speed for compressive test was maintained at 10 mm/min and the test was carried out at

Table 1. Physical and mechanical properties of pseudo-stem banana and palmyra fibers.

Fibers	Ultimate tensile strength (MPa)	Young's Modulus (GPa)	Elongation at break (%)	Density (g/cm^3)	Micro fibrillar angle (degrees)
Banana	500	12	5.9	1.35	11
Palmyra	196	2.5-5.4	2.0-4.5	0.7-1.2	29-32

Table 2. Botanical compositions of pseudo stem banana fiber.

S/no	Constituents	Percentage (%)
1	Cellulose	31.27
2	Hemicellulose	14.98
3	Lignin	15.07

Table 3. Botanical composition of palmyra fiber.

S/no	Constituents	Percentage (%)
1	Cellulose	62.90
2	Hemicellulose	18.42
3	Lignin	12.20

room temperature. In each case, five samples were tested and the average value tabulated. Test specimens with 150 mm × 15 mm × 3 mm were cut from glass molds having dimensions 200 mm × 200 mm × 3 mm as per ASTM D 3039-76 specifications.

Hardness

The hardness of treated and untreated samples of pseudo-stem banana and palmyra fibers reinforced matrix blend hybrid biocomposites were measured using Rockwell hardness testing machine supplied M/S PSI scales pvt., Ltd., New Delhi. The test was carried out at room temperature. In each case, five samples were tested and average value tabulated. The test specimens with the dimensions 10 mm × 10 mm × 6 mm were cut from glass molds according to ASTM D 785 specifications. The diameter of the ball indenter used was 0.25 inches and the maximum load applied was 60 kg as per the standard L-scale of the tester. All the readings were taken 10 s after the indenter made firm contact with the specimen. All the sample surfaces were rubbed with smooth emery paper, which facilitates accurate reading. The banana-palmyra fibers impregnated in a unidirectional manner with different % fiber content are shown in the Table 5 and Figure 3.

SEM analysis of samples

In order to evaluate changes in the composite surface morphology, fibers and polymer matrix were analyzed by scanning electron microscopy (SEM). The excitation energy used was 5 keV. To achieve good electrical conductivity, all samples were first carbon sputtered followed by sputtering a gold palladium mixture before examination. SEM micrographs of these samples showed the morphology of the green composites, thus, prepared. These micrographs showed the distribution or arrangement of fibers in the polymer matrix blend, polymer-fibers interactions and fibers wetting in matrix or polymer.

The morphological results evidently showed that when polymer matrix blend is reinforced with the untreated and treated fibers, a morphological change takes place depending upon the interfacial interaction between matrix and varying percentage of untreated and treated fibers. Morphological results clearly showed the condition of fiber wetting in the matrix, composites with matrix rich, presence of voids and spatial distribution of micro voids; fiber content is observed to affect the void formation of mechanisms. In the current study, effects of fiber volume fraction on void content, void morphology and spatial void distribution are investigated. Increasing the fiber content was reported to change the void content from low to high and wet out quality from good to incomplete.

Fiber treatment

Pseudo-stem banana and palmyra fibers were taken in a glass tray, to which 5% NaOH solution was added and fibers were soaked in the solution for about 1 h. The fibers were then washed thoroughly with water to remove the excess of NaOH sticking to the fibers. Final washing was carried out with distilled water and the fibers were then dried in hot air oven at 70°C for 4 h.

RESULTS AND DISCUSSION

Tensile properties

The variation of tensile strength, tensile modulus and % elongation at break with the variation of fibers content on the fibers reinforced blend biocomposites with and without alkali treatment is shown in Figures 1, 2 and 3 and Tables 4, 5 and 6. The interfacial bonding between pseudo-stem banana-palmyra fibers and polymer matrix has been found to affect the properties of blend hybrid biocomposites. It was observed that 20% volume of treated fibers composite showed higher and optimum value of the tensile strength, tensile modulus and %

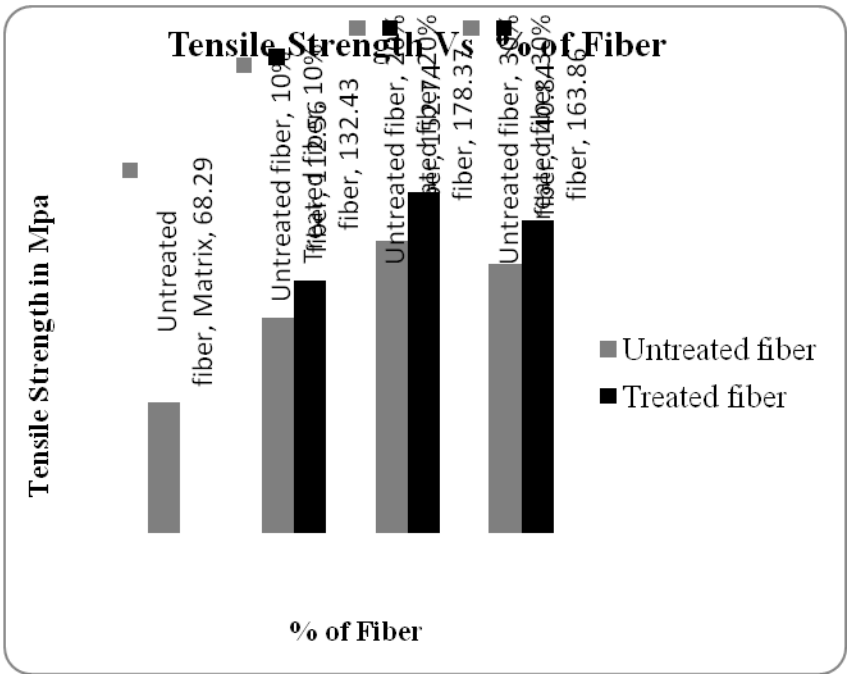

Figure 1. Tensile strength of untreated and treated fibers reinforced blend biocomposites with the varying percentage of fiber content.

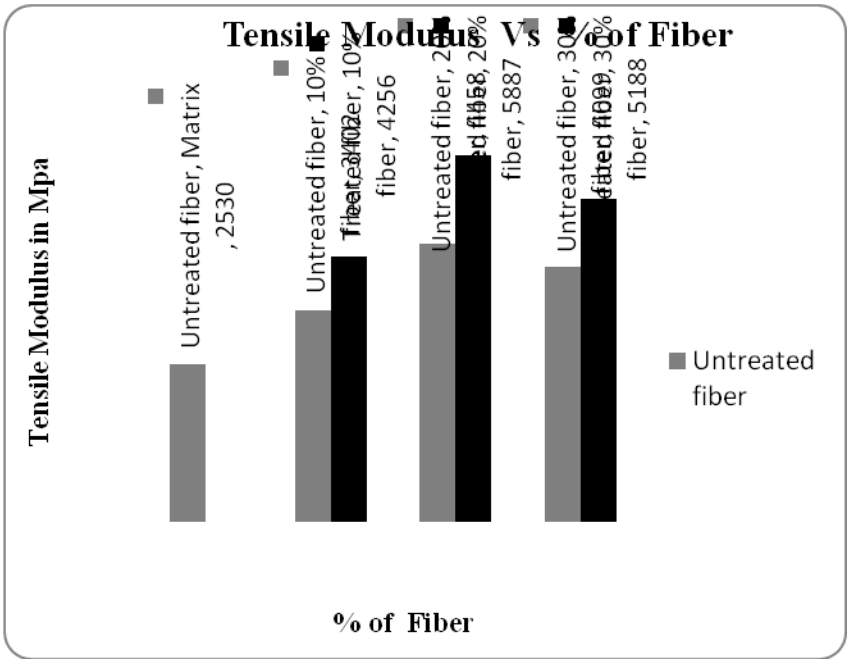

Figure 2. Tensile Modulus of untreated and treated fibers reinforced blend biocomposites with the varying percentage of fiber content.

elongation at break than the untreated composites. Previous works revealed that alkali treatment reduces fiber diameter and increases surface roughness (Mohanty et al., 2001; Bessadok et al., 2008). The alkali treatment by means of NaOH cleans the fiber's surface by removing hemicellulose, waxes, impurities and part of lignin from the natural fibers yields the higher percentage of (alpha) cellulose in natural fibers (Ashok et al., 2010). Chemical analysis revealed that after alkali treatment, the percentage of α cellulose of palmyra-

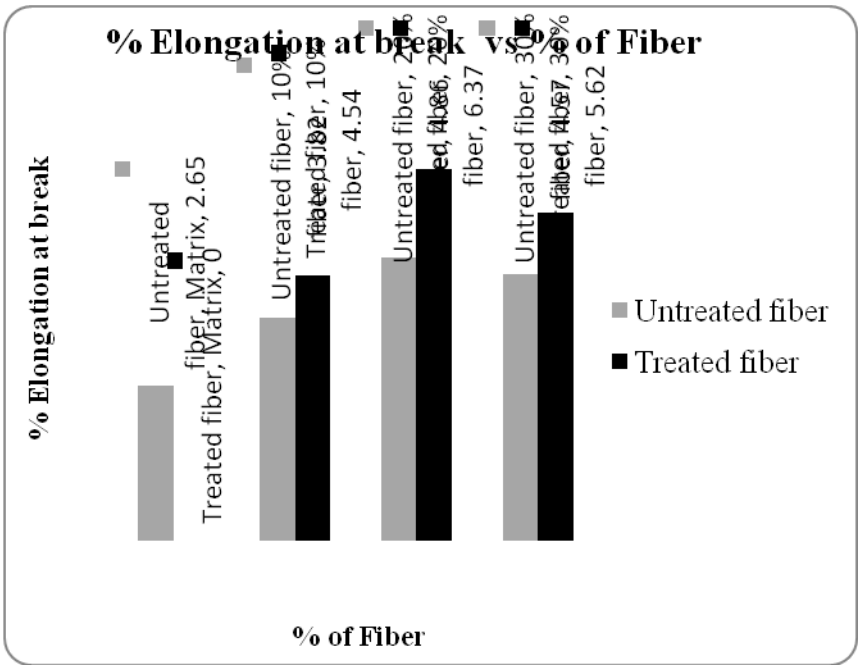

Figure 3. Percentage elongation at break of untreated and treated fibers reinforced blend biocomposites with the varying percentage of fiber content.

Table 4. Tensile strength of untreated and treated fibers reinforced blend hybrid biocomposites with varying percentage of fiber content.

S/no	Percentage of fiber	Tensile strength MPa	
		Untreated composites	Treated composites
1	Matrix (0)	68.29	-
2	10	112.56	132.43
3	20	152.74	178.37
4	30	140.84	163.86

Table 5. TensileModulus of untreated and treated fibers reinforced blend hybrid biocomposites with varying percentage of fiber content.

S/no	Percentage of fiber	% Elongation at break	
		Untreated composites	Treated composites
1	Matrix (0)	2.65	-
2	10	3.82	4.54
3	20	4.86	6.37
4	30	4.57	6.37

banana fibers increased from 58 to 65%. This will render the fiber surface coarser, leading to better interface between matrix and fiber and thus, improve fiber fitness and adhesive characteristics of the surface of the banana and palmyra fibers and the strength (Roy et al., 2001; Noorunisa et al., 2007). Hence, surface offers an excellent fiber-matrix interface adhesion and an increase in the mechanical properties. From Figure 1, it was also observed that 20% volume of treated fibers composite had a higher tensile strength, tensile modulus and % elongation at break than 10 and 30% composites due to high fiber-matrix compatibility, good fiber-matrix interaction and wetting. The alkali-treated fiber composites recorded 16.78% increase in tensile strength, 32.05% increase in tensile modulus and 31.06% increase in % elongation at break at 20% treated fibers content

Table 6. Percentage elongation at breakof untreated and treated fibers reinforced blend hybrid biocomposites with varying percentage of fiber content.

S/no	Percentage of fiber	% Elongation at break	
		Untreated composites	Treated composites
1	Matrix (0)	2.65	-
2	10	3.82	4.54
3	20	4.86	6.37
4	30	4.57	5.62

Table 7. Hardness of untreated and treated fibers reinforce blend hybrid biocomposites with varying percentage of fiber content.

S/no	Percentage of fiber	Hardness	
		Untreated composite	Treated composite
1	Matrix (0 fiber)	86	-
2	10	88	91
3	20	93	97
4	30	90	92

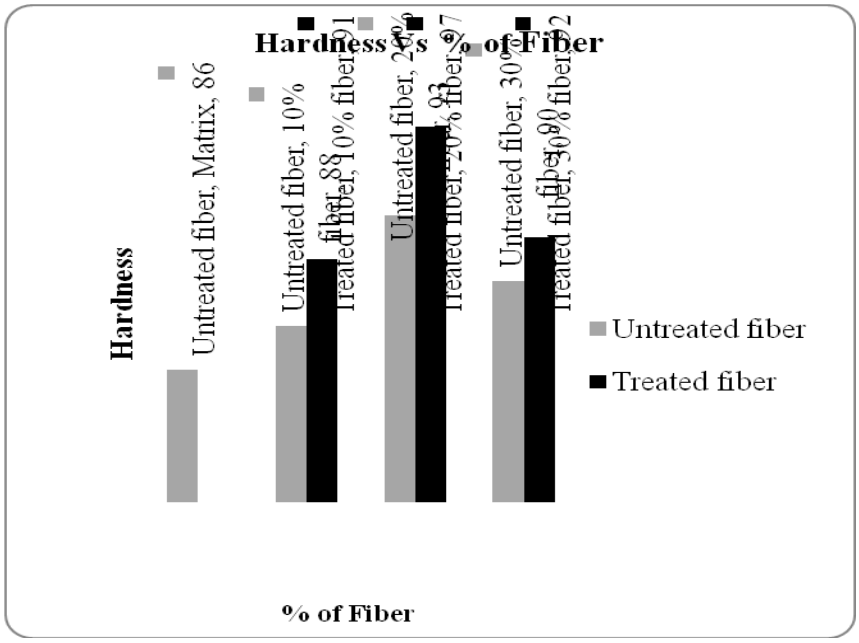

Figure 4. Hardness of untreated & treated palmyra and banana fibers reinforced blend hybrid biocomposites with the variation of fibers content.

than untreated fiber composites.

Hardness

The variation of hardness with the variation of fibers content on the fibers reinforced blend biocomposites with and without alkali treatment is shown in the Table 7 and Figure 4. The hardness depends on the surface topology of the fibers, because each fiber forms an individual interface with the matrix. It was observed that 20% volume of treated fibers composite had a higher hardness than 10 and 30% treated composites due to high fiber-matrix compatibility, good fiber-matrix interaction and wetting. It is reasonable that enhanced fiber-matrix interaction due to high fiber-matrix compatibility and alkali treatment at 20% volume of

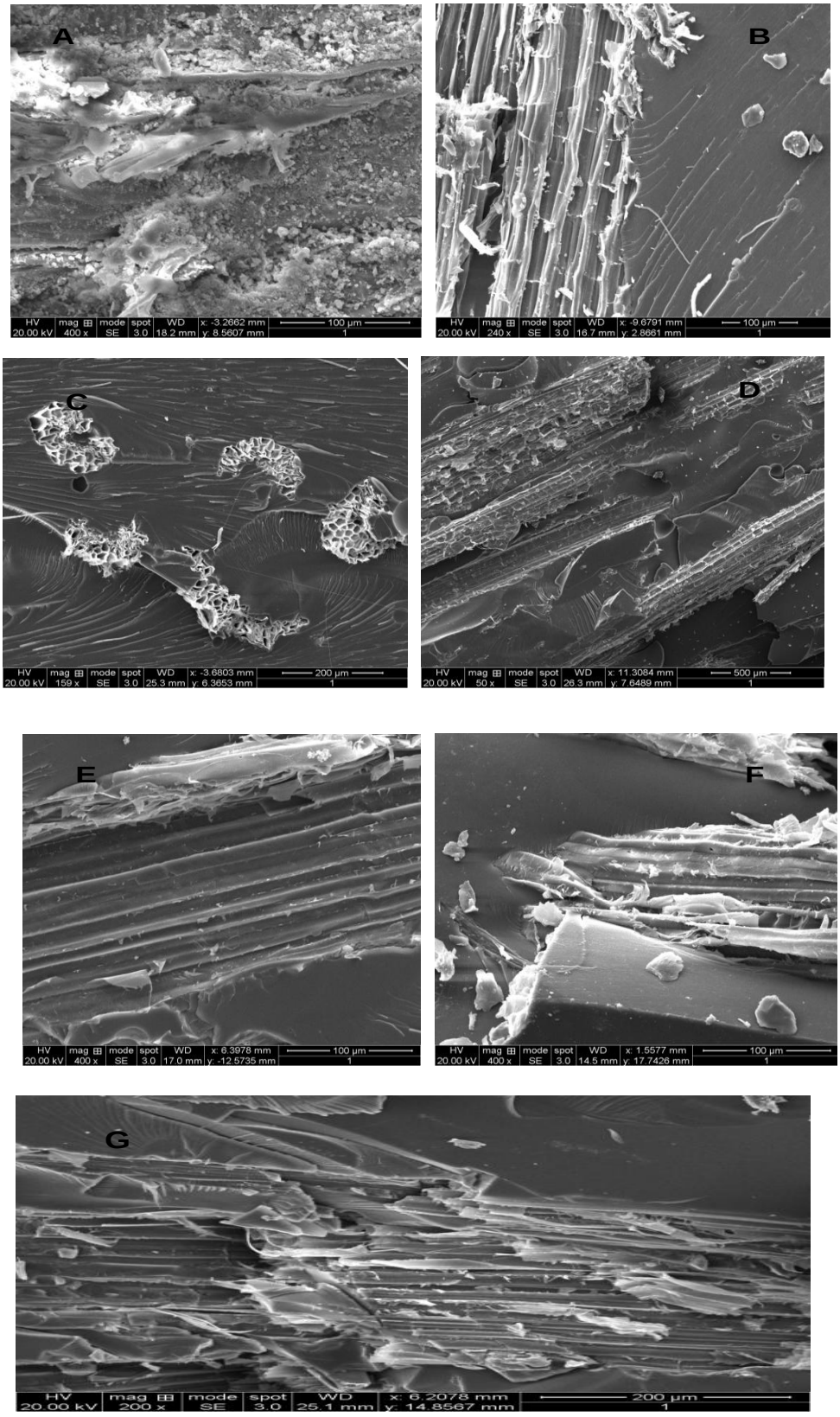

Figure 5. (A) Matrix blend with 0% by volume; (b) 10% by volume content of content of fibers untreated fibers; (C) 20% by volume content of untreated fibers; (D) 30% by volume content of untreated fibers; (E) 10 % by volume content of treated fibers; (F) 20% by volume content of treated fibers and (G) 30% by volume content of treated fibers.

treated fibers composite, value of the hardness was found to be higher and optimum than the untreated composites (Pothan et al., 2006; Velmurugan and Manikandan, 2007). This was because alkali treatments have been proven effective in cleaning fiber's surface by removing impurities from fibers, decreasing moisture sorption, enabling mechanical bonding and thereby, improves matrix reinforcement interaction (Noorunisa et al., 2007).

As the alkali treatments have been proven effective not only in cleaning fiber's surface by removing impurities and hemicellulose from fibers but also will render the fiber's surface coarser leading to better interface between fibers and matrix blend. Furthermore, the interfacial bonding between polymer matrix and biofiber depends on the surface topology of these natural fibers (Gassan and Bledzki, 1999; Bessadok et al., 2008).

Alkali treatment also causes fibrillation that is, breaking of fiber bundles into smaller fibers which would increase the effective surface area available for wetting by the matrix material (Yan et al., 2000). After fibrillation, due to the reduced diameter of fibers, the aspect ratio of fibers increased and yields rough surface topography which in turn offers a better fiber-matrix interface adhesion, enables and improves the fiber fitness, adhesive characteristics of the surface of the banana and palmyra fibers, fiber-matrix interaction and wetting, which results in an increase in the mechanical properties (Noorunisa et al., 2007; Singha et al., 2008; Singha and Thakur, 2009). The alkali-treated fiber composites recorded 4.3% increase in hardness at 20% treated fibers content than untreated fiber composites.

Scanning electron microscope observations

SEM micrographs of various composites containing untreated and treated fibers with varying fibers content are shown in Figure 5a to d and e to g. Examination of fractured surfaces can provide information related to fiber-matrix interface adhesion. The neat blend sample shows fractured surface, indicative of miscible characteristics between the epoxy and polyester as in the Figure 5a. Varada et al. (2003) and Li and Sain (2003), have successfully proved that epoxy-polyester blends have good miscibility.

Morphological results showed that there was a proper intimate mixing of fibers with the matrix blend thus, synthesized. Morphological results evidently showed that when polymer matrix blend was reinforced with the untreated and treated fibers, morphological changes takes place depending upon the interfacial interaction between matrix blend and varying percentage of untreated and treated fibers (Kaith et al., 2008; Jawaid et al., 2010; Raghavendra et al., 2009). SEM analysis indicates that there was good fiber/matrix interaction at 10 and 20% fibers content, but for 30% fibers, reinforced blend composites due to more fibers content; indicates less number of voids with decreased void size caused by incomplete wetting between fibers and matrix.

Conclusion

The variation of hardness and tensile properties for the fibers reinforced unsaturated polyester blended with epoxy composites for 0, 10, 20 and 30% respectively of fibers content was studied as the function of with and without alkali treatment. It was observed that composites having 20% treated fiber content posses higher values for aforementioned properties than untreated composites, 10 and 30% treated fibers composites.

The interfacial area plays a major role in determining the tensile properties and hardness of polymer composite material because each fiber forms an individual interface with the matrix. After the alkali treatment, it was found that, treated composites posses higher values of the aforementioned mechanical properties than the untreated composites, because the alkali treatment improved the adhesive characteristics of the surface of the banana and palmyra fibers by removing hemicellulose, waxes, impurities and part of lignin from the fibers, leading to higher crystallinity of palmyra and banana fibers.

In the present work, it was found that optimum values and significant improvements were at 20% treated fiber reinforced composites than untreated composites (Gassan and Bledzki, 1999; Roy et al., 2001; Babu et al., 2006). Morphological changes takes place depending upon the interfacial interaction between matrix blend and varying percentage of untreated and treated fibers.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the laboratory support extended and kind cooperation given by the Department of Mechanical Engineering, BITM, and Bellary-583104, Karnataka, India, to conduct this research work.

REFERNCES

Ashok kumar, M., Ramachandra Reddy, G., Siva Bharathi, Y., Venkata Naidu, S. and Naga Prasad Naidu, V. (2010). Frictional Coefficient, Hardness, Impact strength and chemical resistance of reinforced Sisal-Glass fiber epoxy hybrid composites, J. of composite materials, 46(26):3195-3202.

Babu Rao,G., Varada Rajulu, A. and Luyt, A.S. (2006). Effect of Alkali treatment on the Flexural properties of Hildegardia fabric composites, J Appl. Poly.Sci.,102:1297-1302 (2006).

Bessadok, A, Marais, S, Roudesli, S., Lixon, C. and Metayor, M. (2008). Influence of chemical modifications on water sorption and mechanical properties of Agave fiber, Composites Part A, 39: 29-45.

Composites, 22(11):1029-1034.

Edeerozey, A.M., Akil, H.M., Azhar, A.B. and Ariffin, M.Z. (2007). Chemical modification of kenaf fibers, Material Letters, 61: 2023-2025.

Gassan, J. and Bledzki, A.K. (1999). Possibilities for improving the mechanical properties of Jute/Epoxy composites by Alkali treatment of fibers, Composite science and technology, 59:1303-1309.

Harani, H., Fellahi, S. and Bakar, M. (1999). Toughening of epoxy resin using hydroxyl- terminated polyester, Journal of Applied Polymer Science, 71:29-38.

Jawaid, M., Abdul khalil, H.P.S., Abu Bakar, A. and Noorunnisa khanam, P. (2010). Chemical resistance, void content and tensile properties of oil palm/jute fiber reinforced polymer hybrid composites, Materials and Design, 32(2):1014-1019.

Kaith, B.S., Singha, A.S., Sanjeev, K. and Susheel, K. (2009). Mercerization of flax iber improves the mechanical properties of fiber reinforced composites, Inter. J. Polym. Mater. 57(1):54–72.

Li, H. and Sain M.M. (2003). High stiffness natural fiber-reinforced hybrid polypropylene composites, Polym. Plastics Technol. Engineering, 42(5):853–862.

Mohanty, A.K., Misra, M.and Drzal, L.T. (2001). Surface modifications of natural fibers and performance of resulting biocomposites, Composite Interfaces, 8(5): 313-343.

Naik, J.B. and Mishra, S. (2007). Esterification effect of maleic anhydride on surface and volume resistivity of natural fiber/polystyrene composites, Polymer-Plastics Technology and Engineering, 46(5):537-540.

Noorunisa, K.P., Mohan, R.M., Raghu, K. and Venkat, N,S. (2007). Tensile, Flexural and Compressive properties of Sisal/Silk hybrid composites. J. of Reinforced Plastics and Composites, 26(9):1065-1069.

Park, S.J., Park, W.B. and Lee, J.R. (1999). Roles of Unsaturated polyester in the epoxy matrix system, Polym. J., 31: 28-31.

Pothan, L.A., Groenikx, G. and Sabu Thomas. (2006). The role of fiber/matrix interactions on the Dynamic Mechanical properties of chemically modified composites, Composites Part A, 37:1260-1269.

Pothan, L.A., Oomen, Z. and Sabu T. (2003). Dynamic Mechanical analysis of banana fibers reinforced polyester composites, J. of Composites Sci. and Technol. 63(2):283-293.

Raghavendra Rao, H., Varada Rajulu, A., Ramachandra Reddy, G. and Hemachandra Reddy, K. (2009). Flexural and compressive properties of Glass /Bamboo fiber reinforced epoxy hybrid composites, J. of Reinforced Plastics and Composites, 29(10):1446-1450.

Roy, D., Sarkar, B.K., Rana, A.K. and Bose, N.R. (2001). Effect of alkali treated Jute fibers on composite properties, Bulletin of Material Science, 24(2):129-135.

Sapuan, S.M., Leenie, A., Harimi, M. and Beng, Y.K. (2006). Mechanical properties of woven banana fiber reinforced epoxy composites, Materials and Design, 27(8):689-693.

Singha, A.S. and Thakur, V.K. (2009). Mechanical, Thermal and Morphological Properties of Grewia Optiva Fiber/Polymer Matrix Composites, Polymer- Plastics Technology and Engineering, 48(2):201-208.

Singha, A.S. and Thakur, V.K. (2010). Physico-chemical and Mechanical Characterization of Natural Fiber Reinforced Polymer Composites, Iranian Polymer J. 19(1):3-16.

Singha, A.S., Anjali, S. and Thakur, V.K. (2008). Pressure induced graft co-polymerization of acrylonitrile onto Saccharum Cilliare fiber and evaluation of some properties of grafted fibers, Bulletin of Material Science, 31(1):7–13.

Udaya, K.C., Ramachandra, R.G., Dabade, B.M. and Rajesham,S. (2007). Tensile Properties of Sun hemp, Banana and Sisal fiber reinforced polyester composites, Journal of Reinforced Plastics and Composites, 26:1043-1050.

Varada Rajulu, A., Ganga Devi, L. and Babu Rao, G (2003). Chemical Resistance and Tensile Properties of Epoxy/Unsaturated Polyester Blend Coated Bamboo fibers, J. of Reinforced Plastics and

Varada, R.A., Ganga, D. and Babu, R.G. (2003). Miscibility studies of epoxy/unsaturated polyester resin blend in chloroform by viscosity, ultrasonic velocity, and refractive index methods, J. App. Polymer Sci., (89): 2970–2972.

Velmurugan, R. and Manikandan, V. (2007). Mechanical properties of palmyra/glass fiber hybrid composites, Composites Part A, 38(10):2216-2226.

Yan Li, Yiu Wing Mai and Lin Y. (2000). Sisal fiber and its composites: a review of recent developments, Composite Sci. and Technol. 60(11):2037–2055.