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Mechanical, thermal and water absorption properties of hybrid sisal/jute fiber reinforced polymer composite

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In the present work, mechanical, thermal and water absorption properties of hybrid sisal/jute fiber reinforced polymer composite have been investigated. Hybrid composites are prepared by hand lay-up technique keeping constant 30 wt% of total fibers content with various weight ratios of jute and sisal fibers. Mechanical properties such as tensile, flexural and impact are investigated as per ASTM standards. Tensile and flexural test are carried out using Tinius Olsen H 10 K-L Universal Testing Machine with cross head speed of 2 mm/min. In addition, impact test is carried out using Tinius Olsen Impact 104 machine as per ASTM D 256. Thermal stability of prepared composites is obtained using Perkin Elmer TGA 4000 apparatus within temperature 30°C - 800°C in nitrogen atmosphere. Water absorption test is carried out as per ASTM D570 to obtain the maximum water uptake, sorption, diffusion and permeability coefficient. Moreover, morphological analysis is carried out to observe the fracture behavior and fiber pull out of the composite samples using scanning electron microscope. The results indicate that hybrid composite having 50% jute and 50% sisal (J50S50) has higher mechanical and thermal property and lower water absorption property than jute, sisal and other hybrid composites. For further improvement in the property of hybrid composite J50S50, alkali treatment of fibers is carried out and its positive effect is observed in terms of increase in mechanical and thermal properties and decrease in water absorption properties. The present prepared composite can be used in packaging, light weight automotive parts and construction applications.

Keywords: Hybrid, Mechanical properties, Thermal properties, Water absorption properties, Alkali treatment.

Natural fibers are being used in place of glass and other synthetic fibers for medium strength applications due to advantages such as low cost, low density, availability in abundance, environmental friendly, non-toxicity, high flexibility, renewability, biodegradability, relative non-abrasiveness, high specific strength and stiffness, and easy processing[1-8]. Besides of these advantages, natural fibers have some disadvantages also such as high moisture absorption, low thermal stability and low impact strength[9-11]. Many researchers have used natural fibers as reinforcement in polymer matrix to prepare the composites and in several cases they observed that natural fiber composites have good mechanical property but unable to reach as strength of glass fiber composites.

Hybridization technique can be used to increase the mechanical strength of single natural fiber reinforced polymer composite. Many researchers have incorporated glass fiber or high strain natural fibers into single natural fiber reinforced polymer composites to improve their mechanical properties and they found positive effect of hybridization in terms of increased mechanical properties. Ramesh *et al.*[12] studied the effect of glass fiber loading on the mechanical properties of sisal and jute fiber hybrid polyester composite. They observed that the addition of glass fiber with jute and sisal fibers reinforced composite as results enhanced their mechanical properties. The glass/jute composite showed the maximum tensile strength, glass/jute/sisal showed the maximum flexural load while glass/sisal showed the maximum impact strength. Venkateshwaran *et al.*[13] investigated the mechanical and water absorption properties of hybrid banana/sisal reinforced epoxy composite. They found that addition of sisal fiber in banana fiber reinforced epoxy composite as results increase in mechanical properties and decrease in the water absorption properties. Boopalan *et al.*[14] presented study on effect of incorporation of banana fiber in jute fiber reinforced epoxy composite. They reported that mechanical and thermal properties of jute composite were increased and water absorption property was decreased due to addition of banana fiber. Shanmugam *et al.*[15] evaluated the properties of hybrid palmyra palm leaf fiber/jute fiber polyester

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composite. They observed that addition of jute fiber with palmyra palm leaf fiber polyester composite as results increased mechanical properties.

Jute fibers have advantages such as high production and low cost but its composites have low mechanical properties. Therefore, the mechanical properties of jute fiber reinforced polymer composites are required to improve. The hybridization approach was used to improve the mechanical properties of jute fiber reinforced polymer composite by adding high strain sisal fibers in this work. Mechanical properties (tensile, flexural and impact), thermal stability and water absorption characteristic parameters (sorption, diffusion and permeability coefficient) of hybrid sisal/jute fiber reinforced polymer composite were investigated.

Materials and Methods

Materials

Sisal and jute fibers were used as reinforcement and epoxy as a matrix in this work. Sisal and jute fibers were purchased from Uttarakhand Bamboo and Fiber Development Board, Dehradun, India. Epoxy AY 105 and corresponding hardener HY 951 was purchased from Bakshi Brothers/Universal Enterprises, Kanpur, Uttar Pradesh, India. The physical properties, mechanical properties and chemical composition of jute and sisal fiber are given in Table 1.

Alkali treatment

The fibers were immersed in 5% NaOH solution for 30 min[15]. The fibers were then cleaned several times with distilled water followed by immersion of fibers in very dilute HCl in order to remove the NaOH adhering to the surface of the fibers. Finally the fibers were again washed several times with distilled water and then dried in an oven maintained at 70ºC for 24 h.

Table 1–Properties of jute fiber and sisal fiber[16,17]

Properties	Jute fiber	Sisal fiber
Density (g/m³)	1.3	1.5
Diameter (μm)	25-200	50-200
Elongation at break (%)	1.5-1.8	2-2.5
Tensile strength (MPa)	393-773	511-700
Young's modulus (GPa)	26.5	9.4-22
Cellulose (%)	61-71	65
Lignin (%)	12-13	9.9
Microfibrillar angle	8^0	22^0
Wax (%)	0.5%	2%
Hemi- cellulose (%)	14-20	22

Fabrication method of composites

Unidirectionally continuous aligned bi-layer hybrid composites were fabricated by reinforcing the sisal and jute fibers in epoxy matrix by hand lay- up technique. The epoxy resin AY 105 and corresponding hardener HY 951 were mixed in a ratio of 10:1 by weight as recommended by suppliers. The mixture was stirred manually to disperse the resin and the hardener in the matrix. A stainless steel mould having dimensions of 300 mm × 200 mm × 3 mm was used for casting of the composites. Silicon spray was used to facilitate easy removal of the composite from the mould after curing. The cast of each composite is cured under a load of 50 kg for 24 h before it is removed from the mould. Dimension of specimens are cut as per ASTM standard using a diamond cutter for analysis of mechanical, thermal and water absorption properties of prepared hybrid composite. The composites manufactured with varying wt% of fibers have been given notations as shown in Table 2.

Characterizations of Composites

The fabricated composites were tested for mechanical, thermal and water absorption properties.

Tensile test

Tensile test of prepared composite samples was performed on Tinius Olsen H 10 K-L Universal Testing Machine with a crosshead speed of 2 mm/min. Tests were conducted as per ASTM D638 with dimension 165 mm × 20 mm × 3 mm. Extensometer was used to measure the strain, which is calculated as the change in length of a specimen divided by gauge length. Five specimens of each composite were tested and average values are reported.

Flexural test

Flexural test of prepared composite samples was carried out using a three point bending test on Tinius

Table 2–Notation for hybrid sisal/jute fiber reinforced polymer composite

Composite	Jute fibers content (%)	Sisal fibers content (%)	Total fiber content (wt %)	Total matrix (wt %)
J100S0	100	0	30	70
J75S25	75	25	30	70
J50S50	50	50	30	70
J25S75	25	75	30	70
J0S100	0	100	30	70
J50S50 T (Alkali treated)	50	50	30	70

J-jute fiber, S-sisal fiber

Olsen H 10 K-L Universal Testing Machine. The samples were cut for the flexural test with dimensions 80 mm × 12.7 mm × 3 mm as per ASTM D790. The flexural test was carried out at room temperature with the crosshead speed of 2 mm/min. Flexural strength and flexural modulus were calculated using Eq. (1)[19].

$$\text{Flexural strength} = \frac{3FL}{2bd^2} \text{ and Flexural modulus} = \frac{mL^3}{4bd^3} \quad \ldots (1)$$

where F is ultimate failure load (N), $L$is span length (mm), b and d are width and thickness of specimen (mm) respectively and m is slope of the tangent to initial line portion of the load-displacement curve. Five specimens of each composite were tested and average values are reported.

Impact test

Impact test of composite was performed on Tinius Olsen Impact 104 machine. The samples were prepared for the impact test of dimensions 65 mm × 12.7 mm × 3 mm and 2.5 mm notch thickness as per ASTM D 256. Five specimens of each composite were tested and average values are reported.

Statistical analysis

Statistical analysis is required to found out that performed test is significant or not. Null hypothesis provides information that there is no difference between samples. If p value, calculated from T-test or ANOVA is less than 0.05, then null hypothesis can be rejected but null hypothesis is considered if p value is greater than 0.05. T-test and Analysis of Variance (ANOVA) were used to find out the statistical analysis of tensile, flexural and impact test. Probability value p=0.05 is consider as an analytical of significance compared to the control composite (J100S0).

Water absorption properties

All natural fiber reinforced polymer composites absorb moisture in humid atmosphere and when immersed in water. The effect of absorption of moisture leads to the degradation of fiber-matrix interface region creating poor stress transfer efficiencies resulting in a reduction of mechanical properties. Water absorption behavior of hybrid sisal/jute fiber reinforced polymer composite was investigated as per ASTM D 570. The specimens were submerged in water in room temperature to study the kinetics of water absorption property. The samples were taken out periodically and weighed immediately. The weight of sample before and after absorption was taken using a precise 4-digit balance. The percentage of water absorption was calculated by Eq. (2).

$$\text{Water absorption (\%)} = \frac{w_2 - w_1}{w_1} \times 100 \quad \ldots (2)$$

where m is weight before soaking into water (g) and t is weight after soaking into water (g).

The kinetic parameter such as diffusion coefficient is calculated using Eq. (3)[14].

$$\text{Diffusion coefficient } (D) = \pi \left(\frac{t^2 m^2}{16 W_\infty^2} \right) \quad \ldots (3)$$

where m is the slope of linear portion of the sorption curve and t is the initial sample thickness (mm).

The diffusion coefficient shows the ability of solvent molecules to move among the polymer segment.

The sorption coefficient which is related to the equilibrium sorption was calculated using Eq. (4)[14].

$$\text{Sorption coefficient } S = W_\infty / W_t \quad \ldots (4)$$

where W_∞ and W_t are percentage of water uptake at infinite time and at time t.

The permeability coefficient shows the net effect of sorption and diffusion coefficient was calculated using Eq. (5)[14].

$$\text{Permeability coefficient } P = D \times S \quad \ldots (5)$$

Thermogravimetric analysis (TGA)

Thermal stability of the composites was analyzed by thermogravimetric Perkin Elmer TGA 4000 apparatus.TGA measurements were carried out on 15-25 mg sample placed in a platinum pan. The composite samples were heated from 30-800ºC at a heating rate of 10ºC/min in a nitrogen atmosphere with a flow rate of 20 mL/min to avoid unwanted oxidation.

Scanning electron microscopy

The morphological study of the composite samples was studied using scanning electron microscope (Carl Zeiss EVO MA 15). The samples were mounted on an aluminum stub using double sided tape and all specimens were coated with very thin layer of gold to prevent electric charging during examinations. The SEM micrographs were obtained under conventional secondary electron imaging conditions.

Results and Discussion

Mechanical properties

The tensile, flexural and impact properties of hybrid sisal/jute fiber reinforced polymer composite are given in Table 3.

Tensile properties

Tensile strength and tensile modulus of prepared composites are given in Table 3 and corresponding data are plotted in Fig. 1. A positive hybrid effect is observed for the composites. The maximum value of tensile strength (102.08 MPa) and tensile modulus (2.03 GPa) are found for the hybrid composite J50S50. Tensile strength and tensile modulus of hybrid composite J50S50 are 30% and 33% more than those of composite J100S0. Tensile strength of hybrid composite J50S50 is 1.4%, 14% and 22% more as compared to those of composites J75S25, J25S75 and J0S100 respectively. Similarly tensile modulus of hybrid composite J50S50 is 20%, 38% and 28% more as compared to those of composites J75S25, J25S75 and J0S100, respectively. According to statistical analysis the value of tensile strength and tensile modulus is found to be significant as compared to the J100S0 composite. The results of ANOVA also show the significant difference between composites (Table 3). The hybrid composite J50S50 shows better tensile strength and tensile modulus. The better tensile strength and tensile modulus of hybrid composite J50S50 can be explained as jute fiber having low elongation may break first and then the load is carried by the sisal fiber having high elongation without the failure of matrix, inducing better stress transfer from matrix to fibers and thus resulting in increased mechanical properties of hybrid composite. The alkali treatment of fibers have further increased the tensile properties of hybrid composite J50S50. The alkali treated hybrid composite J50S50 T shows the highest value of tensile strength (106.95 MPa) which is 4.5% more than that of the hybrid composite J50S50. Alkali treatment of fibers increases the surface roughness resulting in better mechanical interlocking and hence increase in mechanical properties[18]. SEM image (Fig. 2) shows the strong adhesion between fibers and matrix and Fig. 3 shows the fracture of fibers after tensile test for hybrid composite J50S50.

Flexural properties

Flexural strength and flexural modulus of prepared composites are given in Table 3 and corresponding data are plotted in Fig. 4. Like tensile

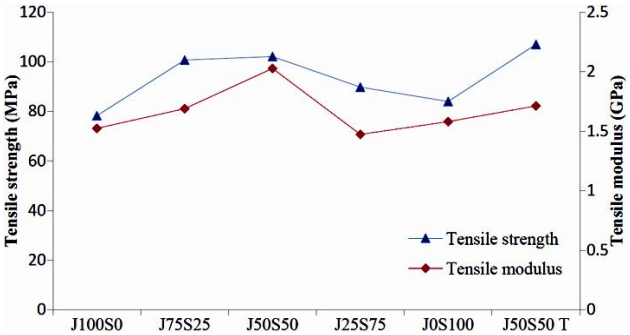

Fig. 1–Tensile strength and tensile modulus of jute, sisal and hybrid composites

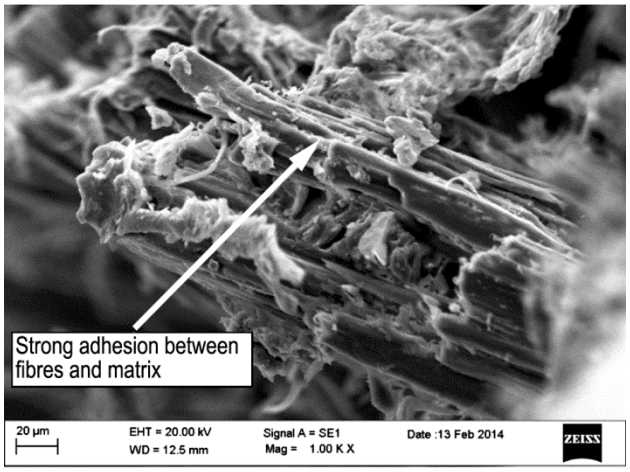

Fig. 2–SEM image of hybrid composite J50S50

Table 3–Mechanical properties of hybrid sisal/jute fiber reinforced polymer composite

Composite	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact Strength (kJ/m^2)
J100S0	78.21±6.12	1.52±0.13	203.48±17.34	9.76±0.82	13.89±0.98
J75S25	100.65±9.92	1.69±0.17	319.03±17.93	16.72±0.90	24.911.70
J50S50	102.08±8.15	2.03±0.14	361.90±24.22	17.50±1.03	30.10±2.09
J25S75	89.74±6.63	1.47±0.11	344.19±26.79	16.01±0.75	25.93±1.18
J0S100	83.96±6.94	1.58±0.08	252.39±12.11	11.31±1.02	22.03±1.74
J50S50T	106.95±10.45	1.71±0.15	419.47±26.80	17.87±1.63	30.73±1.66

S.D. represents the standard deviation

strength and tensile modulus results, flexural strength and flexural modulus are also found maximum for hybrid composite J50S50. Flexural strength and flexural modulus of hybrid composite J50S50 are found to be 361.90 MPa and 17.50 GPa respectively which is 78% and 79% more as compared to those of composite J100S0. Flexural strength of hybrid composite J50S50 is 13%, 5% and 43% more than those of composites J75S25, J25S75 and J0S100 respectively. Similarly flexural modulus of hybrid composite J50S50 is 5%, 9% and 55% more than those of composites J75S25, J25S75 and J0S100, respectively. According to statistical analysis the value of flexural strength and flexural modulus is found to be significant as compared to the J100S0 composite. The results of ANOVA also show the significant difference between composites (Table 3). The composite J50S50 shows the better flexural strength and flexural modulus due to effect of hybridization. The flexural strength and flexural modulus of the alkali treated hybrid composite J50S50T is found to be 16% and 2% higher than those of composite J50S50 respectively which is attributed to alkali treatment. The flexural properties have to be higher than tensile properties, as in flexural test load is applied on a point, where least number of flaws are possible, however for the tensile test the load is applied over a longer length where many number of flaws are possible. Figure 5 shows the SEM image of fractured specimen after flexural test for composite J50S50.

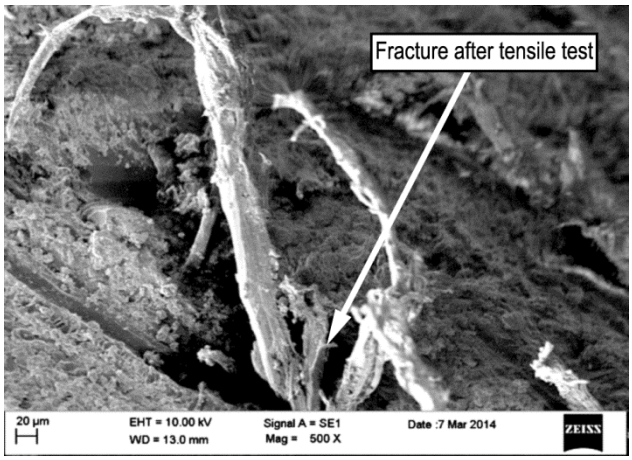

Fig. 3–SEM image of fractured specimen of tensile test for hybrid composite J50S50

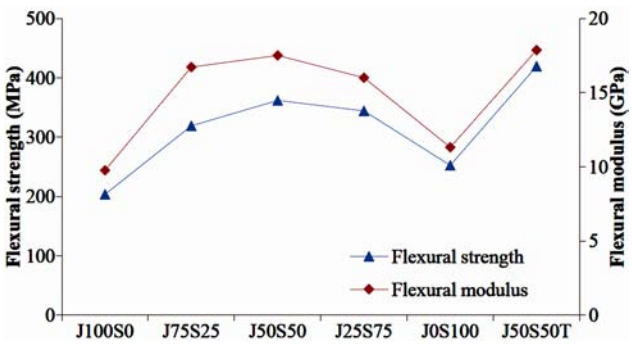

Fig. 4–Flexural strength and flexural modulus of jute, sisal and hybrid composites

Impact strength

The impact strength of prepared composites is given in Table 3 and corresponding data are plotted in Fig. 6. Like tensile and flexural strength, impact strength is also found maximum for hybrid composite J50S50. The impact strength of hybrid composite J50S50 is 116% more than those of composite J100S0. Impact strength of hybrid composite J50S50

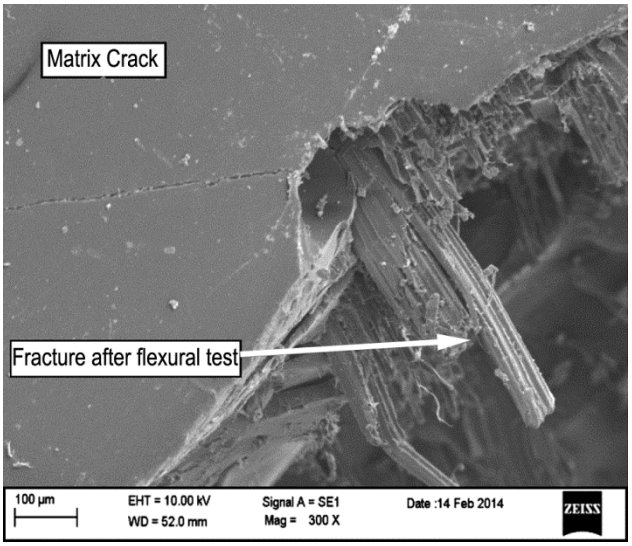

Fig. 5–SEM image of fractured specimen of flexural test for hybrid composite J50S50

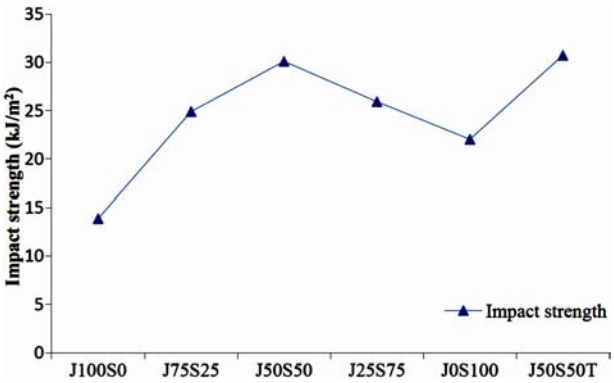

Fig. 6–Impact strength of jute, sisal and hybrid composites

is 21%, 16% and 37% more than those of composites J75S25, J25S75 and J0S100, respectively. The hybrid composite J50S50 shows the maximum value of impact strength due to addition of low modulus fiber (sisal) with high modulus fiber (jute fiber). The high modulus fiber provides the load bearing capacity whereas low modulus fiber provides more damage tolerant. According to statistical analysis the value of impact strength is found to be significant as compared to the J100S0 composite. The results of ANOVA also show the significant difference between composites (Table 3). The alkali treated hybrid composite J50S50 T shows comparably the highest impact strength which is higher by 2% compared to that of hybrid composite J50S50. Figure 7 shows the SEM image of fractured specimen after impact test for composite J50S50.

Mechanical properties of present hybrid sisal/jute fiber reinforced polymer composite are compared with different published work as given in Table 4. The tensile strength of the present hybrid composite is found to be higher by 447%, 438%, and 59% as compared to those of composites banana/sisal/epoxy[13], jute/banana/epoxy[14] and palmyra palm leaf stalk/jute/polyester[15], respectively. Flexural strength of present hybrid composite is observed to be higher by 506%, 504% and 148% as compared to those of composites banana/sisal/epoxy[13], jute/banana/epoxy[14] and palmyra palm leaf stalk/jute/polyester[15], respectively. Impact strength of present hybrid composite is 68%, 55% and 11% more than those of hybrid composites banana/sisal/epoxy[13], jute/banana/epoxy[14] and palmyra palm leaf stalk/jute/polyester[15], respectively.

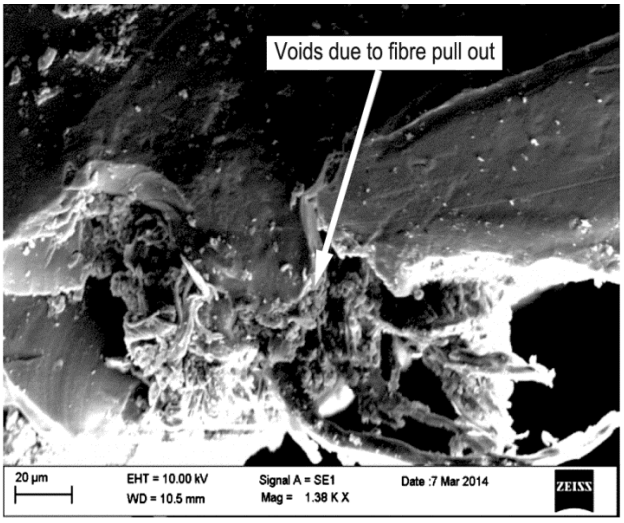

Fig. 7–SEM image of fractured specimen of impact test for hybrid composite J50S50

Thermogravimetric analysis

The TGA results of prepared composites are plotted in Fig. 8. It is observed that there are three significant regions of weight loss due to rise in temperature as shown in Fig. 8. The initial weight loss (up to 5%) of composites occurs at low temperature due to removal of moisture from the composites. The major weight loss (up to 75%) occurs at higher temperature due to degradation and volatization of epoxy along with fibers present in composites. The final weight loss of residue which is formed after major degradation requires higher temperature. The initial, major and final weight loss and its corresponding temperature of composites are given in Table 5. Shifting of major degradation towards higher

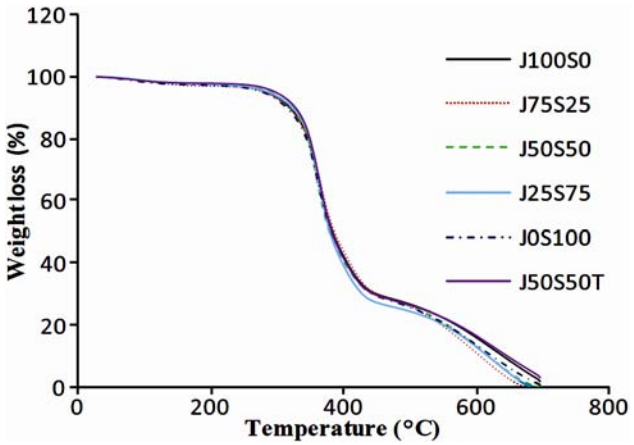

Fig. 8–Variation in weight loss (%) of jute, sisal and hybrid composites with temperature

Table 4–Comparison of mechanical properties of present hybrid composite with published work

Reinforcement	Matrix	Fiber content	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact strength (kJ/m^2)	Ref.
Banana/sisal	Epoxy	50/50	18.66	0.68	59.68	9.13	17.90	[13]
Banana/jute	Epoxy	50/50	18.96	0.72	59.84	9.17	18.23	[14]
Palmyra palm leaf stalk/jute	Polyester	50/50	64.30	2.45	145.66	17.95	27.01	[15]
Jute /sisal	Epoxy	50/50	102.08	2.03	361.90	17.50	30.10	Present work

Table 5–TGA analysis of hybrid sisal/jute fiber reinforced polymer composites

Composites	Initial weight loss (%)	Initial weight loss at temperature (ºC)	Major weight loss (%)	Major weight loss at temperature (ºC)	Final weight loss at temperature (ºC)
J100S0	5	286	75	510	698
J75S25	5	283	75	511	684
J50S50	5	292	75	513	652
J25S75	5	288	75	490	674
J0S100	5	279	75	508	694
J50S50T	5	298	75	517	693

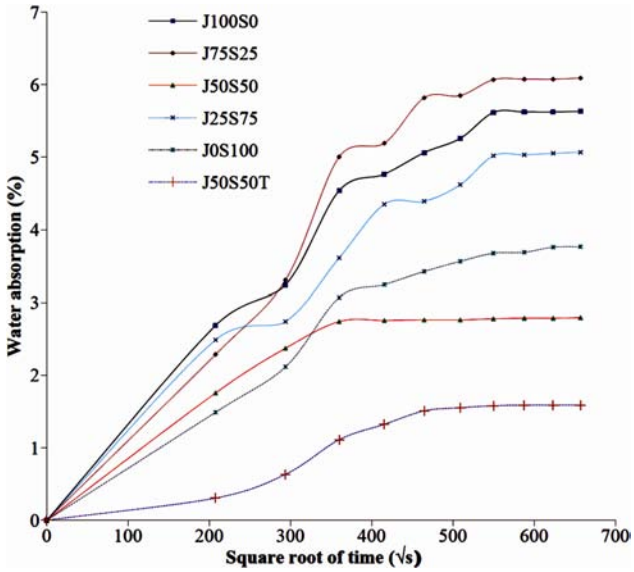

Fig. 9–Water absorption (%) of jute, sisal and hybrid composites as a function of square root of time

temperature (513°C) for hybrid composite J50S50 shows better thermal stability than jute, sisal and other hybrid composites. Temperature associated with major degradation is found 517°C for alkali treated hybrid composite J50S50 T. This shows that alkali treatment of fibers has increased the thermal stability of hybrid composite J50S5. The highest degradation temperature of alkali treated hybrid composite J50S50 T is due to strong adhesion between fibers and epoxy matrix.

Water absorption behaviour

The water absorption of hybrid sisal/jute fiber reinforced polymer composite is plotted against the square root of time as shown in Fig. 9. The percentage water absorption of composites J100S0, J75S25, J50S50, J25S75, J0S100 and J50S50T are found 5.63, 6.09, 2.79, 5.06, 3.76 and 1.58, respectively at infinite time. The composite J50S50 shows lower water absorption and swelling due to better interfacial bonding between matrix and fibers. The hybrid

Table 6–Sorption, diffusion and permeability coefficient of hybrid sisal/jute fiber reinforced polymer composite

Composites	Percentages of water uptake at infinite time	Sorption coefficient *S*	Diffusion coefficient *D* (mm^2/s)	Permeability coefficient *P*(mm^2/s)
J100S0	5.63	2.10	1.058E-5	2.217E-5
J75S25	6.09	2.66	0.655E-5	1.744E-5
J50S50	2.79	1.59	1.840E-5	2.923E-5
J25S75	5.06	2.03	1.124E-5	2.285E-5
J0S100	3.76	2.54	0.716E-5	1.820E-5
J50S50T	1.58	5.18	0.173E-5	0.896E-5

composite J50S50 shows 50% lower water absorption as compared to jute composite J100S0 but after alkali treatment hybrid composite J50S50 shows 72% lower water absorption as compared to J100S0. It is observed that the alkali treated hybrid composite J50S50T shows the lowest percentage of water absorption and swelling as compared to jute, sisal and other hybrid composites, which is attributed to alkali treatment. The percentage change in thickness of composites J100S0, J75S25, J50S50, J25S75, J0S100 and J50S50 T are found 2.30%, 1.58%, 0.9%, 1.31%, 2.0% and 0.8%, respectively. The sorption, diffusion and permeability coefficient of prepared composites are given in Table 6. The composite J50S50 shows the lowest sorption coefficient while alkali treated hybrid composite J50S50 T shows the lowest value of diffusion and permeability coefficient.

Scanning electron microscopy

Figure 2 shows the micrographs of unfractured specimen of hybrid composite J50S50 which shows uniform distribution of fibers into epoxy matrix. Figures 3, 5 and 7 show the micrographs of fractured specimen of tensile, flexural and impact test for composite J50S50 respectively. Breakage of fibers after tensile, flexural and impact test for hybrid composite J50S50 can be easily seen in Figs 3, 5 and 7, respectively. Few voids present due to fiber pull out

can be also seen which shows adhesion between fibers and matrix. A very few number of voids created during deformation indicate strong fibers-matrix adhesion.

Conclusions

Mechanical, thermal and water absorption properties of hybrid sisal/jute fiber reinforced polymer composite are studied and the following conclusions are drawn: The hybrid composite J50S50 shows the better thermal property and mechanical properties such as, tensile strength, tensile modulus, flexural strength, flexural modulus and impact strength. The hybrid composite J50S50 has lower water absorption than jute, sisal and other hybrid composites. Alkali treated sisal and jute fiber has further enhanced the mechanical and thermal properties and reduced the water absorption properties of hybrid composite J50S50. The present hybrid composite can be used in field of automobile, packaging and building.

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References

1 Prasad A V R, Rao K M & Nagasrinivasulu, *Indian J Fibre Textile Res*, 34 (2009) 162-167.
2 Gupta M K & Srivastava R K, *Mater Today: Proc*, 2 (2015) 2909-2917.
3 Mukhopadhyay S, Pal R, Narula V & Mayank M, *Indian J Fibre Text Res*, 38 (2013) 87.
4 Huda M S, Drzal L T, Mohanty A K & Misra M, *Compos Sci Technol*, 66 (2006) 1813-1824.
5 Bajpai P K, Singh I & Madaan J, *J Reinforced Plast Compos*, 31 (2012) 1712-1724.
6 Ramnath B V, Kokan S J, Raja R N, Sathyanarayanan R, Elanchezhian C, Prasad A R & Manickavasagam V M, *Mater Des*, 51 (2013) 357-366.
7 Bakare I O, Okieimen F E, Pavithran C, Khalil H P S A & Brahmakumar M, *Mater & Des*, 31 (2010) 4274-4280.
8 Yan L, Chouw N & Jayaraman K, *Composites: Part B*, 56 (2014) 296-317.
9 Bajpai P K, Singh I & Madaan, wear, 297 (2013) 829-840.
10 Gupta M K & Srivastava R K, *Polym Plast Technol Eng*, 55(2016) 626-642.
11 Alawar A, Hamed A M, Al-Kaabi K, *Composites: Part B*, 40 (2009) 601-606.
12 Ramesh M, Palanikumar K & Reddy K H, *Composites: Part B*, 48 (2013) 1-9.
13 Venkateshwaran N, Perumal A E, Alavudeen A & Thiruchitrambalam M, *Mater Des*, 32 (2011) 4017-4021.
14 Boopalan M, Niranjanaa M & Umapathy M J, *Composites: Part B*, 51 (2013) 54-57.
15 Shanmugam D & Thiruchitrambalam M, *Mater Des*, 50 (2013) 533-542.
16 Faruk O, Bledzki A K, Fink H P & Sain M, *Progr Polym Sci*, 37 (2012) 1552-1596.
17 Fuqua M A, Huo S & Ulven C A, *Polym Rev*, 52 (2012) 259-320.
18 Li X, G Lope & Panigrahi S, *J Polym Environ*, 15 (2007) 25-33.
19 Prasad V R, Rao K M M, Rao K M & Kumar M A, *Indian J Fibr Text Res*, 31(2006) 335.