

## FLEXURAL BEHAVIOUR OF ARECA FIBERS COMPOSITES

Srinivasa Chikkol Venkateshappa,<sup>a</sup>\* Basavaraju Bennehalli,<sup>b</sup> Mownesh Gadde Kenchappa,<sup>a</sup> and Raghu Patel Gowda Ranganagowda<sup>c</sup>

A study has been carried out to evaluate physical and flexural properties of composites made by areca fibers with a randomly distributed orientation of fibers. The extracted areca fibers from the areca husk were alkali treated with potassium hydroxide (KOH) to get better interfacial bonding between fiber and matrix. Then composites were developed by means of a 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 and flexural tests. The results show that flexural strength increases with increase in the fiber loading percentage. Compared to untreated fiber, significant change in flexural strength has been observed for treated areca fiber reinforcement.

*Keywords: Natural Fibers Composites; Areca Fibers; Alkali Treatment; Water Absorption; Flexural Strength*

*Contact information: a: Department of Mechanical Engineering, GM Institute of Technology, Davangere-577 006, India; b: Department of Chemistry, Navodaya Institute of Technology, Raichur-584101, India; c: Department of Analytical Chemistry, Univ. B.D.T. College of Engineering, Davangere-577004, India; \*Corresponding author: srinikanadamani@gmail.com*

### INTRODUCTION

Environmental awareness, new rules, and legislation are forcing industries to seek new materials that are more environmentally friendly. Over the past two decades, plant fibers have been receiving considerable attention as substitutes for synthetic fiber reinforcements. Unlike the traditional synthetic fibers, such as glass and carbon, these lignocellulosic fibers are able to impart certain benefits to the composites, including low density, high stiffness, low cost, renewability, biodegradability, and a high degree of flexibility during processing.

In recent years, owing to the increased environmental awareness, the usage of lignocellulosic fibers as a potential replacement for synthetic fibers such as carbon, aramid, and glass fibers in composite materials have gained interest among researchers throughout the world. Extensive studies which have been done on lignocellulosic fibers such as sisal (Kuruvilla et al. 1996; Oksman et al. 2002), jute (de Albuquerque et al. 2000; Abdullah-Al-Kafi 2006), pineapple (Timir Baran Bhattacharyya et al. 1986; George et al. 1998; Uma Devi et al. 1997; Mishra et al. 2001), banana (Laly et al. 1997; Quintana et al. 2009; Liu et al. 2009), and oil palm empty fruit bunch fibers (Rozman et al. 1999; Abdul Khalil et al. 2009) have shown that lignocellulosic fibers have the potential to be an effective reinforcement in thermoplastics and thermosetting materials.

According to Bledzki *et al.* (2002) and Wambua *et al.* (2009), lignocellulose fibers offer several advantages over their synthetic fiber counterparts. Lignocellulose

fibers are abundant in nature, renewable raw material, and generally have a low cost. Owing to their low specific gravity, which is about 1.25-1.50 g/cm<sup>3</sup>, compared to synthetic fibers, and especially glass fiber, which is about 2.6 g/cm<sup>3</sup>, 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 glass fiber dust from the trimming and mounting of glass fiber components causes skin irritation and respiratory diseases among workers. Besides that, the less abrasive nature of the lignocellulose fibers offers a friendlier processing environment, as the wear of tools could be reduced. Furthermore, lignocellulose fibers offer good thermal and insulating properties, and they are easily recyclable and are biodegradable, especially when used as reinforcement in a biopolymer matrix.

Although there have been numerous studies on the 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 Linnaeus* under the family Palmecea and originates in the Malaya Peninsular, East India (Akhila Rajan et al. 2005). Major Indian cultivation is in East India and other countries in Asia. 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 to 80% of the total weight and volume of the fresh fruit. The average filament length (4 cm) of the areca 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 such as thick boards, fluffy cushions, non-woven fabrics, thermal insulators, and non-woven fabrics (Arifulla et al. 2007). The present use of this high-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 (Anil et al 2008; Swamy et al. 2004). Therefore, extensive planning for the disposal of husk is required. Thus, the use of this unmanaged husk as a structural material requires detailed study of physical, chemical, and thermal characteristics.

In order to develop composites 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 interfacial 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 has indicated the effect of alkali treatment in improving fiber strength, fiber-matrix adhesion, and the performance of the natural fiber composites.

Currently, there is no information on the flexural properties of areca fibers reinforced with melamine urea formaldehyde and epoxy resins. Therefore, this study seeks to determine the physical and flexural 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.

## **MATERIALS AND METHODS**

### **Matrix Materials**

Urea formaldehyde and Melamine urea formaldehyde were supplied by Akolite Synthetic Resins, Mangalore, Karnataka, India. The Epoxy-556 resin and the Hardener (HY951) were supplied by Ciba Geigy India Ltd. Areca empty fruit bunch fibers (husk) were obtained from Madhu Farm House Nilgal, Davangere, Karnataka, India.

### **Methods**

#### *Fiber extraction*

Selected areca fruit husks were used to prepare the composites. Dried areca husk was soaked in deionised water for about five days. The soaking process loosens the fibers, which then 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 were designated as untreated fibers.

#### *Alkali treatment*

First the 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 hours at a temperature of 30° C; they were thoroughly washed in running water and 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 was approximately 7 (neutral). Then they were dried at room temperature for 48 hrs to obtain alkali-treated fibers.

#### *Preparation of composites*

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

- a) Composites containing 50 and 60 wt% of alkali-treated and untreated areca fibers, containing urea formaldehyde resin (UFR) and designated as UF50 Treated, UF50 Untreated, UF60 Treated, and UF60 Untreated.
- b) Composites containing 50 and 60 wt% of alkali-treated and untreated areca fibers, containing melamine urea formaldehyde resin (MUF), and designated as MUF50 Treated, MUF50 Untreated, MUF60 Treated and MUF60 Untreated.
- c) Composites containing 50 and 60 wt% 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. This mixture was left for 10 minutes, and then the mixture was filled into the mould of 300x300x50 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 minutes. After that, the composites were post-cured at room temperature ( $27\pm 3^{\circ}\text{C}$ ) for 24 hours.

#### *Characterization*

The prepared composite boards 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  $27^{\circ}\text{C}$  and 46% relative humidity.

The major drawback of natural fiber reinforced composites is due to its greater affinity to water. According to ASTM D570-99 procedure (ASTM 1999), rectangular specimens were cut from each sample with dimensions of 25.4 mm x 76.2 mm. According to ASTM-D790 the composite specimen was prepared for three-point bend tests. Each test specimen was prepared with 50 mm width, length 240 mm, and thickness 10 mm. The span of the supports was 100 mm. Each specimen was loaded at the center of the span through a loading cell, and the loading rate was 2mm/min.

## **RESULTS AND DISCUSSION**

The experimental method employed is one of the most important techniques for 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, as well as 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 that different degrees of reinforcement effects are achieved by the addition of hydrophilic fibers to different polymers. This may be due to the different adhesion strength between matrix and fibers.

#### **Dimensions and Density of Areca Fibers**

Natural fibers exhibit considerable variation in diameter along with the length of individual filaments. 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 0.01 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, 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 presented in Table 1. The diameter of the fiber varied from 0.0285 to 0.89 mm, the length of the fibers varied from 18-38 mm, and the density varied from 1.05-1.25 g/cm<sup>3</sup>. Three types of fibers were observed, and these were classified as short, medium, and long fibers.

**Table 1.** Physical Properties of Areca Fiber

Diameter(mm)	Length of Fiber (mm)				Density(g/cm <sup>3</sup> )
	Short	Medium	Long	Average	
0.285-0.89	18-29	30-38	39-46	29-38	1.05-1.25

### Chemical Composition

Lignocellulosic 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, thermoplasticity, and degradability by ultraviolet light, acids, and bases. All of these characteristics will result in specific end use characteristics 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. Table 2 shows chemical compositions of 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, 4.4% of ash, and a negligible percentage of cellulose. The areca fibers exhibited a high percentage of hemicellulose compared to other natural fibers listed in Table 2.

**Table 2.** Chemical Composition and Structural Parameters of Natural Fibers

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

<sup>#</sup>Arifulla, A. et al. 2007; <sup>\*</sup>Anil, S.G. et al. 2008; <sup>\*\*</sup>Rajan, A. et al. 2005

Selective removal of non-cellulosic compounds constitutes the main objective of fiber chemical treatment. 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. 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 applications.

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 lignocellulosic, consisting of helically wound cellulose micro fibrils in an amorphous matrix of lignin and hemicellulose.

### Water Absorption

According to ASTM procedure D570-99 (ASTM 1999), rectangular specimens were cut from each sample with dimensions of 25.4 mm x 76.2 mm. The composite samples were first dried by heating in an oven at 50°C for about 24 hours, then cooled in a desiccator, and weighed immediately to the nearest 0.001 g.

To measure the water absorption of the composites, all of the samples were immersed in beaker containing water for about 24 hours at room temperature. After every 24 hours the specimens were taken out, and excess water on the surface of the samples was removed thoroughly before weighing the samples. The percentage increase in weight during immersion was calculated to the nearest 0.01%. Three replicate specimens were tested, and the results were presented as average of the tested specimens. The details of amount of water absorbed by composites were studied and reported in Table 3.

**Table 3.** Details of Water Absorption of Areca Fibers Composites

Composite	Fiber loading (wt. %)	Fiber Type	Percentage of Water Absorbed by the Composites		
			Lake Water	River Water	Sea Water
Areca-UF Composite	50	Untreated	29.87	25.65	39.02
		Treated	28.93	23.53	37.89
	60	Untreated	29.57	24.68	38.22
		Treated	28.33	22.79	36.48
Areca MUF Composite	50	Untreated	32.03	39.06	26.68
		Treated	30.11	37.96	24.23
	60	Untreated	31.01	38.53	25.07
		Treated	29.34	37.86	23.88
Areca-Epoxy Composite	50	Untreated	28.03	21.08	25.60
		Treated	26.78	19.42	23.04
	60	Untreated	27.05	20.67	24.78
		Treated	22.50	18.01	21.02

The tabulated value indicates that the effect of chemical treatment on fibers is to drastically reduce the percentage of water absorbed by the composites. The fibers reinforced with urea-formaldehyde resin had greater tendency to absorb sea water (39.02%), the fibers reinforced with melamine urea formaldehyde had more affinity towards river water (39.06%), and the areca-epoxy composite had more affinity towards

lake water (28.03%). It can also be seen that the composite using higher fiber volume content (60 wt. %) have lower water absorption than composite using a lower fiber volume content (50 wt. %). This may be due to the higher compatibility between the hydrophilic fiber and matrix for composite (60 wt. %). When using the composite with (50 wt. %) the weak compatibility between the fiber surface and the adhesive could lead to the formation of void structures within the composites, which facilitates water absorption. Therefore these results shows that the composite made of areca fibers with chemically treated had significantly less water absorption than wood based particle board (more than 40%).

### Flexural Properties

Flexural 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 fibers composites. The effect of volume fraction of fiber and alkali treatment on flexural strength for areca fiber reinforced with urea formaldehyde, melamine urea formaldehyde, and epoxy composites are presented in Figs. 1 through 3, respectively. The results showed that, as expected, the flexural strength was higher for the samples with alkali-treated fibers, compared with those without alkali treatment. It is observed that the flexural strength of all fiber reinforced composites considered in the present study increased with volume fraction of fiber.

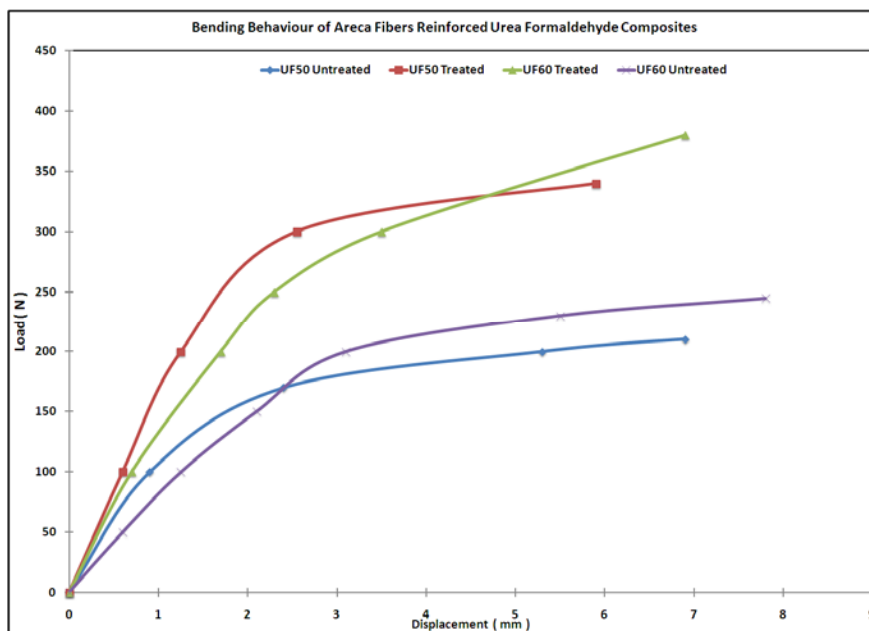


Fig. 1. Bending behaviour of areca fibers reinforced urea formaldehyde composites

The load–deflection curve for areca fibers reinforced urea-formaldehyde composites is shown in Fig. 1. This figure shows that the flexural load for the composites increased with increase in volume fraction of fiber. From Fig. 1 the UF60 Treated composite achieved the maximum flexural load compared to other composites, and the

UF50 Untreated composite showed the least flexural load bearing capacity.

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

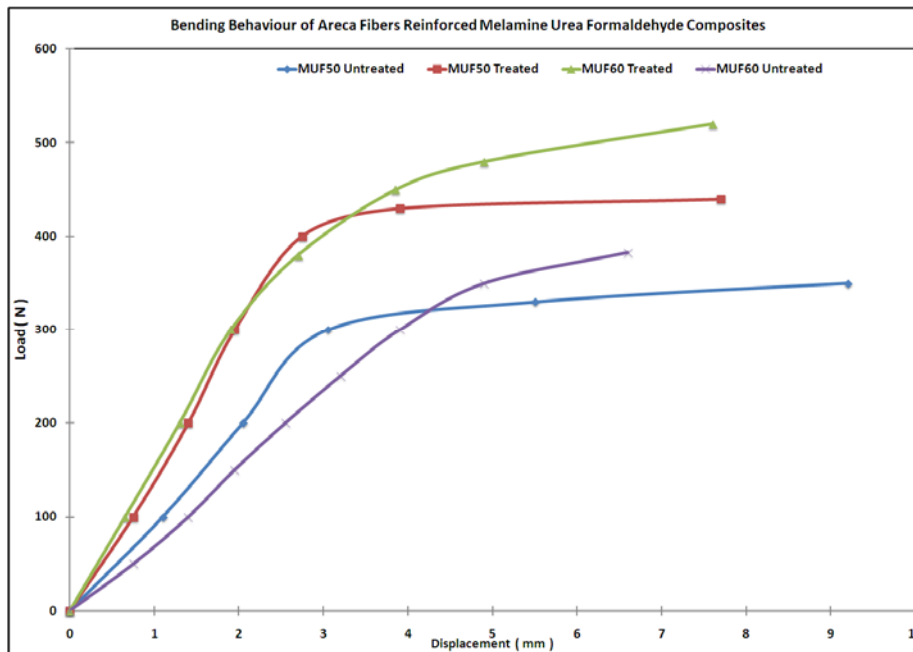


Fig. 2. Bending behaviour of areca fibers reinforced melamine urea formaldehyde composites

Figure 2 shows the load–deflection curve for areca composites using melamine-urea-formaldehyde resin. 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 addition of melamine to urea formaldehyde has better adhesion strength, as reported by Zhong et al. (2007). It is seen that the flexural load of the composite increased with increase in the fiber content. The untreated areca melamine-urea-formaldehyde (MUF50) composite achieved a maximum flexural load of 350 N. It is also seen that, this value increased to 440 N for alkali-treated samples with the same proportion of fiber loading. Similarly, MUF60 (with an addition of 10wt%) for treated and untreated fibers composite, the maximum flexural load withstanding capacity increased to 383 N and 464 N, respectively. A similar trend was observed in case of flexural strength of these composites. These results clearly indicate that the addition of melamine to the urea formaldehyde increased the bonding strength and in turn increased the flexural load withstanding capacity of the composite. The percentage of increase in the flexural load withstanding capacities of melamine urea formaldehyde were 40%, 22.72%, 36.03%, and 18.10% when compare to UF50 Untreated, UF50 Treated, UF60 Untreated, and UF60 Treated, respectively.



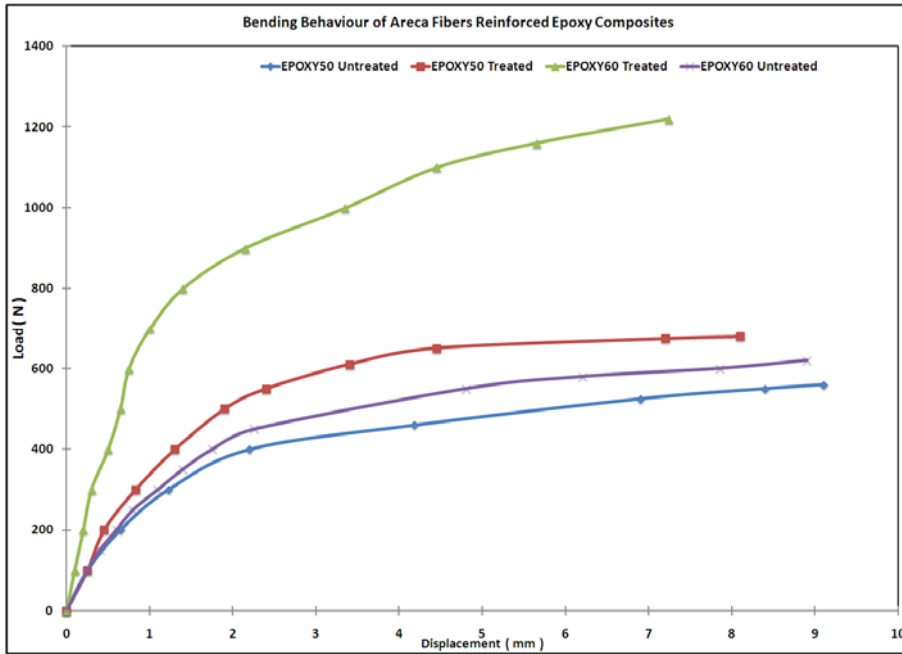


Fig.3. Bending behaviour of areca fibers reinforced epoxy composites

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

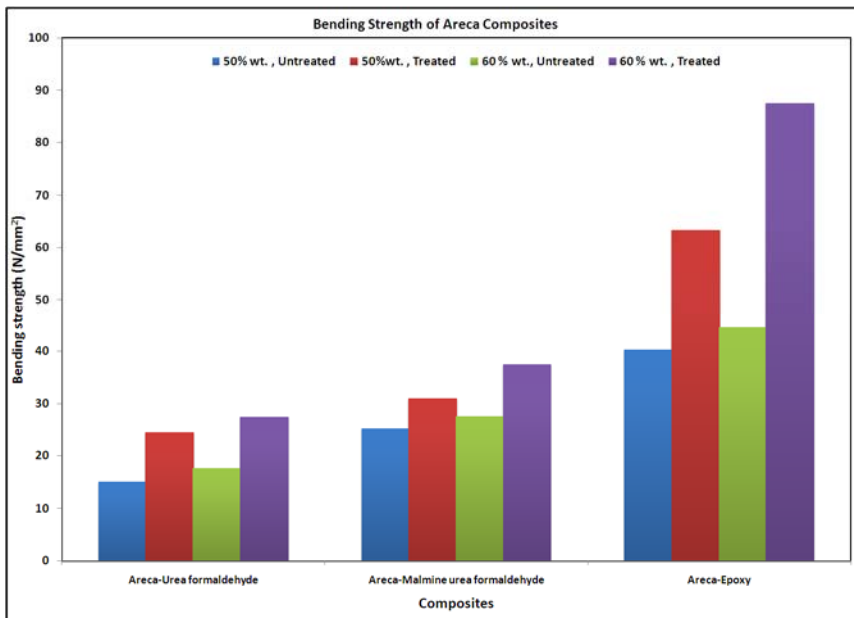
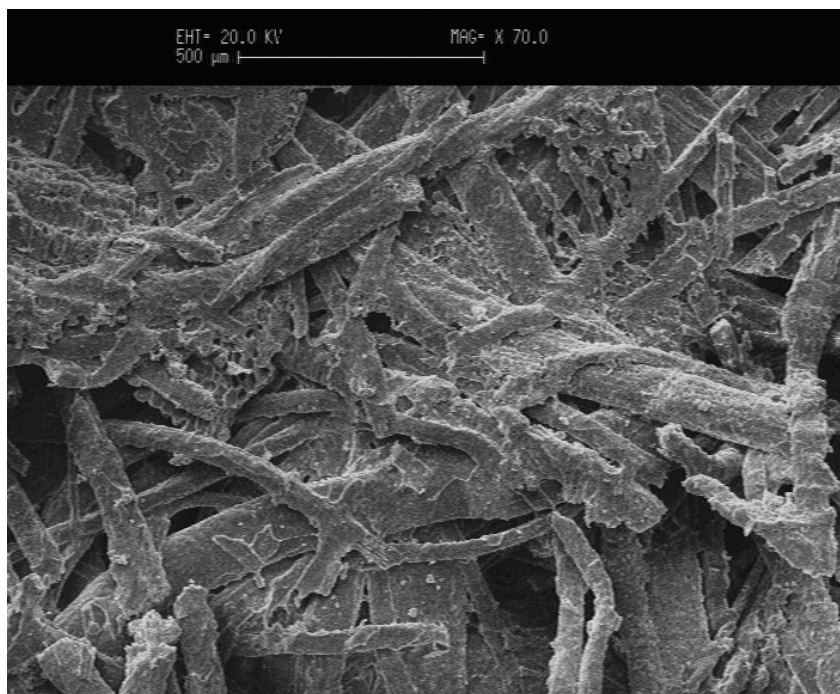


Fig. 4. Bending strength of areca composites

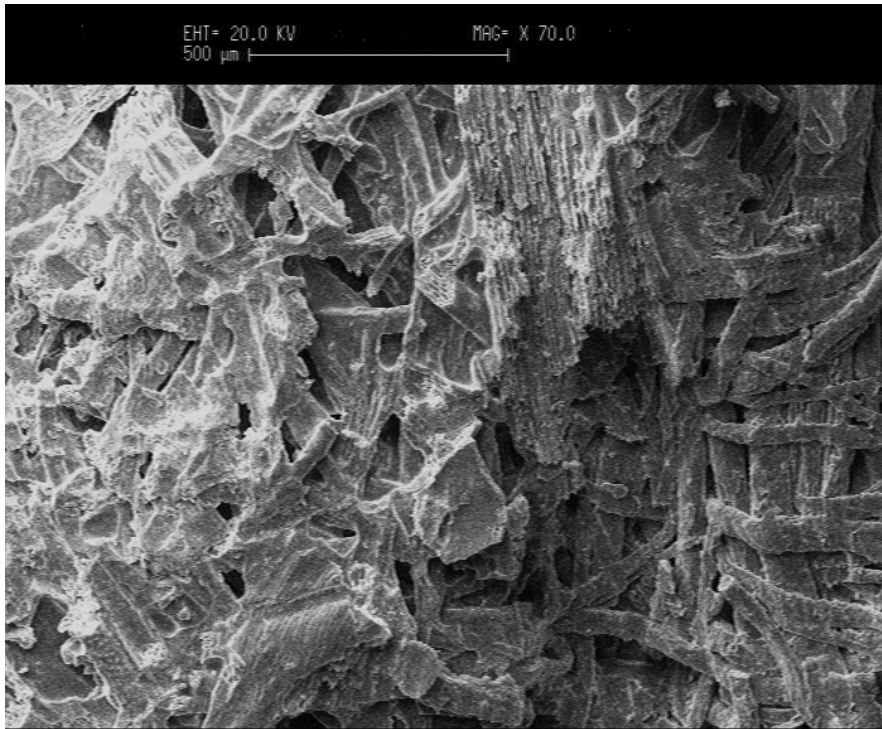
The flexural strength of all composites considered in the present study increased with volume fraction of fiber in the composite as well as the post-curing time. Overall, the results showed that areca fibers using epoxy exhibited higher flexural strength than areca fibers using formaldehyde groups. This may be because the fiber has better reinforcement effects in epoxy than in formaldehyde groups. Also an improved mixing will provide better distribution of areca fibers, and the gaps between the fibers can be bridged more effectively.

### Morphological Study

Scanning electron microscopic (SEM) photographs of untreated and alkali-treated areca fibers composite samples were obtained with a JEOL JSM-T330A scanning electron microscope at the accelerating voltage of 20 kV. The SEM micrographs of untreated and alkali-treated areca fibers reinforced with epoxy are shown in Figs. 5 and 6, respectively. Changes in the surface topography of the fibers after treatments were studied by using a scanning electron microscopy. It can be observed that the untreated areca fiber (Fig. 5) presents a network structure in which the fibrils are bound together by hemicellulose and lignin. By contrast, in Fig. 6, it is clear that the hemicellulose and lignin were partially removed, resulting in surfaces with a higher degree of roughness and effective surface area. In addition, this fibrillation could have increased the effective surface area available for contact with the matrix in the composites, as well as reduced the diameter of areca fibers, thereby increasing their aspect ratio. This may offer better fiber-matrix interfacial adhesion and improve stress transfer. These will give rise to improvement in mechanical properties.



**Fig. 5.** Microstructure of the fiber-matrix interface of the untreated areca fibers reinforced epoxy composite (untreated, ER60)



**Fig. 6.** Microstructure of the fiber-matrix interface of the treated areca fibers reinforced epoxy composite (Alkali Treated-ER60)

## CONCLUSIONS

The results presented in this work can be summarized as follows:

- 1) In general it is possible to enhance the properties of fiber-reinforced composites through fiber surface modification.
- 2) Composites based on the alkali-modified fiber surfaces have, in general, superior mechanical properties to composites containing unmodified fibers.
- 3) This is primarily a result of improved adhesion and enhanced polar interactions at the fiber-matrix interfaces.
- 4) Hence, based on the availability, low cost, and good strength characteristics of areca fiber composites investigated in the present study, the composite can be considered as a very promising material for 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.

The present work limits fiber loading in matrix systems to about 60% by weight of fiber. To produce high fiber content composites for commercial use while maintaining adequate mechanical properties requires innovative processing techniques.

## ACKNOWLEDGMENTS

The authors would like to thank Karnataka State Council for Science and Technology, Bangalore, Karnataka, India for providing financial assistance (30S345 and 31S268), Sri G Rangana Gowda, Proprietor, Madhu Farm House, Nilogal for providing a good quality areca fruit husk, and Sri G.M. Lingaraju, Secretary, GM Institute of Technology, Davangere, Karnataka, India, who has made this work possible.

## REFERENCES CITED

- Abdullah-Al-Kafi (2006). "Study on the mechanical properties of jute/glass fiber-reinforced unsaturated polyester hybrid composites: Effect of surface modification by ultraviolet radiation," *Journal of Reinforced Plastics and Composites* 25(6), 575-588.
- Abdul Khalil, H. P. S., Hanida, S., Kang, C. W., and Nik Fuaad, N. A. (2009). "Agro-hybrid composite: The effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites," *Journal of Reinforced Plastics and Composites* 26(2), 203-218.
- Anil, S. G., Ashish, J., Jaeethendra, H. J., and Santhosh, T. (2008). "Effect of matrix and composite curing time on mechanical behaviour of areca composites – An experimental study," *B.E dissertation*, Dept. of Mechanical Engineering, GM institute of Technology, Davangere, Karnataka, India.
- Arifulla, A., Goutham, N., Ravikumar, R. B., and Santhosh Kumar, D. G. (2007). "Mechanical characterization of areca composites – An experimental study," *B.E dissertation*, Dept. of Mechanical Engineering, GM Institute of Technology, Davangere, Karnataka, India.
- Bhattacharyya, T. B., Biswas, A. K., Chatterjee, J., and Pramanick, D. (1986). "Short pineapple leaf fibre reinforced rubber composites," *Plastics and Rubber Processing and Applications* 6(2), 119-125.
- Bledzki, A. K., Sperber, V. E., and Faruk, O. (2002). "Natural and wood fibre reinforcement in polymers," *Rapra Review Reports* 13(152).
- de Albuquerque, A. C., Kuruvilla, J., de Carvalho, L. H., and Morais d'Almeida, J. R. (2000). "Effect of wettability and ageing conditions on the physical and mechanical properties of uniaxially oriented jute-roving-reinforced polyester composites," *Composites Science and Technology* 60(6), 833-844.
- Jayamol, G., Sreekala, M. S., and Sabu, T. (1998). "Stress relaxation behavior of short pineapple fiber reinforced polyethylene composites," *Journal of Reinforced Plastics and Composites* 17(7), 651-672.
- Kuruvilla, J., Varghese, S., Kalaprasad, G., Thomas, S., Prasannakumari, L., Koshy, P., and Pavithran, C. (1996). "Influence of interfacial adhesion on the mechanical properties and fracture behaviour of short sisal fibre reinforced polymer composites," *European Polymer Journal*, 32(10), 1243-1250.
- Liu, H., Wu, Q., and Zhang, Q. (2009). "Preparation and properties of banana fiber-reinforced composites based on high density polyethylene (HDPE)/Nylon-6 blends," *BioresourceTechnology* 100(23), 6088-6097.

- Mishra, S., Misra, M., Tripathy, S. S., Nayak, S. K., and Mohanty, A. K. (2001). "Potentiality of pineapple leaf fibre as reinforcement in PALF-polyester composite: Surface modification and mechanical performance," *Journal of Reinforced Plastics and Composites* 20(4), 321-334.
- Oksman, K., Wallström, L., Berglund, L. A., and Toledo Filho, R. D. (2002). "Morphology and mechanical properties of unidirectional sisal-epoxy composites," *Journal of Applied Polymer Science* 84(13), 2358-2365.
- Pothan, L. A., Thomas, S., and Neelakantan, N. R. (1997). "Short banana fiber reinforced polyester composites: Mechanical, failure and aging characteristics," *Journal of Reinforced Plastics and Composites* 16(8), 744-765.
- Quintana, G., Velasquez, J., Betancourt, S., and Ganán, P. (2009). "Binderless fiberboard from steam exploded banana bunch," *Industrial Crops and Products* 29(1), 60-66.
- Rajan, A., and Kurup, J. G. (2005). "Biosoftening of arecanut fiber for value added products," *Biochemical Engineering Journal* 25(3), 237-242.
- Rozman, H. D., Tay, G. S., Kumar, R. N., Abubakar, A., Ismail, H., and Mohd. Ishak, Z. A. (1999). "Polypropylene hybrid composites: A preliminary study on the use of glass and coconut fiber as reinforcements in polypropylene composites," *Polymer-Plastics Technology and Engineering* 38(5), 997-1011.
- Swamy, R. P., Mohan Kumar, C., and Vrushabhendrapa, Y. (2004). "Study of areca-reinforced phenol formaldehyde composites," *Journal of Reinforced Plastics and Composites* 23(13), 1372-1382.
- Uma Devi, L., Bhagawan, S. S., and Thomas, S. (1997). "Mechanical properties of pineapple leaf fiber-reinforced polyester composites," *Journal of Applied Polymer Science* 64, 1739-1748.
- Wambua, P., Ivens, J., and Verpoest, I. (2003). "Natural fibres: Can they replace glass in fibre reinforced plastics?," *Composites Science and Technology* 63(9), 1259-1264.
- Zhong, J. B., Lv, J., and Wei, C. (2007). "Mechanical properties of sisal fibre reinforced urea formaldehyde resin composites," *eXPRESS Polymer Letters* 1(10), 681-687.

Article submitted: June 7, 2010; Peer review completed: June 28, 2010; Revised version received: July 2, 2010; Accepted: July 13, 2010; Published: July 15, 2010.