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Investigation for natural fiber reinforced hybrid composite

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Natural fiber reinforced hybrid composite is developed to meet the environment friendly and sustainable demand of industry. Jute and sisal fibers are mixed in different composition to produce Jute-Sisal-Epoxy hybrid composites using hand layup methods. Hybrid composites are developed by mixing 15% of fiber fraction by weight with 85% epoxy resin and hardener. Both are mixed respectively in the ratio of 70 to 30. Tensile test and moisture absorption test have been carried out according to ASTM standard to determine the most appropriate fiber combination. It has been observed that moisture gain was highest in 100% sisal fiber composite and decreases gradually with raise in the percentage of jute fiber. However, tensile strength was highest for sisal fiber composite as compared to jute fiber.

Keywords: Hybrid Composite, Jute, Moisture Absorption, Sisal, Tensile Strength

1 Introduction

Natural fibers such as fibers extracted from jute, sisal, hemp, pineapple, coir, flax, banana and many more are being used now a day in making of composites due to recyclability and environmental friendly material properties[1-5]. Hence, these composites of natural fibers are also called as Green Composites[6]. Research shows that the composite from natural fibers possess significant improvement in several properties e.g. thermal stability, specific strength, low density, non-abrasive, ease of manufacturing, biodegradability in addition to low in cost[7-10]. Therefore, natural fibers seem to be the materials that can replace non-renewable, abrasive and expensive synthetic fibers[11-14]. Therefore, wide applications of these composites are being observed in aerospace, automotive, marine and sporting industries[2,7,15].

Natural fiber composites exhibit comparable tensile, impact, inter laminar shear strength, thermal, moisture absorption and tribological properties with synthetic fiber composites[2]. Nevertheless, the usage of natural fibers in polymer composites is still facing challenges owing to inferior thermal properties and excess moisture absorption. In fact, several properties i.e. thermal conductivity, acoustic insulation and electric resistance of natural fibers need to be investigated in detail[2]. Ku *et al.*[3] in their review work reported that due to excellent tensile properties natural fibers are being used to replace conventional fiber e.g. glass, carbon in reinforced plastic material. However, contains major drawback of incompatibility, hence, weak adhesion between matrix resins and natural fibers leads to lower tensile strength of composite. Therefore, chemical and physical modification processes were developed to enhance tensile properties and interfacial bonding between fiber matrixes of the composites.

John *et al.*[4] in their work modified natural fibers by chemical process to enhance the adhesion between hydrophilic fibers and hydrophobic matrix. They explained that alkali treatment of fibers raises the performance of natural fibers. However, acetylation seems to be effective method to modify the natural fibers and making it more hydrophobic. Valadez-Gonzalez *et al.*[7], also treated natural fibers surface chemically to enhance the strength of composites. They reported that the alkaline treatment increase the surface roughness of the fiber that lead to better mechanical interlocking. The interfacial shear strength between natural fibers and thermoplastic matrix can be enhanced by the chemical alteration of the fiber surface. Srinivas *et al.*[11] compared the mechanical property of natural fiber with synthetic fiber and observed that tensile strength of the natural fibers is low as compared to the synthetic fibers.

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Gopinath *et al.*[1] worked with different hardener to produce natural fiber composite of jute. The jute fiber treated with NaOH solution was mixed with various epoxy resin and polyester. They have reported that jute fiber reinforced composites treated with 5% NaOH have superior tensile strength than 10% NaOH treated fiber.

Azwa *et al.*[13] in a review work measured the degradability of natural fiber composite on exposure to moisture, fire and ultraviolet environment. They have reported that the natural fibers are more susceptible to biodegradation as compared to composite with synthetic fibers. The cellulose is liable for strength of fiber, hemicelluloses for thermal, moisture and biological degradation, whereas, lignin for char formation and ultraviolet degradation. They have also reported that natural fibers are very susceptible to moisture attack and moisture durability of natural fiber composite decreases with increment in fiber content. They have suggested the application of water resistance coating or chemical treatment of composites to enhance strength, moisture durability and thermal performance.

Saheb and Jog[14] in their review work reported the importance of biochemical composition of natural fiber. The cellulosic fibers are hydrophilic, thus, absorbs moisture in the range of 5 to 10 percentage. The moisture absorption affects the mechanical behaviour of the composites and lead to dimensional variation during uses. Hybridization with multiple natural fiber reinforcements was observed as a possible technique to fabricate composites with enhanced certain mechanical properties[1]. Maslinda *et al.*[10] investigated the effect of water gain on mechanical behaviour of hybrid interwoven cellulosic-cellulosic reinforced hybrid epoxy composites. They have reported that water resistant and mechanical behaviour of jute, hemp and kenaf fibers can be improved through hybridization. Ramesh *et al.*[16] have also reported that the use of sisal and jute improves the mechanical properties of glass fiber reinforced polyester composites. Patel *et al.*[17] in another experimental work investigated the mechanical behavior of hybrid sisal and banana fiber. They have reported that sisal fiber has higher tensile strength, however, low impact and bending strength. The tensile strength of composites made from 50% sisal and 50% banana is lower as compared to the composite of 80% sisal and 20% banana fiber.

Based on published literature, it can be mentioned that the properties of the hybrid composites depend resin, fiber origin, fiber reinforcement, fiber orientation, number of layer, fabrication method, crystallinity index and crystallite size, added volume and weight fraction of fiber, fiber condition, chemical treatment and many more[8,14,18-21]. Numerous investigations are available for natural fiber composite made of vakka, sisal, bamboo, banana, jute and their different combinations, however, investigations for combination of sisal and Jute in particular are scanty[1,2,6,22-25]. In one of the study Gupta and Shrivastava[14] reported that hybrid composite of 50 % fraction of sisal and jute by weight shows better result as compared to other investigated combinations which can further be improved with alkali treated fibers. They fabricated the hybrid composite using AY 105 as epoxy matrix and HY951 as with reinforcement by unidirectional continuous aligned bi layer of sisal and jute fiber. In present work also fiber of jute and sisal in different combination is used for investigating mechanical properties and moisture gain for reinforced hybrid composite. However, the hybrid composite is fabricated by discontinuous natural fiber in random orientation in epoxy as a matrix. Epoxy resin Araldite AW 106 and Hardener HV 953U are being used to develop hybrid fiber composite by hand layup method.

2 Materials and Methods

2.1 Experimental procedure and preparation of composite

The reinforce composite was developed by mixing of epoxy hardener to fiber in the ratio of 85:15 by weight. The epoxy hardener was prepared with epoxy to hardener in the ratio of 70:30 by weight. Initially fiber were chopped into 1 cm size (Fig. 1) and mixed

Fig. 1 — Chopped sisal fiber.

with epoxy resin by hand, thereafter, hardener was mixed. Five different combination of composite was prepared by varying the weight percentage of sisal and jute fiber as depicted in Table 1. The physical and chemical properties of sisal and jute fiber used for composite are shown in Table (2 and 3).

The mixture of fiber and epoxy was filled into a mould of 16 cm x 16 cm, the compressive force of 295N was applied to the mould and mixture is allowed to set for 48 hr at room temperature. The extra material from composite was removed and final sample of 15cm x 15 cm was prepared. The final fabricated composite is shown in Fig. 2.

The test samples for tensile properties were prepared from the developed hybrid composited according to ASTM D638. The dimensions of specimen used for tensile test is presented in Fig. 3. Uniaxial load was applied at the ends of the specimen during testing. During tensile test the ultimate tensile strength, breaking point stress and % elongation at break was recorded. Same UTM, was used both for tensile and flexural test. Three point bending test was performed to determine the flexural strength. The samples were developed according to ASTM D790 standard and tested at a crosshead speed of 1mm/min. Three samples of each combination were tested at room temperature and their average value was used in the analysis.

The moisture gain test was performed according to ASTM D-570 and specimens were prepared as per standard. The test samples were dipped in water at room temperature for different time interval. The samples were then taken out and weighed regularly till the saturation state. The moisture gain was measured with the difference of weight percentage as shown in Eq. (1).

$$\% \text{ Water of absorption} = (m_2 - m_1) \times 100/m_1$$

Table 1 — Composition for natural fiber hybrid composite

Sample No.	Percentage of fiber	
	Sisal	Jute
S	100	0
S	75	25
S	50	50
S	25	75
S	0	100

Table 2 — Chemical properties of sisal and jute fiber [4]

Fiber	Cellulose (Wt. %)	Lignin (Wt. %)	Wax (Wt. %)	Hemicellulose (Wt. %)
Sisal	78	12.1	2	25.7
Jute	59-71.5	11.8-13	0.5	13.6-20.4

Table 3 — Physical properties of sisal and jute fiber [11, 20]

Fiber	Tensile strength (MPa)	Elongation Percentage	Flexural strength(MPa)
Sisal	600-700	2-3	288.6
Jute	320-800	1.16-1.5	45

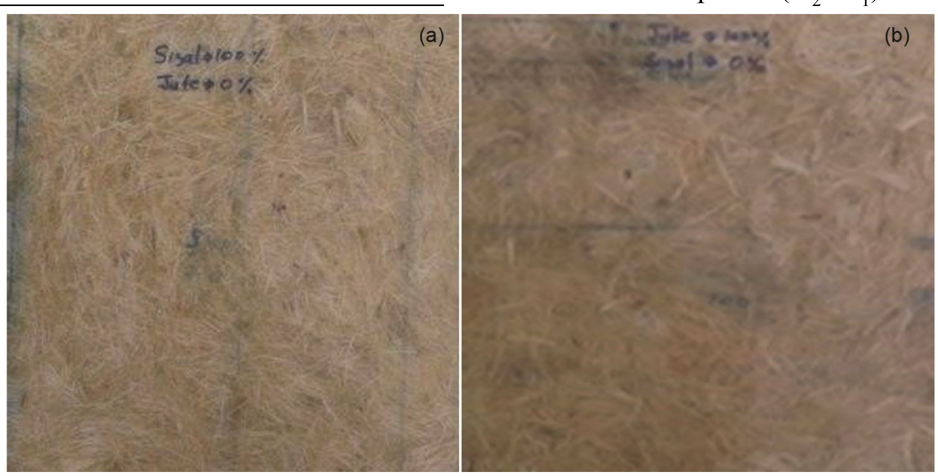

Fig. 2 — Fiber hybrid composite (a) sisal 100% and jute 0 % (b) sisal 0%, and jute 100%.

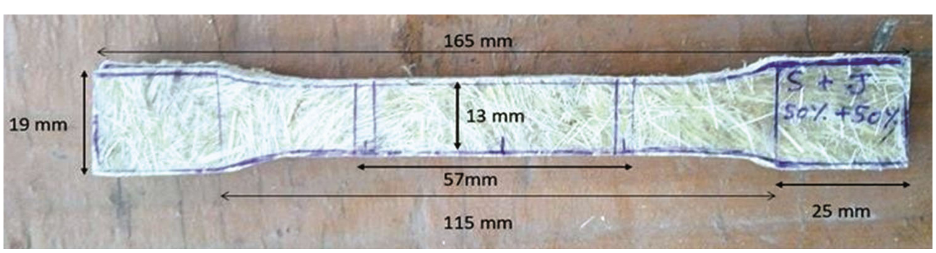

Fig. 3 — Dimension of tensile test specimen.

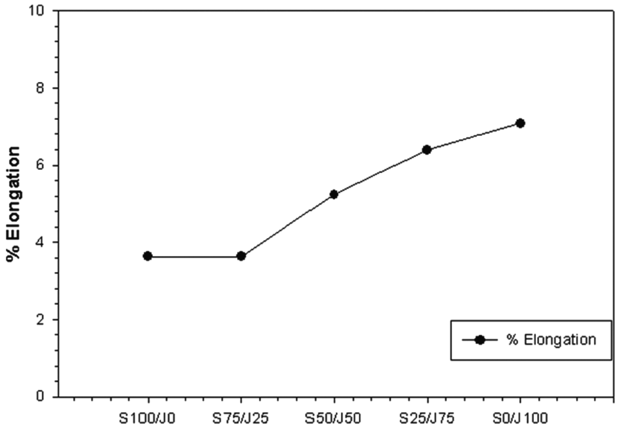

Fig. 4 — % Elongation for Sisal/ Jute hybrid composite.

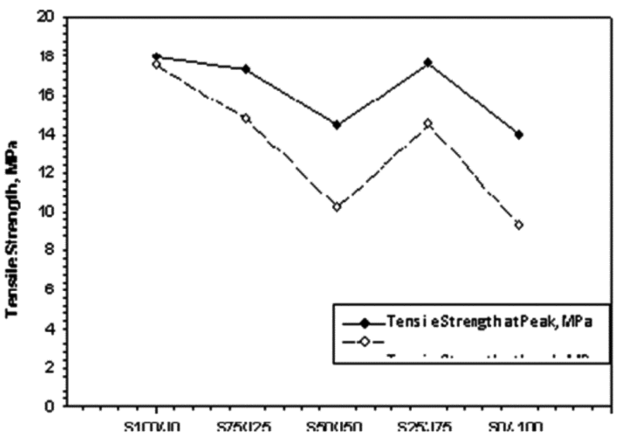

Fig. 5 — Tensile strength for Sisal/ Jute hybrid composite.

3 Results and Discussion

The mechanical behaviour of investigated samples of sisal and jute hybrid composite is shown in Figs (4-6). It has been observed that percentage elongation is highest for sample, S-5, (sisal-0/jute-100) (Fig. 4), tensile strength is the highest for sample, S-1, (sisal- 100/jute- 0) (Fig. 5), whereas flexural strength is the highest for sample, S-3, (sisal- 50/jute- 50). This can also be observed with Figs (5 and 6) that the flexural strength is always on higher side than the tensile strength for all the investigated samples. This is due the fact that during tensile test, load is applied to the complete length, where, possibilities of flaws/voids are more as compared to the flexural test, where load is applied on a point.

These results are in line with the results shown by Patel *et al.*[19], Gupta & Shrivastava[23], the change in composition of natural fiber does not follow any peculiar trend for mechanical properties. As the percentage weight of jute increases in composite,

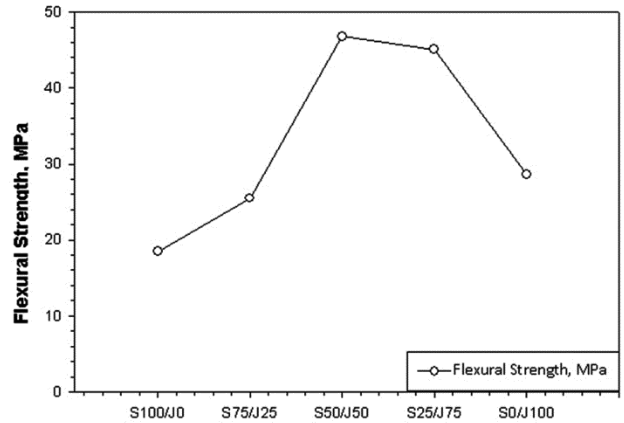

Fig. 6 — Flexural strength for Sisal/ Jute hybrid composite.

tensile strength initially decreases then increases and after attaining peak again decreases. Gupta & Shrivastava[23] attains the minimum tensile strength for sisal-75/jute-25, whereas our result shows minimum tensile stress at sisal 50/jute 50. However, flexural strength shows similar trend, it increases up to sisal 50/jute 50 and after attaining the peak reduces. The range of tensile and flexural strength reported by Gupta & Shrivastava[23] is approximately 5 time and 8 times of the present investigation respectively. These deviations of results can be attributed by the condition of natural fiber used for hybrid composite. Gupta & Shrivastava[23] used unidirectional continuous aligned bi-layer of natural fiber, whereas, in present investigation hybrid composite were made by discontinuous random orientation of natural fiber. Probably random orientation of fibers may lead to weak interfacial bonding between matrix and fiber, results in lower mechanical strength. Some of mechanical properties of hybrid composites of natural fibers published by other investigators are listed in Table 4.

3.1 Moisture absorption test

After fabricating reinforced hybrid composite of sisal and jute, moisture absorption test has been performed in distilled water. Composite was cut into pieces of 28 mm × 30 mm in dimension and dipped in distilled water. The weight of the sample is measured in regular interval till the state of saturation reaches. The percentage gain of weight by the samples due to moisture absorption is shown in Fig. 7. The moisture absorption test shows that the hybrid composite of natural fibers shows Fickian behavior since the test was performed at room temperature[13]. Initially percentage gain in weight or water absorption is very

Table 4 —Mechanical properties of hybrid composites of natural fibers

Author	Composite	Tensile Strength MPa	Flexural Strength MPa
Venkateshwaran et al. [5]	Banana	8.54-16.39	21.58-57.53
Venkateshwaran et al. [5]	Banana/Sisal	16.12-21.2	57.33-62.04
Boopalan et al. [8]	Banana/Jute	16.62-18.96	57.22-59.84
Dhakal et al. [9]	Hemp/UPE	20-55	55-110
Maslinda et al. [10]	Woven Jute, Hemp, Kenaf	80, 81, 84	68.5, 68.2, 77
Gupta and Shrivastava [23]	Jute/Sisal	72-110	194-385
Mamo and Subramanian [24]	Jute/Sisal		82.29-103.68
Santhanam and Chandrasekaran [25]	Banana/Glass	34.50-47.32	32.54-35.54

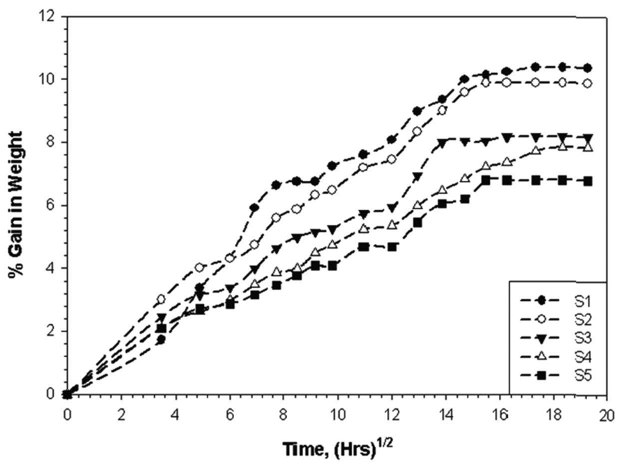

Fig. 7 — Moisture absorption for Sisal/ Jute hybrid composite.

fast, almost linear and thereafter gain is slow before reaches to the saturation state. This behavior is due to concentration gradient, spreading of water from high to low concentration area. The cellulose content in natural fiber hybrid composite is responsible for moisture gain in addition to fiber volume fraction, permeability of fiber, reaction between water and matrix, orientation of reinforcement, diffusivity, fiber surface protection and area of exposed surface[10,13]. The natural fiber that has higher cellulose content absorbs more moisture due to its hygroscopic nature[10]. It is also very difficult to dissolve cellulose fibers due to their high crystallinity, hence, it retains the liquid between the interfibrillar spaces[13]. In fact continuous exposure of moisture to natural fiber hybrid composites leads to micro-cracking in brittle thermosetting resin. Water molecules enter through these cracks and continuously attacks at the interface, lead to debonding of matrix and fiber[9,10]. The higher cellulose content results in more water penetration into fiber matrix interface. The cellulose content in sisal fiber is more as compared to jute fiber (Table 2), hence sample-1, sisal-100/jute-0, absorbed more water as compared to other investigated samples. The sample-5, sisal-0/jute- 100, completely made of jute is

Table 5 —Moisture Absorption by Hybrid Composites of Natural Fibers

Author	Composite	Moisture absorption% wt
Venkateshwaran et al. [5]	Banana	21.25
Venkateshwaran et al. [5]	Banana/Sisal	16.66-28.64
Dhakal et al [9]	Hemp/UPE	10.97 @888 h
Maslinda et al. [10]	Woven Jute, Hemp,Kenaf	12,10,12 @400hrs 13.5,12,14 @900hrs
Gupta and Shrivastava [23]	Jute/Sisal	6.09-3.76
Santhanam and Chandrasekaran [25]	Banana/Glass Fiber	4.26-10.55

showing lowest water absorption characteristics. The lower water absorption or swelling of sample-5, sisal-0/jute-100 may also be due to better interfacial bonding between matrix and fiber. The percentage weight of moisture gain at saturation state is highest for sample-1, sisal- 100/jute-0, and reduces approximately by 20 and 40 percent respectively for sample 3, sisal- 50/jute-50 and sample 5, sisal-0/jute-100. The percentage weight gain due to moisture for investigated samples of hybrid composites are in the range of 6.8 – 10.40 at saturation state. The results of moisture absorption are in line with the results reported by other investigators for hybrid composites of natural fibers, as shown in Table 5.

Hybrid composite of banana fiber shows higher % gain of moisture, this may be due to the fact that banana fiber contents more cellulose and hemicellulose as compared to jute and sisal fiber. The percentage weight gain reported by Gupta & Shrivastava[23] for sisal and jute composite are approximately 40 percent lower. This may be due to the fact that they have used continuous fiber, whereas, in present investigation we have used discontinuous fibers in random orientation. Probably with discontinuous fibers in random orientation the chance of capillarity and transport of water flow into the fiber matrix is more. Therefore, percentage weight gain reported in present investigation is in on higher side than the result reported by Gupta & Shrivastava[23].

4 Conclusion

In present work an investigation for reinforced hybrid composite of discontinuous jute and sisal fiber in random orientation has been conducted. The tensile properties and moisture absorption behavior of epoxy hybrid composites in five different weight combinations of sisal and jute fibers have been examined. It has been observed that percentage elongation, moisture gain, tensile and flexural stress varies with the change in fiber compositions. As the percentage of jute fiber increases percentage elongation at break increases. The tensile stress is highest with 100% sisal fiber and minimum with 100% jute fiber. The flexural stress is always higher than the tensile stress for all the investigated samples. The moisture absorption percentage is highest for 100 % sisal fiber and decreases with increase in the percentage of jute fiber in hybrid composite. With this experimental study it can be suggested that if moisture resistance is crucial parameter then use of 100% jute fiber composite is recommended and if tensile property alone is crucial then 100% sisal fiber composite should be used. If tensile strength and moisture resistance both are equally important then the use of 75% jute and 25% sisal hybrid composite is recommended. This combination seems to be an optimal combination on the basis of cost as well, due to cheaper jute fiber than sisal fiber.

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