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Effect of stacking sequence of bi-directional jute/flax fibre on tensile strength, water absorption and tribological behavior of epoxy based hybrid composites

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Effect of different stacking sequence of jute and flax fabrics on the tensile, water absorption and wear properties of hybrid composite laminate has been studied. The composites have been manufactured by hand lay-up technique. The stacking sequence configurations are set as JJJJJ (jute-jute-jute-jute-jute), JFJFJ (jute-flax-jute-flax-jute), JFFFJ (jute-flax-flax-flax-jute), FJJJF (flax-jute-jute-jute-flax) and FJFJF (flax-jute-flax-jute-flax). It is found that the specimen with FJFJF sequence has highest tensile strength (149.12 MPa), less water absorption and better wear resistance than that of the other sequences.

Keywords: Flax fibre, Hybrid composites, Jute fibre, Stacking sequence, Tensile strength, Tribological property, Water absorption

Natural fibre composites are derived from binding of plant fibres and the traditional polymer matrices such as epoxy. Natural fibres have various advantages, such as abundant availability, light weight, environmental friendliness and so on. The versatile properties of natural composites found vast applications in various fields, thus replacing the traditional materials with new age composites. Besides having high specific properties, the factors such as fibre percentage, chemical composition of fibres, stacking sequence of fibres in composites, structure of composites significantly affect the final properties of the composite. Chemical composition plays an important role in influencing the fibre characteristics. Hence, the properties of the composites may be affected by the composition[1-3]. Snehalatha *et al.*[4] investigated glass/bamboo fibre-reinforced epoxy hybrid composites. They experimentally evaluated stacking sequence effect on tensile, flexural, and erosive wear properties and found that the properties of hybrid composite are enhanced by incorporation of glass in bamboo fibre composites. They concluded that the sequence of layering significantly affects the flexural and tensile strength. Hybridization (jute-hemp/epoxy) showed reduction in water absorption characteristic of natural fibre based composites[5]. Dixit and Verma[6] observed improvement in composite properties with hybridization. This study states that the sandwich construction of natural fibre composites can significantly improve the tensile properties of natural fibre composites. This study also claims that sandwich construction of natural fibre composites shows significant reduction in water absorption. Osmanet *et al.*[7] found that by hybridization, better water resistant properties of composite can be achieved. He also stated that the use of synthetic fibre can be reduced by hybridization process. Gupta and Srivastava[8] study indicates that J50S50 (jute 50 and sisal 50) hybrid composite shows better mechanical properties and also has lower water absorption as compared to sisal, jute and other hybrid composites. Venkatesh *et al.*[9] explored the effect of hybridization on water absorption and mechanical properties of sisal fibre. From the results, it can be noted that 50/50 sisal/bamboo hybridization results in maximum mechanical and minimum water absorption characteristic. It has been also concluded that the addition of bamboo fibre by 50% results in 19% increase of tensile strength. Zhao *et al.*[10] investigated behavior of new type of metakaolingeo polymeric composite with polyacetal (POM) fibres reinforcement. They found that the friction coefficient decreases with increasing POM fibres content. A low friction level of 0.46 was observed at 20 wt% of fibre content. Cao *et al.*[11] investigated friction and wear properties of Ultra-high molecular weight polyethylene (UHMWPE) composites reinforced with basalt fibre and found that the addition of basalt fibre reinforcement improves the friction and wear properties. It has also been observed that on increasing the basalt fibres content from 5 wt% to 20 wt%, there is decrease in toughness, but the hardness, creep resistance and strength improve. The wear loss of the UHMWPE composites was observed to be

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approximately one-ninetieth of the wear loss of UHMWPE. China and Yousifb[12] investigated the tribological behavior of kenaf fibre reinforced epoxy composites and observed that the arrangement of kenaf fibres in N-O orientation increased the wear performance of epoxy by about 85%. They also observed that wear resistance in N-O orientation is consistently high as compared to those in AP-O and P-O orientations.

To the best knowledge of authors, no work has been reported on the effect of hybridizing jute-epoxy composites with flax fibres. The present work aims at investigating the influence of sequencing of flax/jute fibres on tensile strength, water absorption and tribological behavior in sandwich structured composites.

Experimental

Fibres

Jute and flax fibres considered in this experimental study were supplied Bi-Directional mat form by local supplier. The properties of jute and flax fibres are given in Table 1.

Resin/Matrix

Araldite LY 556 (bisphinol-A-diglycidyl-ether), a type of epoxy resin and its curing agent hardener HY 951(2 aminoethylethane-1,2diamin) were used for composite fabrication in the experimental study. HY 951 is a low viscosity, aliphatic amine hardener. They were supplied by Shankar Dyes and Chemicals, Delhi. The epoxy resin and hardener were mixed in the ratio of 10:1. The properties of araldite LY 556 (a kind of epoxy resins) and hardener are given in Table 2.

Fabrication of Composites

Composites were prepared with traditional hand lay-up technique. Composites plates were prepared in sandwich structure with 5 layer of fibre and 6 layer of epoxy resin. Epoxy and hardener were taken in the ratio of 10:1, whereas fibre and matrix were taken in the weight ratio of 75:25, for fabrication of composites using laminate stacking sequence (all the laminates at 0°/90° angle orientation). Other researcher also developed the hybrid composites with different stacking sequences. Sanjay *et al.*[15] laminated the hybrid composites with different stacking sequences of carbon and basalt fibre. In the present work, flax and jute reinforced epoxy hybrid composites were fabricated with different fibre stacking sequence, namely JJJJJ (jute-jute-jute-jute-jute), JFJFJ (jute-flax-jute-flax-jute), JFFFJ (jute-flax-flax-flax-jute), FJJJF (flax-jute-jute-jute-flax) and FJFJF(flax-jute-flax-jute-flax), as shown in Fig. 1.

Testing of Specimens

Tensile Test

The tensile strength of material can be defined as the maximum amount of tensile stress a material can withstand without failure. The tensile test was carried out on UTM TUE-C-400. The specimens for tensile testing were cut in dog bone shape as per ASTM D 638 standard. Specimens were firmly gripped in UTM and subjected to a uniaxial pulling force at a uniform rate. The peak load (maximum load specimen can withstand without fracturing) obtained divided by the area of specimen gives the tensile strength.

Water Absorption Test

Water absorption behavior of fabricated composites was studied as per ASTM 570 standard at ~ 27 ºC. The samples to be tested were immersed into a tub containing water. The samples were taken out from water at regular intervals and cleaned with a neat cloth to remove water sticking onto the surface and weighed by a digital weighing machine of 0.01 g accuracy within 30 s. The test was continued until all the samples reached saturation point. The percentage of water absorption by sample was calculated by using the formula:

Table 1 — Properties of flax and jute fibres[12-14]

Properties	Flax	Jute
Cellulose, %	71	61-71
Hemicelluloses, %	18.6-20.6	14-20
Lignin, %	2.2	12-13
Waxes, %	1.5	0.5
Tensile strength, MPa	345-1055	393-773
Young's modulus, GPa	27.6	26.5
Elongation- at - break, %	2.7-3.2	1.5-1.8
Density, g/cm^3	1.5	1.3

Table 2 — Property of epoxy and hardener [12-14]

Properties	Araldite LY 556	HY951
Physical form	Liquid	Liquid
Appearance	Clear	Clear
Epoxy content, eq/kg (ISO 3000)	5.30 - 5.45	-
Viscosity at 25 °C, mPa s (ISO 12058-1)	10000-12000	10-20
Density at 25 °C, g/cm^3 (ISO 1675)	1.15-1.20	1.0 -1.05
Flash point, °C (ISO 2719)	> 200	110

$$\text{Water absorption (\%)} = \frac{M_f - M_i}{M_i} \times 100 \quad \ldots (1)$$

where M_i and M_f are the initial weight, before absorption and final weight after absorption respectively.

Tribological Behavior Test

Wear tests were performed using a pin-on-disc tribometer under dry condition. The specimens were prepared as per ASTM G99-95 standard[16]. Sliding tests were conducted at ambient conditions of temperature and humidity with different normal loads (10, 20 and 30 N) and sliding velocities (2 m/s and 3 m/s) for 3000 m standard sliding distance[17]. The composite specimen was rubbed over a Sic abrasive paper (G2000) prior to each test, to ensure proper contact between the sliding face of the specimen and the stainless steel disc counter face. The test was conducted at different places on the steel disc to ensure same friction for all the experiments[18]. The sliding tests were conducted for normal orientation (N-O) of fibre with respect to the sliding direction of the disc (Fig. 2).

The weight of the composite specimen was determined before and after each experiment using weight balance of 1 mg accuracy.

Results and Discussion

Effect of Stacking Sequence on Tensile Strength

Stacking sequence of jute/flax fibres shows a significant effect on the tensile properties of jute fibre composite. The tensile strength of flax fibre is more than that of jute fibre[19, 20]. Figure 3 shows comparison among different fibre sequences. Fibres arranged in FJFJF sequence have the highest tensile strength value (149.12 MPa). It is due to the more weight fraction of flax. An alternate sequence of flax and jute was found with proper bonding (as jute has rough surfaces) as compared to JFJFJ (143.17 MPa tensile strength). In this case, jute fibre content is more as compared to flax. In JFFFJ (142.46 MPa tensile strength) weight fraction of flax fibre is same as in FJFJF, but the sequence of flax-jute is not alternate in JFFFJ. In FJJJF, tensile strength is 138.94 MPa, as jute is more than flax in this sequence.

Effect of Stacking Sequence on Water Absorption

The composite specimens are then tested to evaluate the effect of fibre stacking sequence on reverse osmosis (R.O.) water absorption characteristic of the composite. Long term immersion test was

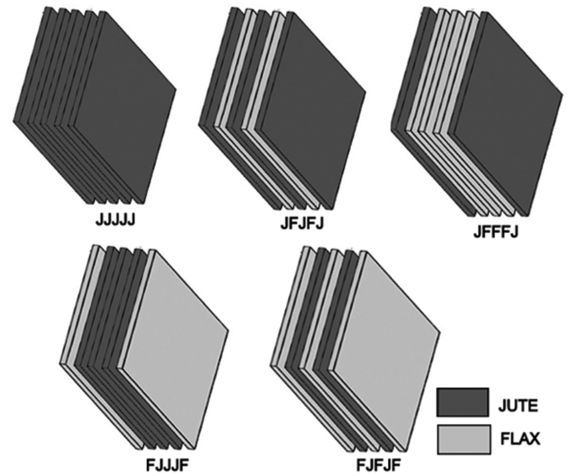

Fig. 1 — Different stacking sequence of jute and flax fibres

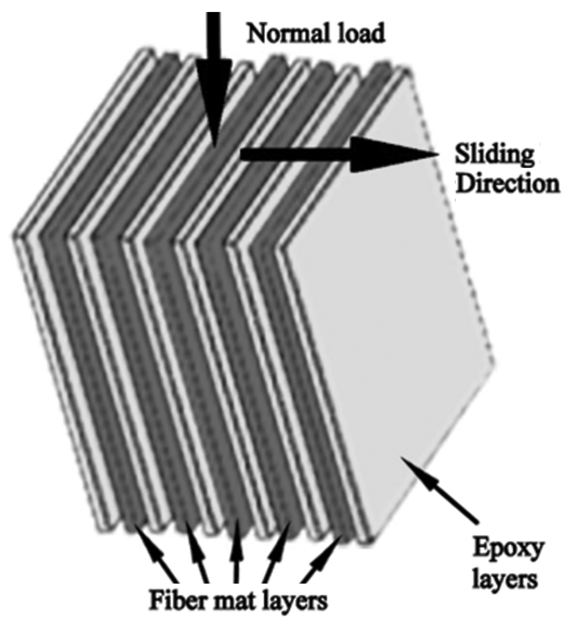

Fig. 2 — Schematic diagram of normal and sliding direction of specimen

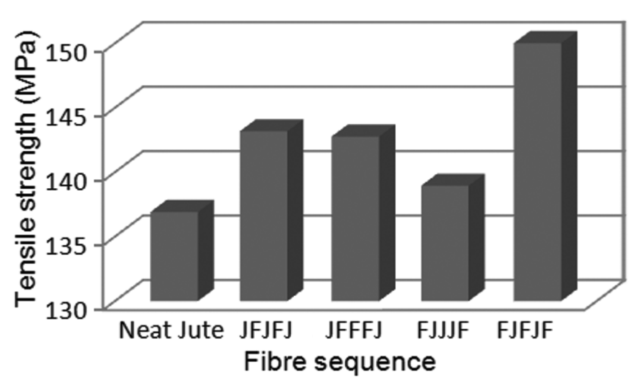

Fig. 3 — Comparison of tensile strength for different fibre sequences

carried out in this experimental investigation. In long term R.O. water absorption, the specimens are immersed into R.O. water and the readings are taken till the specimen is saturated. The difference between the saturated specimen weight and dry specimen weight is considered as the water absorbed. The test has been carried out at ~ 27 ºC. The specimens are immersing into R.O. water (TDS=46) and the weights are measured at different time interval (after every 6 h) by a digital weighing machine of 0.01 g accuracy. The specimens are taken out of R.O. water and then thoroughly cleaned to remove the excess water on the surface. The specimens are then immediately weighed to avoid evaporation from specimen. To understand the effect of staking sequence on the water absorption behavior of composite, the jute epoxy composite and the hybrid composites with various sequences are tested. The saturation point for specimen is achieved at 228 h. The percentage of water absorption for specimens at different time periods is calculated and tabulated. The results show that hybridization of jute epoxy composite with flax has positive effect on water absorption behavior. This is mainly due to the difference in properties and chemical compositions of jute and flax fibre.

It is clearly observed that fibre stacking sequence also plays a crucial role in water absorption characteristic. The results show that composite with FJFJF fibre layer sequence has less water absorption as compared to those of other fibre sequences. FJFJF has less water absorption due to the fact that weight fraction of jute is less and that of flax is more (percentage of water absorption of jute fibre is more as compared to flax fibre[19]). Figure 4 shows the water absorption behavior of different composite specimens.

Effect of Stacking Sequence on Tribological Behavior

Wear test has been conducted on composite specimens to study the effect of stacking sequence on tribological behavior of the composites. The tests are conducted for a standard sliding distance of 3000 m at ambient temperature (27 ºC) with different normal loads (10, 20 and 30 N) and sliding velocities (2 m/s and 3 m/s). Figure 5 (a) shows the comparison of the wear occurred for different sequencing orders of specimens under loads of 10N, 20N and 30N for sliding speed of 2 m/s and a sliding distance of 3000 m. Stacking sequence shows a remarkable effect on the tribological behavior of the composite.

It is clearly visible that the jute-epoxy composite (JJJJJ) has more wear as compared to other sequences for all loads applied. It can also be noted that the sequence FJFJF shows comparatively less wear which significantly indicates the increase in wear resistance of the composite. It can be observed from the plotted graph that the specimens with three layers of flax show better properties than that of the specimens with two layers of flax.

Figure 5 (b) shows the comparison of the wear occurred for different stacking sequencing of specimens under loads of 10N, 20N and 30N for sliding speed of 3 m/s and a sliding distance of 3000 m. It can be noted that the wear of specimens is increasing with increase in load from 10 N to 30 N in the order of JFJFJ, JFFFJ and FJFJF. But, in case of jute-epoxy (JJJJJ) and FJJJF sequenced composites, a

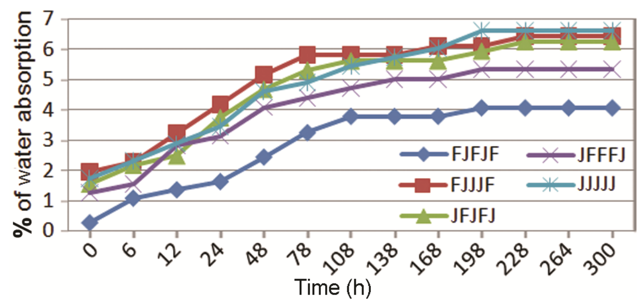

Fig. 4 — Water absorption behavior of specimens

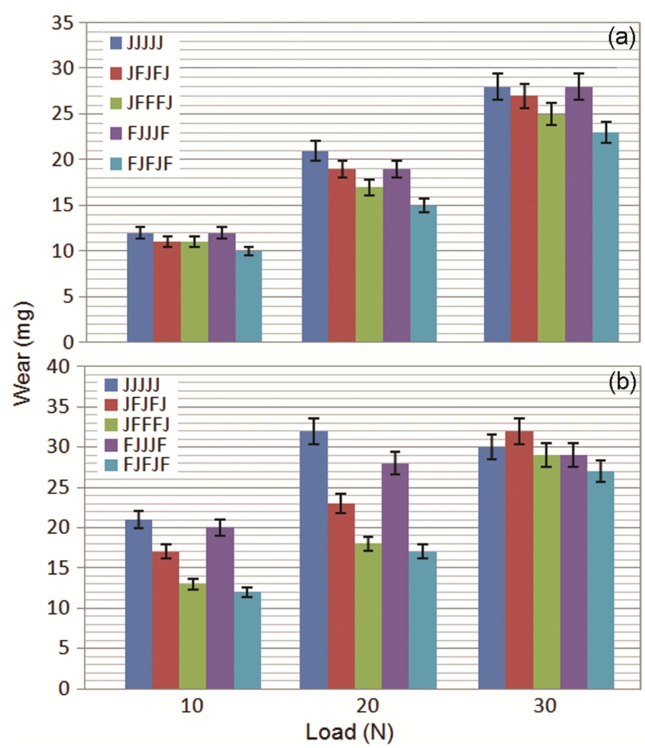

Fig. 5 — Wear of composite specimens at (a) 2 m/s and (b) 3 m/s sliding speeds

growth in wear is observed when load is increased from 10N to 20N, and when the load is further increased from 20N to 30N, a decline curve is observed; comparatively larger in case of epoxy-jute (JJJJJ) composite. This is mainly due to the delamination that occurs during the sliding test of the composite specimens. This delamination is caused due to the more hydrophilic nature of the jute fibre present in the composite, which results in poor interfacial adhesion between fibre and matrix. It is clearly visible that stacking sequence shows a positive effect on the tribological behavior of the composite. It is also observed that with increasing load the percentage of wear is decreasing in case of jute-epoxy (JJJJJ) and FJJJF, which, in turn, signifies a deviation from the expected result. This is mainly due to the delamination phenomena that occurs at heavy loads and results in failure of material rather than wearing out of the material. Stacking sequence FJFJF has shown better wear resistance and less delamination comparatively.

Hybridization of jute composite with flax fibre shows a positive effect on the tensile strength, water absorption characteristic as well as on tribological characteristic of composite. Addition of flax fibres into jute epoxy composite also shows better interfacial bonding between resin and matrix, i.e. specimens with flax show less delamination phenomena that occurs during the wear testing of specimens. Sequence of stacking of fibres plays an important role on the characteristics of the composite. Different staking sequences yield different properties. In this study, specimen with FJFJF sequence has obtained highest tensile strength, less water absorption and better wear resistance than that of the other sequences.

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