Materials and Design 32 (2011) 2469–2475

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Technical Report

Static bending and impact behaviour of areca fibers composites

C.V. Srinivasa [a,*], A. Arifulla [b], N. Goutham [b], T. Santhosh [b], H.J. Jaeethendra [b], R.B. Ravikumar [b], S.G. Anil [b], D.G. Santhosh Kumar [b], J. Ashish [b]

[a] Faculty, Department of Mechanical Engineering, GM Institute of Technology, Davangere 577 006, Karnataka, India
[b] Graduate Students, Department of Mechanical Engineering, GM Institute of Technology, Davangere 577 006, Karnataka, India

ARTICLE INFO

Article history:
Received 29 May 2010
Accepted 9 November 2010
Available online 3 December 2010

ABSTRACT

Natural fibers are considered to have potential use as reinforcing agents in polymer composite materials because of their principle benefits: good strength and stiffness, low cost, and be an environmental friendly, degradable, and renewable material. A study has been carried out to evaluate physical, flexural and impact properties of composite made by areca fibers with randomly distributed fibers. The extracted areca fibers from the areca husk were alkali treated with potassium hydroxide to get better interfacial bonding between fiber and matrix. Then composite laminates were fabricated by using urea formaldehyde, melamine urea formaldehyde and epoxy resins by means of compression molding technique with varying process parameters, such as fiber condition (untreated and alkali treated), and fiber loading percentages (50% and 60% by weight). The developed areca fiber-reinforced composites were then characterized by physical, bending and impact test. The results show that flexural and impact strength increases with increase in the fiber loading percentage. Compared to untreated fiber, significant change in flexural and impact strength has been observed for treated areca fiber reinforcement.

1. Introduction

Environmental awareness, new rules and legislations are forcing industries to seek new materials which are more environmental friendly. Over the past two decades, plant fibers have been receiving considerable attention as substitutes for synthetic fiber reinforcements for applications like interior door panel of an automobile, packaging, low-cost housing, and other structures [1–3]. Unlike the traditional synthetic fibers like glass and carbon these lignocellulosic fibers are able to impart certain benefits to the composites such as low density, low cost, renewability, biodegradability and high degree of flexibility during processing [4]. Nowadays natural fibers like, cotton, coir, sisal jute and other natural fibers have attracted the attention of scientists and technologists. It has been found that the natural fiber composites possess required mechanical strength and other properties with better electrical resistance, good thermal and acoustic insulating properties.

In recent years, extensive studies which have been done on lignocellulosic fibers such as sisal [5,6], jute [7,8], pineapple [9–12], banana [13–15], and oil palm empty fruit bunch fibers [16,17] have shown that lignocellulosic fibers have the potential to be used as an effective reinforcement in thermoplastics and thermosetting materials. According to Bledzki et al. [18] and Wambua et al. [19], lignocellulose fibers exhibit several advantages over their synthetic fiber counterparts. Lignocellulose fibers have drawn attention due to their abundant availability, low cost and renewable nature. Owing to their low specific gravity, which is about 1.25–1.50 g/cm^3 compared to synthetic fibers, in particular glass fiber which is about 2.6 g/cm^3, lignocellulose fibers are able to provide a high strength to weight ratio in plastic materials. The usage of lignocellulose fibers also provides a healthier working condition than the synthetic fibers. This is due to the fact that, the glass fiber dust from the trimming and mounting of glass fiber components causes skin irritation and respiratory diseases among workers [20,21]. Besides that, the less abrasive nature of the lignocellulose fibers exhibits a friendlier processing environment as the wear of tools could be reduced. Furthermore, lignocellulose fibers exhibit good thermal and insulating properties, easily recyclable and are biodegradable especially when used as reinforcement in biopolymer matrix.

Although there have been numerous studies on mechanical behaviour of natural fiber-reinforced composites, only a few references are available on areca fiber-reinforced composites. Among all the natural fiber reinforcing materials, areca appears to be a promising material because it is inexpensive, abundantly available, and a very high potential perennial crop. It belongs to the species *Areca catechu* L., under the family Palmecea and originated in the Malaya Peninsular, East India [22]. In India, areca cultivation is coming up in a large scale basis with a view to attaining self sufficiency in medicine, paint, chocolate, chewable gutka, etc. The husk of the areca constitutes about 60–80% of the total weight and volume of the fresh fruit. The average filament length (4 cm) of the areca

* Corresponding author. Tel.: +91 8192 233345; fax: +91 8192 233344.
E-mail address: srinikanadamani@gmail.com (C.V. Srinivasa).

0261-3069/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2010.11.020

husk fiber is too short compared to other biofibers. Mainly two types of filaments are present – one very coarse and the other very fine. The coarse ones are about ten times as coarse as the jute fibers and the fine are similar to jute fiber. The fiber could be used for making value added items like thick boards, fluffy cushions and non-woven fabrics, thermal insulators and non-woven fabrics [23]. The present use of this highly cellulose material is as a fuel in areca nut processing. Unmanaged areca husk left in the plantation causes bad odour and other decay-related problems [24]. Therefore, an extensive planning for the disposal of husk is required. Thus, the use of this unmanaged husk as structural material required a detailed study of physical, chemical and thermal characteristics.

In order to develop composite made from natural fibers with enhanced strength, stiffness, durability and reliability, it is necessary to study the mechanical behaviour of natural fiber composites. The mechanical properties of a natural fiber-reinforced composite depend on many parameters, such as fiber strength, modulus, fiber length, orientation, and fiber–matrix interfacial bond strength. A strong fiber–matrix interface bond is critical for high mechanical properties of composites. 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. Most research reviewed indicates the effect of alkali treatment in improving fiber strength [25], fiber–matrix adhesion [26] and the performance of the natural fiber composites [27]. Therefore, this study seeks to determine the physical, flexural and impact properties of areca composites. A better understanding will help to develop productive uses for an empty areca fruit bunch, mitigating environmental problems from waste biomass while also developing an alternative material to wood.

2. Chemical composition

The structure and chemical make-up of natural fibers varies greatly and depends on the source and many processing variables. However, some generalizations are possible. Natural fibers are complex in structure. They are generally lignocellulose, consisting of helically wound cellulose micro fibrils in an amorphous matrix of lignin and hemicellulose [28].

Lignocellulose fibers are a kind of biopolymer composite with the following components, in different proportions, depending on the species considered: cellulose, hemicellulose, lignin and other components in small proportions. These polymers are the basic constituents of the cell wall and are responsible for most of the physical and chemical properties, such as dimensional instability to moisture, biodegradability, flammability, thermo plasticity and degradability by ultraviolet light, acids, and bases. All of these characteristics will result in specific end use of lignocellulosics in composite formulation. Lignocellulosics can also be called *phytomass*, bio based fibers, or biofibers, including wood, agricultural residues, water plants, grass, agricultural fibers, and any other plant substance [29]. Table 1 shows chemical compositions in the natural fibers and their chemical and structural compositions of areca fibers and other natural fibers. The total hemicellulose content of the fiber was found to be 35–64.8%, 13–24.8% lignin and a 4.4% of ash and negligible percentage of cellulose. The areca fibers having high percentage of hemicellulose compare to other natural fibers listed in Table 1.

Table 1
Chemical composition of natural fibers.

Fiber	Cellulose (%)	Hemi cellulose (%)	Lignin (%)	Ash (%)	Pectin (%)	Wax (%)
Hemp [23]	70.2–74.4	17.9–22.4	3.7–5.7	2.6	0.9	0.8
Kenaf [23]	31–39	15–19	21.5	4.7	–	–
Jute [23]	61–71.5	13.6–20.4	12–13	–	0.2	0.5
Flax [24]	71–78.5	18.6–20.6	2.2	1.5	2.2	1.7
Palf [24]	70–82	–	5–12	–	–	–
Cotton [24]	82.7	5.7	–	–	–	0.6
Sisal [32]	67–78	10–14.2	8–11	–	10.0	2.0
Coir [32]	36–43	0.15–0.25	41–45	–	3–4	–
Areca [32]	–	35–64.8	13–24.8	4.4	–	–

Selective removal of non-cellulosic compounds constitutes the main objective of fiber chemical treatment [30]. Both the hemicellulosic and pectin materials play important roles in fiber bundle integration, fiber bundle strength and individual fiber strength as well as water absorbency, swelling, elasticity and wet strength [31]. The production of individual fibers without the generation of kink bands will generate fibers with much higher intrinsic fiber strength which is very useful for composite application.

3. Materials and methods

3.1. Materials

Urea formaldehyde (0.6 g/cm^3) and melamine urea formaldehyde (0.55 g/cm^3) were supplied by the Akolite Synthetic Resins, Mangalore, India. The Araldite LY-556 epoxy resin (1.16 g/cm^3) and the Hardener (HY951) are supplied by Ciba Geigy India Ltd. Areca empty fruit bunch fibers (husk) were obtained from Madhu Farm House Nilogal, Davangere, Karnataka, India.

3.2. Methods

3.2.1. Fiber extraction

Selected areca fruit husks were used to prepare the composites. Dried areca husk was soaked in deionised water for about 5 days. The soaking process loosens the fibers and can be extracted out easily. Finally, the fibers were washed again with deionised water and dried at room temperature for about 15 days. The dried fibers are designated as untreated fibers.

3.2.2. Fiber surface treatment

First the extracted areca fibers were treated in a solution of 10% KOH (potassium hydroxide) where the total volume of solution was 15 times the weight of areca fibers. The fibers were kept in this alkaline solution for 36 h at a temperature of 30 °C; it was then thoroughly washed in running water then neutralized with a 2% acetic acid solution. Lastly it was again washed in running water to remove the last traces of acid sticking to it, so that the pH of the fibers is approximately 7 (neutral). Then they were dried at room temperature for 48 h to get alkali treated fibers.

3.2.3. Preparation of composite laminates

Fiber configuration and volume fraction are two important factors that affect the properties of the composite [33]. In the present study the following composites were prepared with randomly distributed orientation of fibers.

(i) Composites containing 50% and 60% by weight of alkali-treated and untreated areca fibers, containing urea formaldehyde resin (UFR) and designated as UF50 Treated, UF50 Untreated, UF60 Treated, and UF60 Untreated.
(ii) Composites containing 50% and 60% by weight of alkali-treated and untreated areca fibers, containing melamine urea formaldehyde resin (MUFR), and designated as MUF50 Treated, MUF50 Untreated, MUF60 Treated and MUF60 Untreated.
(iii) Composites containing 50% and 60% by weight of alkali-treated and untreated areca fibers, containing epoxy resin (ER) and designated as ER50 Treated, ER50 Untreated, ER60 Treated, and ER60 Untreated.

First, the mould was polished and then a mould-releasing agent (polyvinyl alcohol) was applied on the surface. The fibers were mixed thoroughly with the matrix materials by hand mixing technique. This mixture was left for 10 min, and then the mixture was filled into the mould of 300 × 300 × 50 mm size. Care was taken to ensure a uniform thickness of the plate and the material was pressed in a hydraulic press at the room temperature and a pressure of 0.5 MPa was applied for 30 min. After that, the composites were post-cured at room temperature (27 ± 3 °C) for 24 h.

3.2.4. Preparation of specimens

The prepared composite laminates were post-cured for 8 days at standard laboratory atmosphere prior to preparing specimens and performing mechanical tests. The appropriate ASTM methods were followed while preparing the specimens for test. At least five replicate specimens were tested and the results were presented as an average of tested specimens. The tests were conducted at a standard laboratory atmosphere of 27 °C and 46% relative humidity.

According to ASTM-D790 the composite specimen was prepared for three-point bending test. Each test specimen of 50 mm width, length 240 mm, and thickness 10 mm are prepared. The span of the supports was 100 mm. The specimen is loaded at the center of the span through a loading cell and the loading rate was 2 mm/min using Inston testing machine. Impact energy absorbed by the specimens were determined by performing both Charpy and Izod method of impact testing methods as per ASTM-D256-90 with notched specimens using Inston Pendulum Tester (9050 Manual Model). The width and depth of each specimen was measured with a micrometer screw gauge to the nearest 0.01 mm, and the length was measured to the nearest 0.1 mm with digital caliper. The mean specimen dimensions were used to calculate strength.

4. Experimental investigations

The experimental investigation of flexural and impact properties of composites is one of the most important techniques in studying the behaviour of composite materials. It has been proved to be the most effective method to study the behaviour of the materials under flexural and impact stress and phase composition of fiber composites and its role in determining these properties. Flexural and impact strength of fiber-reinforced composites depend on the nature of matrix material and the distribution and orientation of the reinforcing fibers, the nature of the fiber–matrix interfaces and of the interphase region. Even a small change in the physical nature of the fiber for a given matrix may result in prominent changes in the overall mechanical properties of composites. It is well known fact that different degrees of reinforcement effects are achieved by the addition of hydrophilic fibers to different polymers [34]. This may be due to the different adhesion strength between matrix and fibers.

4.1. Dimensions and density of areca fibers

Natural fibers exhibit considerable variation in diameter along with the length of individual filaments [35]. Quality and other properties of fibers depend on factors such as size, maturity and processing methods adopted for the extraction of fiber. Properties such as density, electrical resistivity, ultimate tensile strength and initial modulus are related to the internal structure and chemical composition of fibers. Desirable properties for fibers include excellent tensile strength and modulus, high durability, low bulk density, good moldability and recyclability.

The density of areca fibers was determined by measuring the mass and volume of a bunch of fibers. Each bunch of fibers was weighed to an accuracy of 0.001 g by using an analytical balance. The mass of each bunch was obtained by calculating the arithmetic mean of the mass of all test samples. The dimensions of each fiber were measured using a sliding caliper having accuracy ±0.02 mm (Mitutoyo Super Caliper SERIES 500), in accordance with BS EN 325:1993. The volume of the fiber was obtained by multiplying the length, and cross sectional area of the samples. Determination of density was done in accordance with BS EN 323:1993. The various physical properties of areca fibers were measured and are tabulated in Table 2. The diameter of the fiber varies from 0.028 to 0.89 mm, length of the fibers varies from 18 to 38 mm and density varies from 1.05 to 1.25 g/cm^3. Three types of fibers are observed and classified as short, medium and long fibers.

4.2. Flexural properties

Bending test results were obtained for areca fibers reinforced with urea formaldehyde, melamine urea formaldehyde and epoxy resins. Tests were performed to investigate the effects of fiber loading and alkali treatment on flexural load carrying capacity of areca composites. The effect of fiber weight percentage and alkali treatment on flexural strength of areca fiber composites are presented in Figs. 1–4.

The load–deflection curve for areca fibers reinforced urea formaldehyde composites as shown in Fig. 1. The composite UF60 Treated has taken the maximum flexural load compared to other composite, and composite UF50 Untreated has least flexural load bearing capacity.

The maximum static flexural load of areca-reinforced UF composite plate is 380 N. The corresponding flexural strength during break for this specimen is 27.36 MPa (Fig. 4). The minimum static flexural load of 210 N is recorded for UF50 Untreated composite and the flexural strength during break for this specimen is 15.12 MPa.

Fig. 2 shows the load–deflection curve for areca composites using melamine urea formaldehyde. It is observed from the Fig. 4 that, areca composite using melamine urea formaldehyde exhibited higher flexural strength than areca composite using urea formaldehyde. This may be because, the adding of melamine to urea formaldehyde has better adhesion strength as reported by Zhong et al. [36]. The untreated areca melamine urea formaldehyde (MUF50) composite has taken a maximum flexural load of 350 N. It is also seen that, this value increases to 440 N for alkali treated with same proportion of fiber loading. Similarly, MUF60 (with an addition of 10 wt%) for treated and untreated fibers composite, the maximum flexural load withstanding capacity increases to 383 N and 464 N respectively. Similar trend is observed in case of flexural strength of these composites. These results clearly indicate that, the addition of melamine to the urea formaldehyde increases the bonding strength in turn increases flexural load withstanding capacity of the composite. The percentage of increase in the bending load withstanding capacities of melamine urea formaldehyde are 40%, 22.72%, 36.03% and 18.10% when compare to UF50 Untreated, UF50 Treated, UF60 Untreated and UF60 Treated respectively.

Fig. 3 shows the load–deflection curve for areca fibers reinforced epoxy composites. It is observed that with increase of areca fiber content from 50 to 60 wt% with treated, the flexural

Table 2
Physical properties of areca fiber.

Diameter (μm)	Length of fiber (mm)				Density (g/cm^3)
	Short	Medium	Long	Average	
28–89	18–29	30–38	39–46	29–38	1.05–1.25

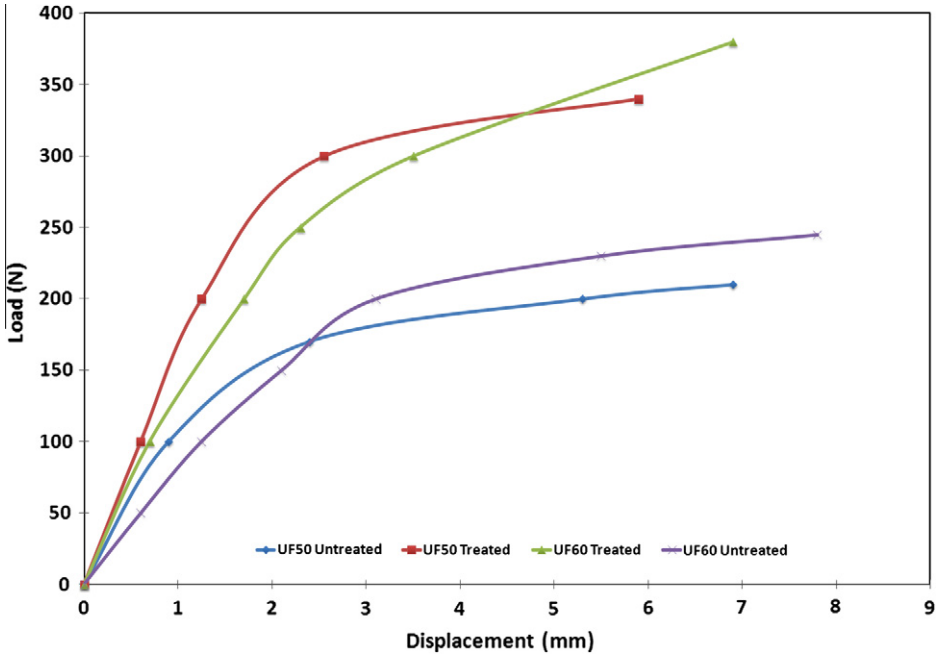

Fig. 1. Flexural behaviour of areca fibers reinforced urea formaldehyde composites.

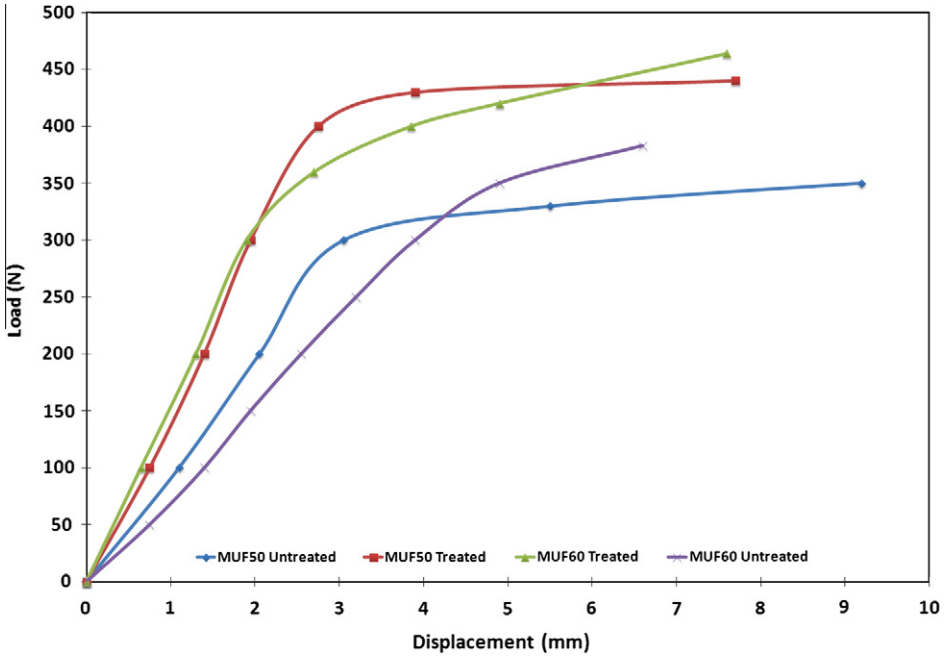

Fig. 2. Flexural behaviour of areca fibers reinforced melamine urea formaldehyde composites.

load increases sharply, i.e., from 680 N to 1220 N, increasing by about 44.26%. Meanwhile, the flexural strength increases from 63.36 MPa to 84.87 MPa. Similarly for untreated the flexural load increases from 560 N to 620 N and strength increases from 40.32 MPa to 44.64 MPa.

The flexural strength of all composites considered in the present study increases slightly with fiber weight percentage in the composite (Fig. 4). Overall, the results showed that areca fibers reinforced with epoxy exhibited higher flexural strength than areca fibers reinforced with formaldehyde groups. This is because fiber has better interfacial bonding strength between fiber and matrix is found to be high in epoxy than in formaldehyde groups due to improved adhesion and enhanced polar interactions at the fiber–matrix interfaces [37]. Also an improved mixing will provide better distribution of areca fibers, the bridging gaps between the fibers can conduct more effectively.

4.3. Impact properties

Fig. 5 shows the influence of the alkali treatment, different matrix materials and fiber loading on the impact energy absorption capacity of the areca fibers based upon Charpy as well as Izod method of impact tests. It can be seen that, a similar behaviours of composites can be observed in both the tests. The energy absorbed

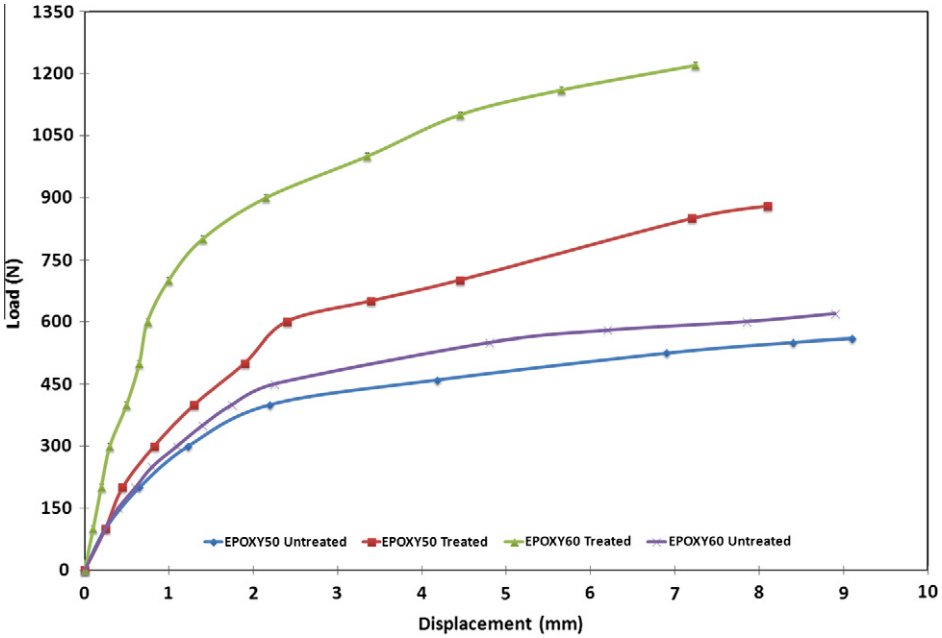

Fig. 3. Flexural behaviour of areca fibers reinforced epoxy composites.

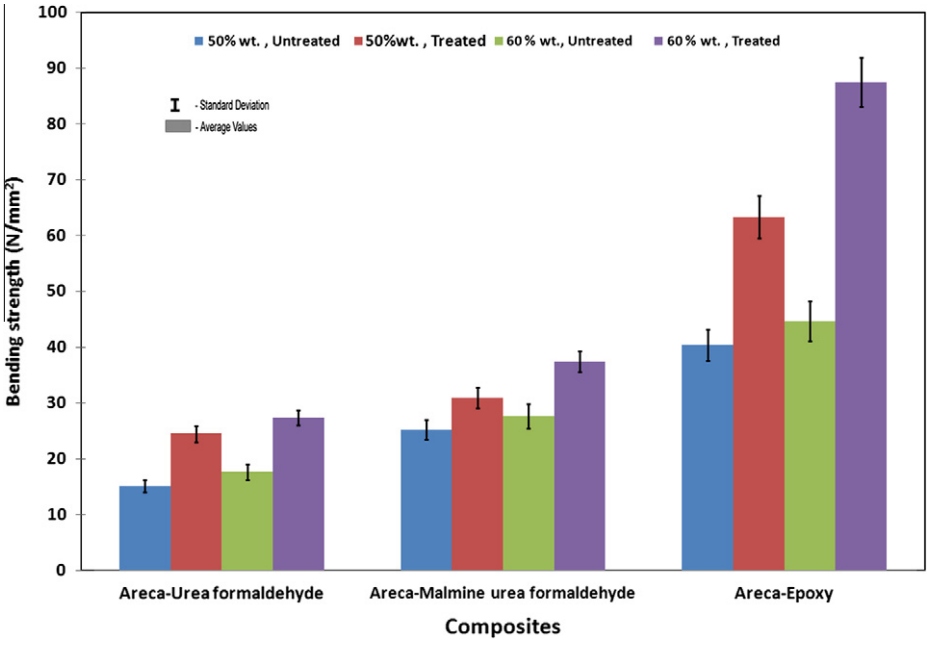

Fig. 4. Flexural strength of areca composites.

by all the composites in case of Izod method is slightly lesser than the Charpy method of impact test. It is thus seen that with the increase in fiber content in the composite, the energy absorption improves although the increment is marginal in case of composites with untreated fibers. In addition; a modification of the fiber surface by alkali treatment leads to an increase of adhesion between fiber and matrix. This in turn increases the energy absorption capacity of the composites irrespective of matrix materials.

Generally, fibers that increase the moduli of composites increase the impact strength of the thermoplastic. This is because impact strength is a function of the relative fiber volume and modulus [38]. This is because the higher molecular weight, the greater the entanglement of polymer chains, therefore, their relative mobility is reduced and adhesion between fiber and matrix increases. This in turn increases the energy absorption capacity of the composites.

Since epoxy resin is having high molecular weight than the urea formaldehyde and melamine urea formaldehyde, the areca fibers reinforced with epoxy composites show superior energy absorption capacity (more than 40%) than the areca fibers reinforced with melamine urea formaldehyde and urea formaldehyde. The maximum impact energy absorption capacity of areca fibers (60 wt%, treated) reinforced with epoxy resin according to Charpy method is more than 34% and 40% respectively for areca fibers reinforced with melamine urea formaldehyde and urea formaldehyde resin. Similarly 43% and 46% in case of Izod method of impact test.

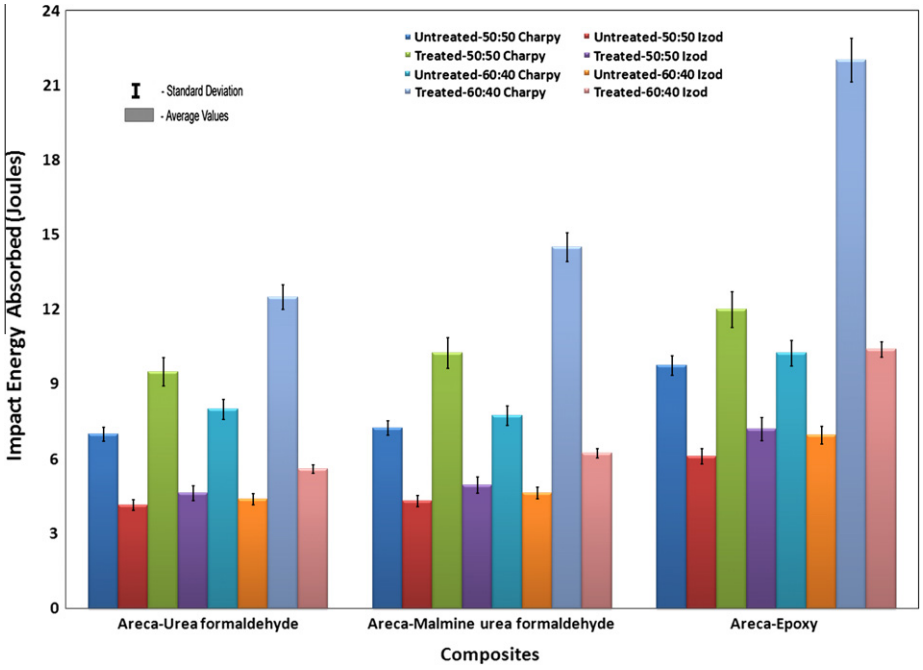

Fig. 5. Impact energy absorbed by areca composites (Charpy and Izod method).

5. Conclusions

The results presented in this work indicate that it is possible to enhance the properties of fiber-reinforced composites through fiber surface modification. Composites based on the modified fiber surface have, in general, superior mechanical properties to composites containing unmodified fibers. This is primarily a result of improved adhesion and enhanced polar interactions at the fiber–matrix interfaces. Hence, based on the availability, cheaper and good strength of areca fiber composites investigated in the present study, the composite can certainly be considered as a very promising material to fabrication of lightweight materials used in automobile body building, office furniture packaging industry, partition panels, etc. compared to conventional wood based plywood or particle boards.

Acknowledgments

The authors would like to thank Karnataka State Council for Science and Technology, Bangalore, Karnataka, India for providing financial assistance (30S345 and 31S268), Madhu Farm House, Nilogal for providing a good quality areca fruit husk and the Management of GM Institute of Technology, Davangere, Karnataka, India for their kind support and help in making this research work fruitful.

References

[1] Magurno A. Vegetable fibres in automotive interior components. Die Angew Makromol Chem 1999;272:99–107.
[2] de Bruijn JCM. Natural fibre mat thermoplastic products from a processor's point of view. Appl Compos Mater 2000;7:415–20.
[3] Aziz MA, Paramasivam P, Lee SL. Natural fibre reinforced concrete in low-coat housing construction. J Ferro Cement 1987;17(3):231–40.
[4] Saheb DN, Jog JP. Natural fiber polymer composites: a review. Adv Polym Technol 1999;18(4):351–63.
[5] Joseph Kuruvilla, Varghese Siby, Kalaprasad G, Thomas Sabu, Prasannakumari L, Koshy Peter, et al. Influence of interfacial adhesion on the mechanical properties and fracture behaviour of short sisal fibre reinforced polymer composites. Eur Polym J 1996;32(10):1243–50.
[6] Oksman K, Wallström L, Berglund LA, Toledo Filho RD. Morphology and mechanical properties of unidirectional sisal–epoxy composites. J Appl Polym Sci 2002;84(13):2358–65.
[7] de Albuquerque AC, Joseph Kuruvilla, de Carvalho Laura Hecker, d'Almeida Jose Roberto Morais. Effect of wettability and ageing conditions on the physical and mechanical properties of uniaxially oriented jute-roving-reinforced polyester composites. Compos Sci Technol 2000;60(6):833–44.
[8] Abdullah-Al-Kafi. Study on the mechanical properties of jute/glass fiber-reinforced unsaturated polyester hybrid composites: effect of surface modification by ultraviolet radiation. J Reinf Plast Compos 2006;25(6):575–88.
[9] Bhattcharyya Timir Baran, Biswas Amit Kumar, Chatterjee Jaydev, Pramanick Dinabandhu. Short pineapple leaf fibre reinforced rubber composites. Plast Rubber Process Appl 1986;6(2):119–25.
[10] Jayamol George, Sreekala MS, Sabu Thomas. Stress relaxation behavior of short pineapple fiber reinforced polyethylene composites. J Reinf Plast Compos 1998;17(7):651–72.
[11] Uma Devi L, Bhagawan SS, Thomas S. Mechanical properties of pineapple leaf fiber-reinforced polyester composites. J Appl Polym Sci 1997;64:1739–48.
[12] Mishra S, Misra M, Tripathy SS, Nayak SK, Mohanty AK. Potentiality of pineapple leaf fibre as reinforcement in palf-polyester composite: surface modification and mechanical performance. J Reinf Plast Compos 2001;20(4):321–34.
[13] Pothan Laly A, Thomas Sabu, Neelakantan NR. Short banana fiber reinforced polyester composites: mechanical, failure and aging characteristics. J Reinf Plast Compos 1997;16(8):744–65.
[14] German Quintana et al. Binderless fiberboard from steam exploded banana bunch. Ind Crops Products 2009;29(1):60–6.
[15] Liu H, Wu Q, Zhang Q. Preparation and properties of banana fiber-reinforced composites based on high density polyethylene (HDPE)/Nylon-6 blends. Bioresour Technol 2009;100(23):6088–97.
[16] Rozman HD, Tay GS, Kumar RN, Abubakar A, Ismail H, Ishak Mohd ZA. Polypropylene hybrid composites: a preliminary study on the use of glass and coconut fiber as reinforcements in polypropylene composites. Polym–Plast Technol Eng 1999;38(5):997–1011.
[17] Abdul Khalil HPS, Hanida S, Kang CW, Nik Fuaad NA. Agro-hybrid composite: the effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. J Reinf Plast Compos 2009;26(2):203–18.
[18] Bledzki AK, Sperber VE, Faruk O. Natural and wood fibre reinforcement in polymers. Rapra Rev Rep 2002;13(152).
[19] Wambua P, Ivens J, Verpoest I. Natural fibres: can they replace glass in fibre reinforced plastics? Compos Sci Technol 2003;63(9):1259–64.
[20] De Vuyst P, Dumortier P, Swaen GMH, Pairon JC, Brochard P. Respiratory health effects of man-made vitreous (mineral) fibres. Eur Respiratory J 1995;8:2149–73.
[21] Penpatra S, Nintita S, Wantanee P, Maritta SJ. Respiratory and skin health among glass microfiber production workers: a cross-sectional study. Environ Health 2009;8:36.
[22] Rajan Akhila, Kurup Jayalakshmi Gopinadha. Biosoftening of arecanut fiber for value added products. Biochem Eng J 2005;25(3):237–42.

[23] Arifulla A, Goutham N, Ravikumar RB, Santhosh Kumar DG. Mechanical characterization of areca composites – an experimental study, B.E. dissertation, Department of Mechanical Engineering, GM institute of technology, Davangere; 2007.
[24] Anil SG, Ashish J, Jaeethendra HJ, Santhosh T. Effect of matrix and composite curing time on mechanical behaviour of areca composites – an experimental study, B.E. dissertation, Department of Mechanical Engineering, GM institute of technology, Davangere; 2008.
[25] Mohanty AK, Misra M, Hinrichsen G. Biofibres, biodegradable polymers and biocomposites: an overview. Macromol Mater Eng 2000;276–277(1):1–24.
[26] Jayamol George, Sreekala MS, Sabu Thomas. A review on interface modification and characterization of natural fiber reinforced plastic composites. Polym Eng Sci 2001;41(9):1471–85.
[27] Kalia Susheel, Kaith BS, Kaur Inderjeet. Pretreatments of natural fibers and their application as reinforcing material in polymer composites – a review. Polym Eng Sci 2009;49(7):1253–72.
[28] Mohanty Amar K, Misra Manjusri, Drzal Lawrence Thaddeus. Natural fibers, biopolymers, and biocomposites. CRC Press; 2005.
[29] Prasad Paras N, Mark James E, Kandil Sherif H, Kafafi Zakya H. Science and technology of polymers and advanced materials – emerging technologies and business opportunities. Springer-Verlag; 1998.
[30] Wang B, Panigrahi S, Tabil L, Crerar W. Pre-treatment of flax fibers for use in rotationally molded biocomposites. J Reinf Plast Compos 2007;26(5):447–63.
[31] Bogoeva-Gaceva G, Avella M, Malinconico M, Buzarovska A, Grozdanov A, Gentile G, et al. Natural fiber eco-composites. Polym Compos 2007;28(1): 98–107.
[32] Swamy RP, Mohan Kumar C, Vrushabhendrappa Y. Study of areca-reinforced phenol formaldehyde composites. J Reinf Plast Compos 2004;23(13):1372–82.
[33] Murali Mohan Rao K, Ratna Prasad AV, Ranga Babu MNV, Mohan Rao K, Gupta AVSSKS. Tensile properties of elephant grass fiber reinforced polyester composites. J Mater Sci 2007;42(9):3266–72.
[34] Singha AS, Thakur Vijay Kumar. Saccaharum cilliare fiber reinforced polymer composites. E-J Chem 2008;5(4):782–91.
[35] Franck RR. Bast and other plant fibres. Cambridge (UK): Woodhead Publisher; 2005.
[36] Zhong JB, Lv J, Wei C. Mechanical properties of sisal fibre reinforced urea formaldehyde resin composites. Express Polym Lett 2007;1(10):681–7.
[37] Karnani Rajeev, Krishnan Mohan, Narayan Ramani. Biofiber-reinforced polypropylene composites. Polym Eng Sci 2004;37(2):476–83.
[38] Pavithran C, Mukherjee PS, Brahmakumar M, Damodaran AD. Impact properties of natural fibre composites. J Mater Sci Lett 1987;6:882–4.