Australian Journal of Basic and Applied Sciences, 9(35) November 2015, Pages: 69-76

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Mechanical properties of *Sida Rhombifolia/Prosopis Juliflora/*glass fiber reinforced sandwich composite laminates

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

[1]*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 -604001, TamilNadu, India.*

ARTICLE INFO

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

Keywords:
Sida Rhombifolia, Prosopis juliflora, glass fiber mat, strength, water absorption

ABSTRACT

Abundance availability, cheap processing and environmental friendly nature of natural fibers has made them a promising substitute for synthetic fibers. The fibers obtained from the bark of weeds such as *Sida Rhombifolia* (SR) and *Prosopis juliflora* (PJ) were found to possess high stiffness and rigidity. In this paper, experimental studies were carried out to assess the mechanical properties of sandwich laminates made using fiber particulates of *Sida Rhombifolia* and *Prosopis juliflora* laid in between the layers of Glass fiber mat. Eight different laminates specimens were made with sandwich material in different sizes and combinations. It was found that laminates made using *Sida Rhombifolia* bark fibers in mixed size exhibit superior mechanical properties compared to all other specimens. The specimens with alternate layers of *Sida Rhombifolia* and *Prosopis juliflora* fibers does not show marked improvement in strength as well as resistance to water absorption.

To Cite This Article: R Gopinath, Ganesan, S.S. Saravana Kumar and R Poopathi., Mechanical properties of *Sida Rhombifolia/Prosopis Juliflora*/glass fiber reinforced sandwich composite laminates. ***Aust. J. Basic & Appl. Sci.,*** *9(35): 69-76, 2015*

INTRODUCTION

Fiber reinforced composites offer potential advantages such as light weight, high specific strength and modulus, excellent corrosion resistance and good fatigue resistance. However, environmental hazards caused during disposal of synthetic fiber reinforced composites necessitates search for alternate fibers for synthetic ones. Abundant presence, environmental friendly nature, high stiffness and strength have made natural fibers, a promising substitute for synthetic fibers. So far, numerous researches have been carried out on large varieties of natural fibers and many of them were successfully incorporated in automobile and marine industries. In spite of its attractive advantages, natural fibers suffer from drawbacks such as hydrophilic nature, low processing temperature and low microbial resistance. Hence, natural fibers need suitable chemical treatments to overcome the deficiencies (Maya and Thomas, 2008). The main components of natural fibers are cellulose, hemicelluloses, lignin, pectin and waxes. The presence of hydroxyl groups on the surface of natural fibers is mainly responsible for its hydrophilic nature, which hinders its effective adherence with matrix. Moreover, pectin and waxy substance covers the reactive functional groups of the fiber and act as barrier in the interlocking with the matrix. The chemical treatments such as mercerization, isocynate treatment, acrylation, permanganate treatment, acetylation, silane and peroxide treatment can reduce the water uptake in the fibers and can reduce the amount of fiber swelling and biological degradation by blocking available OH group on the fiber surface. Thermal stability of natural fibers can be enhanced by removing certain proportions of hemicelluloses and lignin constituents from the fiber by different chemical treatments (Kabir *et al*., 2011). In tropical country like India, plenty of weed varieties are available in abundant quantity throughout the year. *Prosopis juliflora* is one such woody weed from which fibers were extracted from the bark and subjected to tensile test. The tensile strength of the fibers was found to be 587MPa with 1.77% of strain rate. The cellulose and lignin content of these fibers were found to be 61.65% and 17.11% (Saravana Kumar *et al*., 2013). Thus, it is evident that fibers obtained from bark of weeds can potentially contribute as good reinforcement in making composites. *Sida Rhombifolia* (SR) is a malvaceous weed spread throughout the tropics and subtropics of the world. Sida is a large genus with about 200 species distributed throughout the world.

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

Traditionally, *Sida Rhombifolia* plant is being used as medicine for health ailments such as headache, skin diseases, diarrhea and dysentery. *Sida Rhombifolia* is a perennial shrub grows to a height of 1.5m and the diameter of bark extends to 10mm approximately. Apart from the medicinal value, good amount of high stiff fiber can be extracted from its bark (Virendra *et al*., 2013). In this paper, the mechanical properties of sandwich composite laminates made using fiber particulates of *Sida Rhombifolia* and *Prosopis Juliflora* as sandwich between the layers of glass fiber mat were studied. Tests such as tensile, flexural, impact and water absorption were conducted on the laminate specimens following the procedure laid down in respective ASTM standards. The results obtained from the test are presented and discussed in detail.

MATERIALS AND METHODS

Materials used:

Glass fiber Woven roving mat of 610 gsm was used to hold the sandwich materials firmly in between them. Vinyl ester resin was used as matrix and compounds such as cobalt naphthanete, methyl ethyl ketone peroxide, and dimethyl amine were used as acceleralator, catalyst, and promoter. Fibers obtained from the stem of *Sida Rhombifolia* and bark of *Prosopis Juliflora* was used as sandwich material. The photographic view of SR and PJ fibers are shown in Figure 1(a) and (b).

Extraction and processing of natural fibers:

Both the natural fibers were extracted by adopting the same procedure. Initially, the stem and bark were cut and soaked in water for a period of two weeks so as to allow for microbial degradation and to facilitate ease removal of outer layers of bark. Then the fibers were extracted from the outer peeled off layer, by using metal teeth. After extraction, the fibers were kept in air oven at 60^0C for a period of 24hrs. The dried fibers were then subjected to alkali treatment by immersing it in NaOH solution at 5% concentration, and at 30^0C for a period of 2hrs. The fibers were then washed multiple number of times using distilled water and after complete washing it is subjected to neutralization process, by using few drops of acetic acid. The fibers were allowed to dry in sunlight for a period of 48hrs. After complete drying, they were cut in to finer sizes and subjected to sieving process using different set of sieves. The portion of fibers retained in appropriate sieve sizes were collected and used for making the laminates. The fiber particulates of SR were segregated in three different size ranges (I) coarse - 15 to 4.75mm, (II) medium - 4.75 to 2.36mm, and (III) fine - 2.36 to 1.18mm.The PJ fiber were used in size ranges, (II) medium and (III) fine.

Fabrication of Composite Laminates:

Two mild steel plates of size 30 x 30 cm and 6mm thickness with bolt nut arrangement for tightening up was used as moulds, for making the laminates. Eight types of laminates were made by varying the sizes, proportion, and combination of sandwich fibers. The detail about the laminate specimens is given in Table 1. For all laminate specimens, the volume fraction of matrix, sandwich fibers and glass fiber mat were kept constant as 48%, 22%, and 30%. The bottom steel plate was coated with releasing agents such as PVA or wax and allowed to dry up for 30 min. Vinyl ester resin was taken in a bowl and mixed with cobalt naphthanate, methyl ethyl ketone peroxide, and dimethyl amine at 1.5% by weight of resin. The mixed up resin was gently applied using brush on the wax coated surface of steel plate. Glass fiber mat cut to a size of 30cm x 30cm was then placed on resin coated surface and gently applied with remaining amount of resin. The entrapped air occupied between fiber-matrix interface was then removed by rolling cylindrical metal rollers gently on the surface of fiber mat. The sandwich material was gradually added to resin mix taken in a bowl and intimately mixed by using a glass rod. After complete mix up, sandwich fibers were spread uniformly over glass fiber mat and tamped gently using brush so that denser packing of fibers can be ensured. On the sandwich course, glass fiber mat was placed and the procedure is repeated so that two course of sandwich layers between glass fiber mats is obtained. After completion of fabrication, mild steel plate coated with releasing agents was placed on top of laminate and both the bottom and top steel plates were tightened up using the bolt and nut fixtures. Then, metal weights were kept over the top of steel plate so that polymerization of matrix occurs under pressure. After 12 hrs, the laminate was demoulded and kept in oven at 60^0C for a period of 2 hrs, so as to initiate post curing process. The laminates were then cut to specific size and shape as stipulated by respective ASTM standards, required for performing the tests.

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(a) (b)

Fig. 1: (a) *Sida Rhombifolia* bark fiber & (b) *Prosopis Juliflora* fiber

Table 1: Details about natural fibers

Specimen	Sandwich Fiber	Details of size fraction of sandwich fibers
S1	*Sida Rhombifolia*	SR-I
S2		SR-II
S3		SR-III
S4		SR-I,II,III in equal proportions
S5		SR- I-25%, II & III -37.5% each
S6		SR- I-50%, II &III -25% each
S7	*Sida Rhombifolia* and *Prosopis juliflora*	SR – II & PJ –II in equal Proportions
S8		SR – III & PJ–III in equal Proportions

Note: I - Coarser, II - Medium, and III - Fine fiber sizes.

Testing Methodology:

Tensile Test:

The specification of ASTM 638-02 was followed for performing the test. 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 100mm 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.

$$\text{Percentage of Water Absorption} = \frac{W_2 - W_3}{W_3} \times 100 \qquad (1)$$

RESULTS AND DISCUSSIONS

Tensile properties:

It can be inferred from Table 2, specimen S3 reported highest tensile strength of 96.8 MPa. The presence of fiber particulates of finer size in the range 2.36mm to 1.18mm has resulted in good bonding characteristics and has increased the fiber availability across the cross section of the specimen. The specimens such as S4 and S5 had exhibited tensile strength almost equal to S3. The presence of fibers in mixed sizes with the proportion of finer fiber sizes more than the coarser fibers yields appreciable increase in tensile strength. The tensile

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strength of specimens S7 and S8 with alternate layers of SR and PJ in medium and fine size fractions were found to be comparatively lower than all other specimens. A view of tensile test specimen before and after the test is given in Figure 2. The plot showing tensile stress vs. strain for various laminate specimens are given in Figure 3. The failure strain of the sandwich composites increases with increase in size of fiber particulates. Figure 4 shows the variation of % elongation at break for various sandwich laminates. It is evident from the plot that coarser fiber particulates increase the percent of elongation. The specimen S4 reported low percent of elongation at break which indicates presence of fibers in all sizes equally results, in brittle behaviour.

Fig. 2: View of tensile test specimen (a) before test (b) after test

Table 2: Mechanical property of sandwich composite laminates

Specimen	Flexural Strength (MPa)	Tensile strength (MPa)	Impact Strength (J/cm^2)	Water Absorption (%)
S1	197.828	67.41	15.26	2.49
S2	228.932	62.73	14.80	3.24
S3	248.973	96.80	13.45	2.35
S4	236.915	94.70	17.66	1.23
S5	236.645	94.23	14.94	2.12
S6	254.393	81.88	15.89	2.13
S7	172.076	62.55	12.47	2.70
S8	192.149	58.42	16.64	3.99

Flexural Properties:

From Table 2, it can be observed that laminates having SRFs in mixed sizes offers maximum flexural strength, with highest being 254.39 MPa for Specimen S6. It is inferred that close packing of sandwich layer occurs when fiber sizes in different ranges are used in combined form. It is further noted that hybrid combination of fibers in specimen S7 and S8 has not resulted in any improvement in flexural strength.

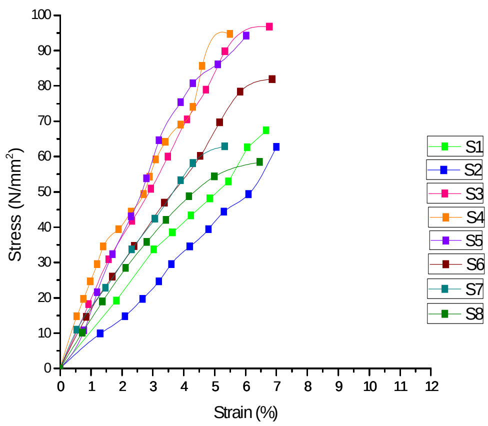

Fig. 3: Plot of tensile stress vs. strain

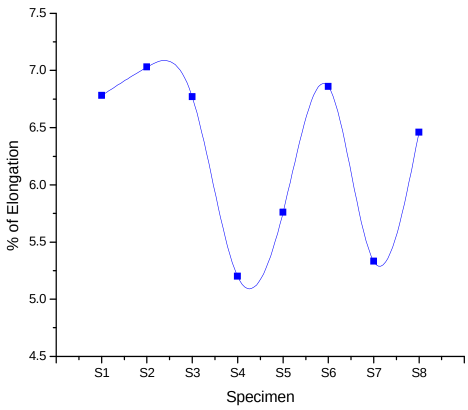

Fig. 4: Variation of % of Elongation at break

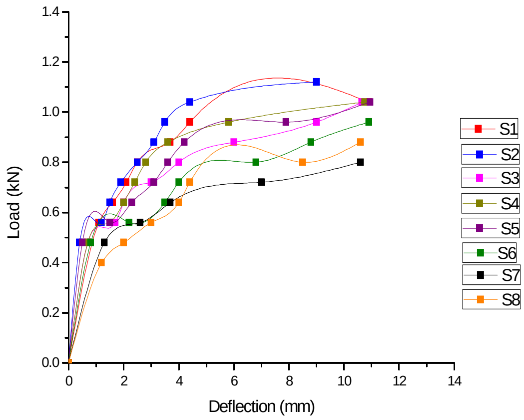

Fig. 5: Plot of Flexural Load vs. Deflection

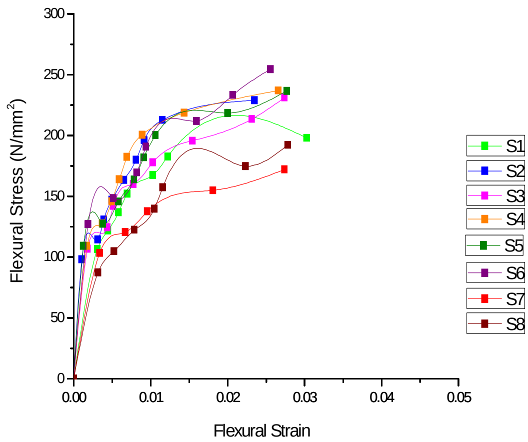

Fig. 6: Plot of Flexural Stress vs. Strain

From the plot of load-deflection curve in Figure 5, it can be observed that highest flexural load of 1.12kN was reported for S2 with deflection recorded as 9.0mm. Specimen S2 was found to carry flexural load 1.4 times that could be carried by hybrid specimens such as S7 and S8.

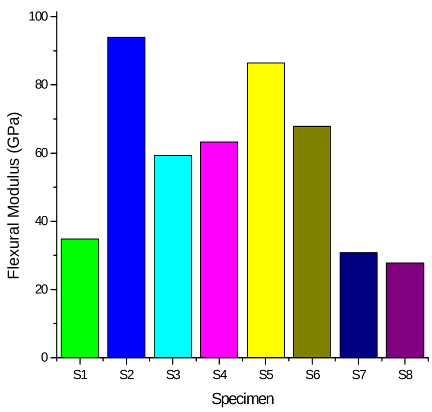

Fig. 7: Variation of Flexural Modulus

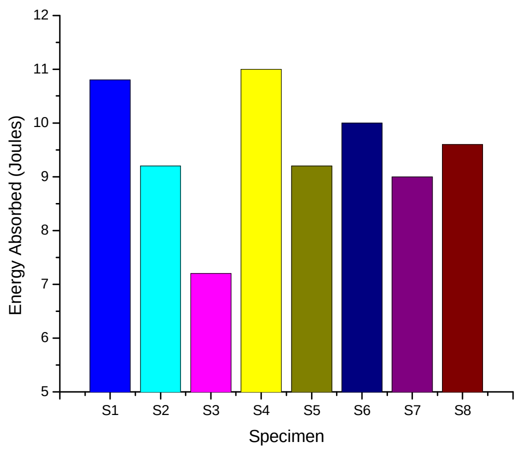

Fig. 8: Variation of Energy Absorption

Maximum deflection of 10.95mm was observed for S4 at a load of 1.04kN. Out of all specimens, S2 sustained maximum flexural load with less deflection. From Figure 6, it can be observed that maximum flexural strain of 3.02% at flexural stress of 197.83MPa was reported for specimen S1.

(a) (b)

Fig. 9: View of Izod impact test specimen (a) before test, (b) after failure

It is also evident from Figure.7 that Specimen S2 exhibit highest flexural modulus 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). Thus presence of fiber sizes in the range 4.75-2.36 mm enable better interlocking with matrix and effective stress transfer between them.

Impact Strength:

From Table 2, it can be read out that maximum impact resistance of 17.66 J/mm^2 was observed for specimen S4. The resistance to impact depends on factors such as type of material, interlaminar strength, stacking sequence and nature of impact. From Figure 8, it can be observed that energy absorption capability of laminates were tend to improve when particulates are of (a) coarser size and (b) mix up form. Further, it can be realized that specimens S7 and S8 perform better against impact, when compared with S3 which reported the lowest impact strength. The SRFs of finer size lacks in internal bond due to their smaller shape where as mixed fibers have better fiber continuity due to close packing of fibers with gaps formed between coarser filled up by the fibers of next lower size. A typical view of IZOD impact test specimen before and after failure is given in Figure 9.

Water absorption characteristics:

It is evident from Table 2, that lowest percentage of water absorption was observed in specimen S4. Mix up of SRFs of all sizes equally has resulted in dense packing of sandwich layer compared to other specimens. Maximum percentage of water absorption was observed for specimen S8 which had alternate layers of SR and PJ in finer size. Thus it is inferred that water absorption characteristics of sandwich layer depends upon the physio-chemical composition of fibers, fiber size, volume of voids and chemical treatment adopted for fiber surface modification. The presence of glass fiber mat on top and bottom faces of sandwich course acts as shielding and prevents the entry of water in to it. Alkali treatment of natural fibers has improved the fiber-matrix adhesion and hence decreased the diffusivity of water molecules.

Morphological Analysis:

Scanning Electron Micrographs of specimen S2 and S4 in Figure.12 &13, reveals that fiber particulates in mixed sizes results in dense packing compared to other specimens. Further fiber-matrix adhesion was found to get improved much better for specimens with mixed size.

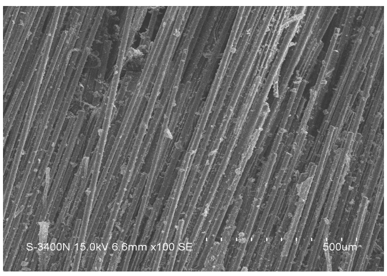

Fig. 10: SEM image of S2

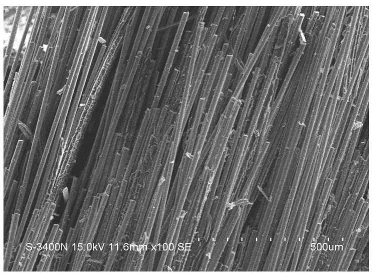

Fig. 11: SEM image of S4

Conclusion:

The tensile, bending, impact and water absorption properties of composite laminates made using fibers of *Sida Rhombifolia* and *Prosopis Juliflora* as sandwich in between glass fiber mat are studied. From the study, it can be concluded that

1. The mechanical properties of laminates containing SR fiber performs much better compared to that of hybrid laminates. Specimens having SR fiber in mixed sizes were found to have minimal voids, better interlocking with matrix and appreciable improvement in strength.
2. Highest tensile strength was reported for specimen having finer size of SRFs. Specimens which had SR in mixed size also performed equally well. The percentage of elongation was found to increase for specimen having coarse size fiber particulates of SR.
3. Specimen with SRFs in proportions 50% coarser, 25% medium and 25% fine offers maximum flexural strength. The specimen with medium size SRFs reported highest flexural load with low deflection. In addition to this, the specimen was found to possess highest flexural modulus which indicate the existence of better interlocking and stress transfer between fiber and matrix.
4. Highest Impact resistance was observed in specimen having SRFs in all sizes equally. Energy absorption capability of specimen subjected impact load was found to appreciably increase with increase in size of fibers.
5. Lowest percentage of water absorption was observed in specimen having SRFs in all sizes equally. The denseness in sandwich layer improves water absorption characteristics of sandwich laminates.
6. Alkali treatment of sandwich fibers has improved the adhesion between fiber and matrix and lowered water absorption characteristics of natural fibers.

Thus it can be concluded that the fibers obtained from weedy plants like *Sida Rhombifolia* and *Prosopis Juliflora* can acts as promising reinforcement in making the composites with high strength and toughness.

ACKNOWLEDGEMENT

The authors are thankful to the undergraduate students of University College of Engineering, Tindivanam for their effort during the course of this project.

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