ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Mechanical Properties of sandwich Composites made using *Prosopis juliflora*, sisal and Glass fibers

[1]R Gopinath, [2]K Ganesan, [3]S.S Saravana Kumar and [4]R Poopathi

[1]*Gopinath Rudramurthy, Research Scholar, Anna University, Chennai-600025 TamilNadu, INDIA*
[2]*Department of Civil Engineering, Sudharshan Engineering College, Pudukkottai, TamilNadu, INDIA.*
[3]*Department of Mechanical Engineering Kamarajar College of Engineering,VirudhuNagar, TamilNadu ,INDIA.*
[4]*Department of Civil Engineering, University College of Engineering, Tindivanam , TamilNadu, INDIA.*

ARTICLE INFO

Article history:
Received 10 October 2015
Accepted 30 November 2015
Available online 24 December 2015

Keywords:
Sandwich composite, alkali treatment, strength, impact, water absorption

ABSTRACT

In this paper, the mechanical properties of composite laminates made using natural fibers as sandwich material between the layers of glass fiber mats has been experimentally investigated and discussed. The fibers obtained from the bark of *prosopis juliflora* tree, and sisal fibers ground to various sizes were used as sandwich material. Vinyl ester resin was used as matrix and compounds such as cobalt naphathanete, methyl ethyl ketone peroxide and dimethyl amine were used as accelerator, catalyst and promoter. In order to improve the adhesion between fiber and matrix, natural fibers were subjected to alkali treatment with NaOH used at 6% concentration. The composite laminates were prepared using hand layup and cold press technique. Eight different types of laminates were made by varying the type, size and proportion of natural fibers and three different size fractions namely coarse, medium and fine were adopted for the natural fibers. It is inferred from the test results that laminates containing *prosopis juliflora* fibers in mixed sizes exhibited substantial improvement in tensile, flexural and impact strength. The percentage of water absorption was found to get lowered for specimen containing *prosopis* fibers in all size fractions equally.

© 2015 AENSI Publisher All rights reserved.

To Cite This Article: R Gopinath, K Ganesan,.S Saravana Kumar and R Poopathi., Mechanical Properties of sandwich Composites made using *Prosopis juliflora*, sisal and Glass fibers. ***Aust. J. Basic & Appl. Sci.,*** *9(35): 1-9, 2015*

INTRODUCTION

Fiber reinforced composites are widely used due to its inherent advantages such as light weight, good corrosion resistance, high resistance against impact and fatigue loads, and high abrasive resistance against wear and tear. The fibers used for reinforcing polymer matrix include both artificial and natural. Some of the most commonly used artificial fibers are glass, aramid, kevlar and carbon. Based on the source of origin, natural fibers are broadly classified as plant, animal and mineral fibers. Plant fibers are extensively used because of their abundant availability, low energy for processing, ease biodegradability and high strength. The main components of plant fibers are cellulose, hemicelluloses, lignin, pectin, waxes and other impurities. Cellulose fibrils embedded in lignin matrix offers the strength, stability and rigidity to the fiber (Kabir *et al*., 2011). Plant fibers which have been used for making composites include cotton, flax, hemp, coir, sisal, jute and abaca. The presence of hydroxyl groups at the surface of cellulose fibers adversely affects the adhesion between the fiber and matrix (John and Thomas, 2008). Various Chemical treatments such as alkali treatment, permanganate treatment, benzoylation, silane, cyanoethylation, acetylation and acrylation are adopted to modify the surface of plant fibers so that better adhesion with the matrix is achieved (Thomas *et al*., 2009; Joseph *et al*., 2008). Apart from hydrophilicity, plant fibers suffer from drawback of degradation at low temperatures. One way to improve the resistance of plant fibers against water absorption and thermal degradation is to hybridize them with synthetic fibers (Jawaid and Abdul Khalil, 2011). Maleic anhydride grafted polypropylene treated banana/glass hybrid composites were found to exhibit higher thermal stability compared to banana fiber reinforced polymer composite (Samal *et al*., 2009). Thermal analysis of hemp/glass fiber reinforced hybrid composites revealed that hybridization of hemp and glass fiber shifts the temperature of degradation to an appreciably higher value than that of hemp fiber reinforced composites (Panthapulakkal and Sain, 2007). Jute/glass fiber reinforced epoxy composites was found to have improvement in water absorption behaviour compared to jute composite and glass

Corresponding Author: Gopinath Rudramurthy, Research Scholar, Anna University, Chennai-600025 TamilNadu, India
E-mail: ramanaocean@gmail.com, Ph: +919994678825.

composite (Koradiya *et al*., 2010). In banana/glass fiber reinforced composites, water absorption was found to get appreciably reduced when glass fibers are provided at the periphery and banana fibers at the core of the laminate (Joseph *et al*., 2008). The mechanical properties of randomly mixed Palmyra/glass fiber hybrid composites were found to get enhanced appreciably when fiber skin core construction is adopted rather than dispersed fiber construction (Velmurugan and Manikandan, 2007). Apart from strength, ductility of composites gets enhanced when fibers are used in hybrid combination rather than in single form (Hariharan *et al*., 2004; Vijaya Ramnath *et al*., 2013). During the past decades, numerous researches have been carried out to explore promising natural fibers for making composites. In tropical country like India, *Prosopis Juliflora* is a woody weed tree grows abundantly in regions of inhospitable environment, on nutrient poor, saline and alkaline soils. The roots of this species extend vertically to a depth of 35m and spreads horizontally in the direction of water flow. They are capable of transferring fertile land into dense thickets of impenetrable tree stands (Pasiecznik *et al*., 2001). High stiff fibers were extracted from the bark of *Prosopis Juliflora* tree and subjected to tensile test. The tensile strength of the fiber was found to be 558MPa (Saravanakumar *et al*., 2013). Among the other lignocellulosic fibers like jute, sisal, coir and pine apple, sisal fibers have high impact strength besides have moderate tensile and flexural properties compared to other fibers (Joseph *et al*., 1999). In this paper, an attempt has been made to study the mechanical properties of hybrid composites made using *prosopis juliflora*, sisal and glass fibers. The fiber surface modification for *prosopis juliflora* and sisal fibers was carried out by subjecting them to alkali treatment using NaOH solution at 5% concentration. Tests such as tensile, flexural, impact and water absorption were performed on the hybrid composite laminates and the results obtained were discussed.

MATERIALS AND METHODS

In the present investigation *Prosopis Juliflora* (PJ), sisal (*Agave sisalana*) and GFRP fibers are used for fabricating the composite specimen. The stems (approx. 25mm diameter) of *Prosopis Juliflora* bark were collected from Tindivanam, TamilNadu, South India. The barks of *PJ* were immersed in water for a period of two weeks so as to allow for microbial degradation and also to facilitate easy removal of inner bark fibers through traditional combing process.[13] Sisal fibers are extracted from the leaves of *Agave sisalana* through decortification process.[15] Vinyl ester resin and compounds such as cobalt naphthanate, methyl ethyl ketone peroxide and dimethyl amine used as accelerator, catalyst and promoter was obtained from M/s. Sakthi fiber glass Ltd., Chennai, India. Glass fiber bi directional woven roving mat of 610gsm was used for top, middle and bottom layers of the five layer laminate. The natural fibers obtained from the bark of PJ tree and sisal fibers were used in different size fractions. Three different size fractions namely (I) Coarse-15 to 4.75mm, (II) Medium-4.75 to 2.36mm and (III) Fine-2.36 to 1.18mm were adopted. The detail about natural fibers used in sandwich layer is given in Table 1.

Table 1: Details about natural fibers used in each specimen

Specimen	Core Material	Details of size fraction of Core material
S1	Prosopis Juliflora (PJ)	PJ- I
S2		PJ- II
S3		PJ- III
S4		PJ- I- 50%, II &III- 25% each
S5		PJ- I- 25% , II & III- 37.5% each
S6		PJ- I, II, III in equal proportions
S7	Prosopis juliflora and Sisal fibers in alternate layers	PJ - II & Sisal - II
S8		PJ- III & Sisal- III

Note: I-Coarser, II-Medium and III-Fine

The composite laminates were fabricated by adopting both hand layup and cold pressing technique. Eight different types of laminates were made with volume fraction of glass fibers and natural fibers kept constant in all specimens as 30 and 22%. In the five layer composite laminate, glass fiber constitutes top, middle and bottom layer with chopped natural fibers in different size fraction placed in between them. Both PJ and sisal fibers were subjected to alkali treatment using sodium hydroxide solution at 5% concentration. Two mild steel plates of size 30 x 30cm with provision for bolt and nut fixtures were used as mould for fabrication. Initially, the bottom of steel plate was coated with releasing agents such as wax or PVA and allowed to dry. Vinyl ester resin added with catalyst, accelerator and promoter at 1.5% by its weight was then applied on the wax coated surface of the mould. Glass fiber mat was then placed on it and uniformly applied with the resin. The surface of fiber mat was subjected to rolling operation using metal rollers, such that air entrapped between fiber-matrix interface is removed.

For the second layer, chopped natural fiber of particular type, size fraction and proportion was intimately mixed with resin taken in a bowl. The mixture was then spread over the surface of glass fiber mat and gently tamped using brush so that dense packing of particulates can be ensured. Glass fiber layer is then placed over it and applied with resin. The fourth and fifth layer consisting of natural fiber and glass fiber were constructed by adopting the procedure as adopted for earlier layers. After completion of layup process, mild steel plate covered with Teflon sheet was then placed on top of the laminate and tightened with bottom steel plate using bolt and nut fixtures. Metal weights were placed on the top of steel plate to ensure the specimen has no air bubble and also ensuring the homogeneity of the specimen. Finally, the specimen was removed from the mould and kept in an oven at 60^0c for 2hours. The specimens were then cut to different sizes for performing the tests as per ASTM standards.

Testing Methodology:

Tensile Test:

The specification of ASTM 638-02 was followed for performing the test. During tensile testing, the specimen is cut in the shape of dumb bell with a gauge length of 50mm. The test was conducted using TUN Universal testing machine with the cross head speed maintained at 5mm/min.

Flexural Test:

The test for flexure was performed according to ASTM 790 and the dimension of the specimen adopted was 150 x 20 x 5mm. The specimen was loaded at mid span with span of specimen kept as 120mm and cross head speed maintained at 1mm/min. The maximum flexural stress was observed on the outer surface of the specimen at mid point.

Impact Test:

The test for determining the IZOD pendulum impact resistance of the laminate was performed following the specifications of ASTM D256. The results obtained during the test gives the energy absorbed per unit of cross sectional area under the notch. The notch in the specimen serves to concentrate the stress, minimize plastic deformation and direct the fracture to the part of the specimen behind the notch.

Water absorption test:

The size of the specimen used for this test was 76.2x 25.4x3.5mm. Test procedure stipulated in D 570 was adopted. Initially, the specimen was kept in oven at 70^0C for 24hrs and then weighed (W_1). The specimen is then soaked in a bath of deionised water at room temperature for 24 hrs and weighed (W_2). The samples were reconditioned for 24 hr at 70^0C in dried condition and reimmersed in water. After the test period the samples were taken out of water, dried and reweighed (W_3). The percentage of water absorption can be computed using the formula as given below.

Percentage of Water Absorption

$$= \frac{W_2 - W_3}{W_3} \times 100 \qquad (1)$$

RESULTS AND DISCUSSION

The test results are given in Table 3 and the photograph of specimens after tensile and impact test is given in Figure 1 and 2.

Table 2: Test results of Laminates

Specimen	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (J/cm^2)	Water Absorption (%)
S1	82.02	369.51	57.96	1.60
S2	87.10	286.29	18.90	2.06
S3	87.03	478.32	19.35	2.14
S4	109.29	279.62	23.98	1.39
S5	70.49	234.95	21.27	1.70
S6	76.76	251.38	15.77	0.73
S7	68.45	173.12	10.91	4.17
S8	88.98	186.67	12.27	2.03

Tensile Properties:

It is evident from Table 2, that maximum tensile strength of 109.29 MPa was reported for specimen S4. The increase in tensile strength could be attributed to the fact that gaps formed between coarser fiber particulates get filled by fibers of next lower size thereby resulting in dense packing of fibers. The other specimens which showed better tensile strength include S8, S2 and S3. Strain compatibility, good bonding characteristics and higher elongation at break could be possible reasons for enhanced tensile strength of S8. In short fiber reinforced composites, critical fiber length is required for the fiber to develop its fully stressed condition in the matrix. When the fiber length is less than critical, fiber debonds from the matrix prematurely at low load. It is also observed that increase in fiber length beyond optimum does not result in increase in tensile strength (Thomas *et al*., 1995). In the present study, the optimum fiber length of prosopis and sisal was found to be in the range between 4.75 to 1.18 mm. In this range of

fiber size, uniform dispersion and effective stress transfer between fiber–matrix results. The plot of tensile stress versus strain is shown in Figure 3.

Fig. 1: Specimens after tensile test

Fig. 2: Specimens after Impact Test

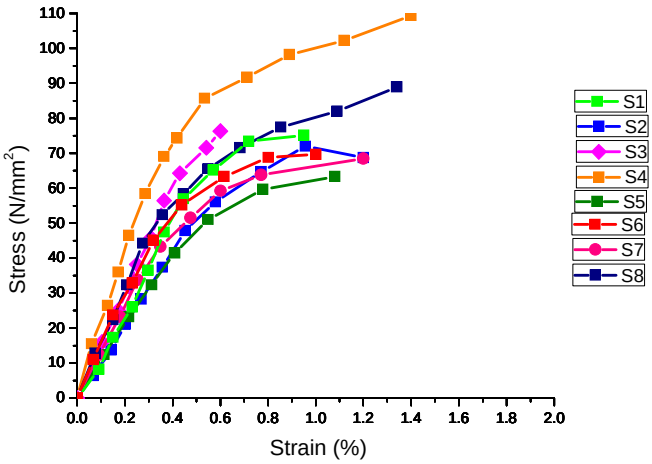

Fig. 3: Plot of Tensile stress vs. strain

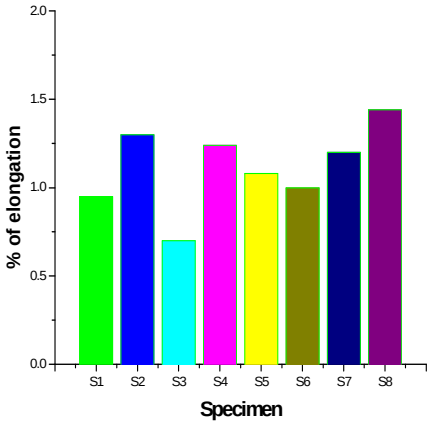

Fig. 4: Plot of percentage of elongation

The initial portion of stress –strain curve for all specimens are observed to be linear and with increase in stress, the curve exhibits nonlinear variation. During the initial part of loading, glass fibers shares the load due to which stress-strain variation was linear and when the strain reaches the *Prosopis Juliflora* failure strain the curve becomes nonlinear (Velmurugan and Manikandan, 2007). The values of percentage of elongation at break of all specimens were found to be very low, as low as 2%. The decrease in percentage of elongation at break for prosopis containing specimens could be attributed to the fact that lower density of prosopis increases its volume fraction and brittleness. The variation of percentage of elongation at break of all specimens is plotted in Figure 4. It can be observed from the

Figure 4, that maximum percentage of elongation at break was reported for S4 and lowest for S3. It can be understood from the results the percentage of elongation mainly depends on fiber loading, fiber length and fiber- matrix adhesion. In a study on short pine apple fiber reinforced low density polyethylene composites, it was observed that at 30% fiber loading the percentage of elongation at break was found to be 4% for fiber length of 2mm and 6mm, and 7% for 10mm (Thomas *et al*., 1995). In the present study, the value of percent of elongation at break was found to be identical for S1 and S2 and get reduced drastically for S3. Thus elongation of fibers of was found to get reduced appreciably with decrease in the length of fiber. It is worth to compare the test results of previous works on five layer hybrid composites with glass fiber skin at top, middle and bottom layers, and chopped natural fibers placed in between glass fiber layers. The tensile strength of Banana/ glass fiber reinforced epoxy matrix composites was found to be 104 MPa and that of Sisal/glass fiber composites was 93 MPa (Arthanarieswaran *et al*., 2014). Thus the tensile strength of Prosopis/glass fiber composite is equally comparable with other sandwich composites made using promising natural fibers.

Flexural Properties:

It can be observed from Table 2, highest flexural resistance was offered by specimen S3 followed by S1. In specimen S3, close contact between fibers of finer size has enabled better stress transfer from region of high stress to supports (Gireesh, 2009). The flexural rigidity of composites was found to appreciably improve with the increase in fiber length (Joseph *et al*., 1999). In Specimen S1, long fibers in impregnated condition have resulted in inter-weaving between each other which has substantially improved the flexural performance. The specimens S7 and S8 with prosopis and sisal fibers in alternate layers, in coarse and medium size fractions does not show any marked improvement in flexural strength. The change in flexural stiffness of fibers in alternate layers eventually results in inefficient transmission of load through shear. The plot of load versus deflection for all specimens is shown in Figure 5. After the ultimate load is reached, the load indicator starts receding back and the ultimate load at which failure takes place is noted. From the Figure 5, it can be observed that initial variation of load-deflection curve remains linear for all specimens. All specimens except S8 were found to sustain large inelastic deformations before failure. In specimen S8, load-deflection curve varies steeply and failure occurs by brittle mode. Ductility of a flexural specimen can be defined as its ability to sustain large inelastic deformation before failure. The area under the load –deflection curve facilitates to measure the energy absorption or ductility of the specimens. From the load-deflection curve, it is observed that S7 exhibit higher energy absorption against flexural deformation when compared to all other specimens. The presence of coarser size fibers of prosopis and sisal in alternate layers might have improved the energy absorption capability of S7 through crack bridging mechanism. The variation of flexural modulus is shown in Figure 6. The flexural modulus of specimen S3 was found to be highest compared to all other specimens. The increase in flexural modulus can be related to good matrix-fiber stress transfer indicating good interaction between them (Almeida *et al.*, 2013).

Impact Properties:

The impact strength of a composite specimen can be defined as its ability to absorb the energy offered by heavy object blowing at high speed. Impact strength of short fiber composite was found to increase with increasing fiber length. Energy absorption capability of composites tends to increase with increase in the length of fiber. The number of fiber ends decreases for long fibers and hence the amount of fiber pullout during failure decreases (Sreenivasan *et al.*, 2011). The variation of impact strength offered by all specimens is plotted in Figure 7. The specimen S1 was found to offer the highest impact strength of 57.96 J/cm^2, compared to all other specimens. The presence of prosopis fibers in coarser size fractions 15 to 4.75mm bridges up the crack effectively and offers good resistance against fiber pullout failure.

The next highest impact resistance was offered by S4 and the reason could be dense packing of fibers with gaps formed between coarser fibers filled up the fibers of next lower size. The specimens S7 and S8 reported the lowest impact resistance of 9 and 9.6 J. As the load travels in the transverse direction, impact properties starts declining with more diversified natural fiber layers than symmetrical layers. Arthanarieswaran *et al*., (2014) has found that hybrid composites made of glass fiber mats at top, middle and bottom layers and chopped sisal fibers in between them offers impact strength of 13.3J. Thus prosopis/glass fiber based five layer hybrid composites offers impact strength appreciably more than sisal fiber reinforced sandwich composites. The presence of higher lignin content in prosopis bark fiber could be possible reasons for its enhanced fracturetoughness.

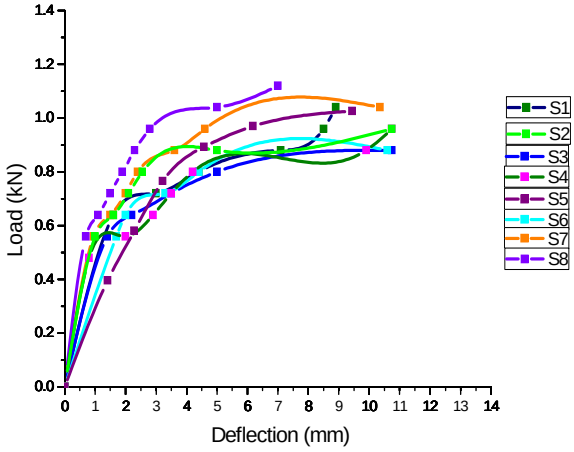

Fig. 5: Plot of load vs. deflection

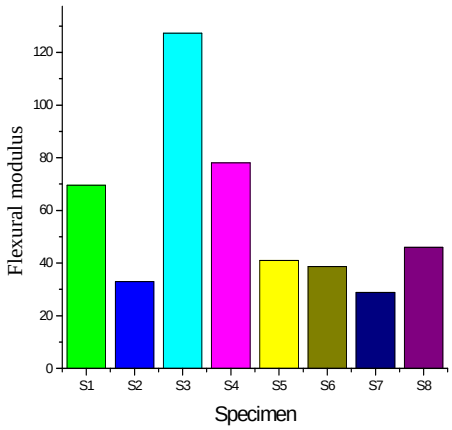

Fig. 6: Plot of Flexural Modulus

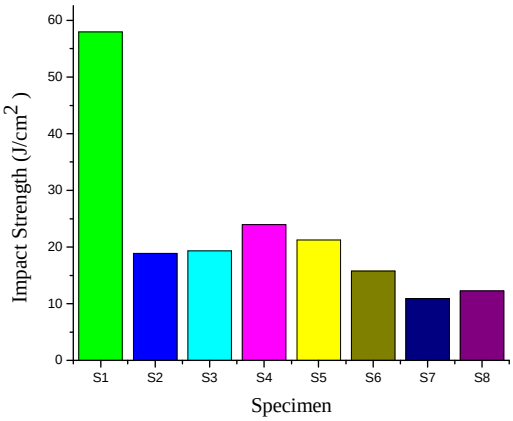

Fig. 7: Plot of Impact Strength

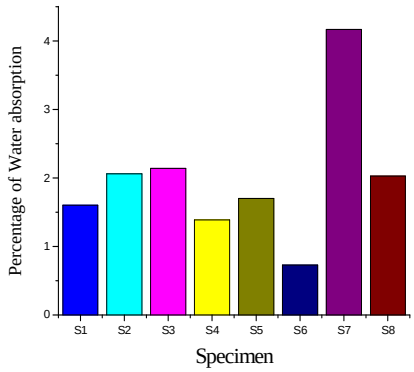

Fig. 8: Plot of % of water absorption

Water absorption Properties:

The variation of percentage of water absorption for all specimens is shown in Figure 8. From Figure 8, it can be observed that the value of percentage of water absorption of all specimens was less than 4%. The presence of glass fiber skin on top and bottom of the laminate has prevented the entry of water in to it and reaching the core material (Joseph *et al*., 2008). In addition to this, alkali treatment of natural fibers improves the fiber-matrix adhesion and thereby ensures the water tightness of the core material (Mishra *et al*., 2003). The lowest percentage of water absorption was reported for Specimen S6 and the reason could be dense packing of core material and improved fiber-matrix adhesion. The other specimens S4 and S5 having prosopis fibers in mixed sizes also performs well with respect to water absorption behaviour. The maximum percentage of water absorption was observed for specimen S7 which had prosopis and sisal fibers of coarser size in alternate layers. The non uniform dispersion of fibers and presence of voids might have increased the water absorption of S7. However, in specimen S8 the presence of prosopis and sisal fibers in medium sizes has enabled uniform dispersion of fibers and hence reduced the water uptake to half of S7. Thus, it can be understood that water absorption characteristics of sandwich composites depend upon the type of fiber used at the faces, denseness of the core material and fiber-matrix adhesion.

Morphological Analysis:

The scanning electron microscope (SEM) images are taken to observe the interfacial properties, mode of failure, and distribution of fibers and internal structure of the fractured surfaces of the composite materials. The specimens were coated with conducting material before observing the surfaces through SEM. Scanning Electron Micrographs of tensile tested specimens S3, S5 and S6are given Figure 9, 10 and 11. During tensile test, the specimens were found to fail by fiber pull out, fiber breakage, matrix cracking and fiber delamination. The failure mode is significantly

influenced by dispersion of chopped natural fibers, absence of continuity in sandwich layer and fiber-matrix adhesion. SEM image of S3 reveals dense packing of fibers and good adhesion between fiber and matrix. In S3, the presence of prosopis fibers in size range 2.36 to 1.18mm results in closes fiber to fiber contact and hence enables efficient stress transfer through them. The voids formed between coarse prosopis fibers needs fibers of lower sizes to get filled in to it. However, when more amount of fine fibers exist with voids to be filled in between coarser fibers are less, then fibers of fine fractions remains as surplus and this leads to non uniform fiber distribution. In specimen S6, the chopped prosopis fibers were mixed in all sizes at equal proportion. The packing of prosopis fibers in S6 were found to better than that of S5. Fiber pullout, matrix cracking and fiber debonding are the observed failure modes in S6.

Conclusion:

In the present study, mechanical properties of sandwich composite made using prosopis and sisal fibers sandwiched between layers of glass fiber mat was experimentally investigated. The hydrophilic nature of the natural fibers was overcome by treating them using sodium hydroxide solution. It is observed from test results that tensile strength of

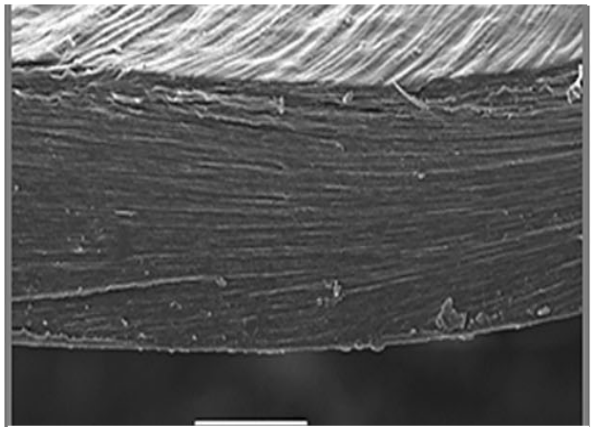

Fig. 9: SEM image of S3

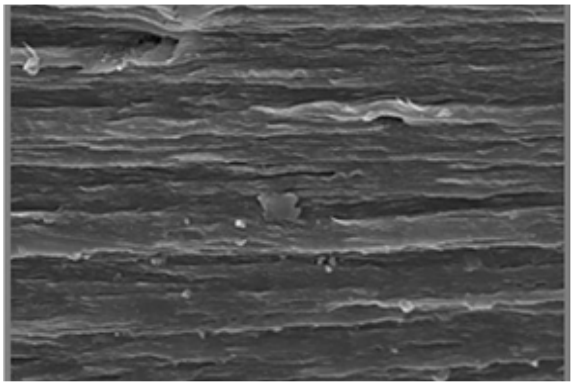

Fig. 10: SEM image of S5

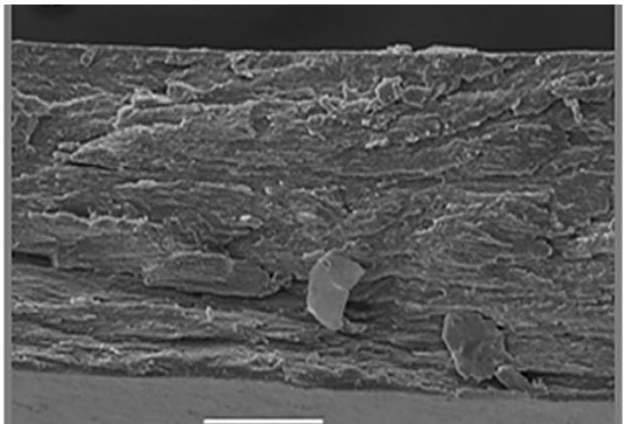

Fig. 11: SEM image of S6

specimen containing prosopis fibers of coarse, medium and finer sizes in proportion 50%, 25% and 25% was found to be highest and the reason could be due to presence of dense core layer with voids formed between coarse fibers filled by fibers of lower size. The percentage of elongation at break was found to get enhanced with increase in fiber size and fiber-matrix adhesion. The flexural strength was found to be highest for specimen having prosopis fibers in finer size. However, impact strength was found to be highest for specimen having prosopis fibers in coarser size. Thus impact resistance was found to increase with increase in fiber length and stiffness. The water absorption was found to be least for specimen containing prosopis fibers in all fiber sizes equally. Thus extent of water absorption is mainly governed by distribution and arrangement of fibers in the matrix. From the study, it can be concluded that prosopis fibers can acts as most promising material in the field of composites.

REFERENCES

Kabir, M.M., H. Wang, T. Aravinthan and *et al*., 2011. Effects of Natural fiber surface on composite properties: A Review. *eddBE2011* Proceedings, pp: 94-99.

John, M.J., and S.Thomas, 2008. Biofibres and biocomposites: Review. Carbohydrate Polymers, 71: 43-364.

Thomas, S., P.A. Sreekumar, S.P. Thomas and *et al*., 2009. Effect of fiber surface modification on the mechanical and water absorption characteristics of sisal/polyester composites fabricated by resin transfer molding. *Composites: Part A*, 40: 1777-1784.

Jawaid, M., and H.P.S. Abdul Khalil, 2011. Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers, 86: 1-18.

Samal, S.K., S. Mohanty and S.K. Nayak, 2009. Banana/glass fiber-reinforced polypropylene hybrid composites: Fabrication and performance evaluation. Polymer-Plastics Technology and engineering, 48(4): 397-414.

Panthapulakkal, S., and M. Sain, 2007. Injection-molded short hemp fiber/glass fiber reinforced polypropylene hybrid composites – Mechanical, water absorption and thermal properties. Journal of Applied Polymer Science, 103(4): 2432-2441.

Koradiya, S.B., J.P. Patel and P.H. Parsania, 2010. The preparation and physicochemical study of glass, jute and hybrid glass–jute bisphenol-C-based epoxy resin composites. Polymer- Plastics Technology and Engineering, 49(14): 1445-1449.

Joseph, S., M.S. Sreekala, P. Koshy and S. Thomas, 2008. Mechanical properties and water sorption behavior of phenol-formaldehyde hybrid composites reinforced with banana fiber and glass fiber. Journal of Applied Polymer Science, 109(3): 1439-1446.

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

Hariharan, A. Abu Bakar and H.P.S. Abdul Khalil, 2004. Influence of oil palm fiber loading on the mechanical and physical properties of glass fiber reinforced epoxy bi-layer hybrid laminated composite. In Proceeding of 3rd *USM-JIRCAS* joint international symposium Penang, Malaysia, pp: 230-233.

Vijaya Ramnath, B., S. Junaid Kokan, R. Niranjan Raja and *et al*., 2013. Evaluation of Mechanical properties of abaca-jute-glass fibre reinforced epoxy composite. Materials and Design, 51: 357-366.

Pasiecznik, N.M., P. Felker, P.J.C. Harris, and *et al*., 2001. The *Prosopips juliflora-Prosopis pallida* Complex: A Monograph. HDRA.Coventry , UK, pp: 162-168.

Saravanakumar, S.S., A. Kumaravel, T. Nagarajan and *et al*., 2013. Characterization of a novel natural cellulosic fiber from Prosopis juliflora bark. Carbohydrate Polymers, 92: 1928-1933.

Joseph, K., R.D.T. Filho, B. James, S. Thomas and L.H. Carvalho, 1999. A review on sisal fiber reinforced polymer composites. Revista Brasileira de Engenharia Agrícola e Ambiental, 3(3): 367-379.

Arthanarieswaran, V.P., A. Kumaravel and M. Kathirselvam, 2014. Evaluation of mechanical properties of banana and sisal fiber reinforced epoxy composites: Influence of glass fiber hybridization. Materials and Design, 64: 194-202.

Thomas, S., J. George, S.S. Bhagawan and N. Prabhakaran, 1995. Short Pineapple-Leaf-Fiber-Reinforced Low-Density Polyethylene Composites. Journal of Applied Polymer Science, 57: 843-854.

Gireesh, K.G., 2009. *Development of bark-based environmental-friendly composite panels.* MS Thesis, University of Torronto, Canada.

Joseph, P.V., J. Kuruvilla, and S. Thomas, 1999. Effect of processing variables on the mechanical properties of sisal-fibre-reinforced polypropylene composite Composite Science Technology, 59(11): 1625-1640.

Almeida, J.H.S., C.A. Sandro, C.B. Edson and D.R.A. Franco, 2013. Hybridization effect on the mechanical properties of curaua/glass fiber composites. *Composites: Part B*, 55: 492-497.

Sreenivasan, V.S., D. Ravindran, V. Manikandan and R. Narayanasamy, 2011. Mechanical properties of randomly oriented short *Sansevieria cylindrica* fibre/polyester composites. Materials and Design, 32: 2444-2455.

Joseph, S., M.S. Sreekala, P. Koshy and S. Thomas, 2008. Mechanical properties and water Sorption behavior of phenol-formaldehyde hybrid composites reinforced with banana fiber and glass

fiber. Journal of Applied Polymer Science, 109(3): 1439-1446.

Mishra, S., A.K. Mohanty, L.T. Drzal and *et al*., 2003. Studies on mechanical performance of biofibre /glass reinforced polyester hybrid composites. Composites Science and Technology, 63: 1377-1385.

Ghani, M.A.A., Z. Salleh, K.M. Hyie and *et al*., 2012. Mechanical Properties of Kenaf/Fiberglass Polyester Hybrid Composite. Procedia Engineering 2(41): 1654-1659.

Kasama, J., and S. Nitinat, 2009. Effect of glass fiber hybridization on properties of sisal fiber–polypropylene composites. Composites: Part B, 40: 623-627.