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Investigation of Mechanical Properties of Hemp and Flax Fibers Hybrid Composites for Biomedical Applications

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1. Introduction

Composites are materials that are made up of two or more constituent materials namely matrix and reinforcement. A matrix is a binding material which binds the reinforcement. Reinforcements are the materials which are embedded in the matrix [1]. These give the additional strength to the composite. The significance of the composites is to provide better, desired physical, chemical, and mechanical properties in an improved manner which differs from the individual constituents. Based on the matrix, composites are categorized as polymer, ceramic, and polymer. Depending upon the reinforcement these are varied as laminate, fibrous, and particulate composites. Depends upon the availability reinforcements are classified as natural and synthetic [2].

If the compound material is metal fiber then it is called as metal matrix composite, if it is polymer matrix then it is called as polymer matrix material. The fiber reinforced polymers (FRPs) consists of high-quality fibers and the modulus implanted in or clung to a matrix with an unmistakable crossing point among them. In this shape, the two matrix and fibers hold their chemical and physical properties [3].

Depending upon the reinforcement these are classified as particulate composites, fibrous composites, laminate composites. Depending upon the availability reinforcements are classified into – natural and synthetic [4]. Though there are many advantages of synthetic composites, there are some disadvantages [5]. Synthetic fibers burn more quickly than natural fibers. Extra electrostatic charge is produced by rubbing than with natural fibers. These are not skin friendly, so uncomfortable for long-wearing and sensitive to some persons. Composites that are made up of combining two or more fibers materials under the same matrix are called hybrid materials and this process is called as hybridization of composites [6].

Normal fibers with reinforcement have so many advantages when compare to the other materials. This leads to grabbing the attention of researchers. They are eco-friendly, naturally well disposed of, completely biodegradable and sustainable. Plant filaments are light appeared differently in relation to glass and carbon strands. Natural fibers, for example, jute, cotton banana, coir, sisal have pulled in the consideration of researchers and technologists for application in the field of biomedical applications such as tissue engineering, orthopedic applications, and dentistry [7]. They are likewise inexhaustible, biodegradability, non-toxicity, and have generally high quality, less weight and more stiffness [8]. Because of these qualities, it can be used in a large range of applications such as Automobile industries, textile industries, Ship manufacturing industry and Aerospace, Petroleum industries, and Sports equipment manufacturing etc.

Natural hybrid composites have decent calorific value and also it doesn't affect the environment and eco-friendly. These are easily available in nature and the cost also less. It exhibits advanced mechanical properties, has less weight, more strength and inexpensive. These great natural properties neighbourly component makes the materials exceptionally prominent in building markets, for example, the car and development industry. S. M. Sapuan [9] investigated the mechanical properties of banana fiber fortified with epoxy resin as matrix material. The factual examination demonstrates the development of mechanical properties such as strength, stiffness, and durability. Maries Idicula [10] considers a review of natural fibers, in the field of biomedical applications. The damping conduct additionally enhanced for sisal polyester composites. N. Venkateshwaran [11] inspected the malleable, flexural and dampness assimilation examinations of banana-epoxy tar composite materials which exhibited a poor result and it might be upgraded better route by the extension of sisal fiber alongside banana fiber in different weight parts. V. Naga Prasad [12] analysed the hybrid composites of unsaturated polyester based sisal/glass fiber hybrid composites. The biomedical application of chitin and chitosan composite material is presented by R. Jayakumar and D. Menon [13]. In this paper, they did research on composite materials in the aspect of different biomedical applications. The investigation of natural fibers utilized in biocomposites and its applications. The source and extraction of natural fibers including their mechanical properties were analysed by S. K. Ramamoorthy, M. Skrifvars [14]. An immediate utilization of the quality of natural hybrid composite fibers is in lines, ropes, and other one-dimensional items; various applications incorporate early suspension spans for by walking section of streams and apparatus for nautical ships in early occasions and into the nineteenth century.

The use of natural fiber composites in the field of biomedical applications is increasing day by day. To use these composites in various fields, they must show the advance physical and mechanical properties. To fulfil the requirements an attempt has been carried out on natural hybrid hemp and flax fiber composite materials. This paper presents analysis of five different composites fabricated on the basis of the rule of hybridization mixtures. Resuslts of contact angle measurement, flexural test and interlaminar shear test of fabricated composites are presented in this paper.

2. Composite fabrication

2.1. Materials

The materials used for the fabrication of composites are hemp fibers, flax fibers and epoxy resin with hardener. Mechanical properties of hemp and flax fibers are discussed in Table 1. Hemp fiber is a type of bast fiber which is readily available in nature and it is extracted from the bank of the hemp plant. Flax fiber is one of the best sorts of natural fibers with honest mechanical performance. Epoxy resin with hardener is used as glue for the preparation of specimens. Wood is used for the preparation of mould.

Table 1

Properties of hemp and flax fibers

Properties	Hemp	Flax
Cellulose content (%)	67-70	65-87
Hemi Cellulose (%)	16	16
Pectin (%)	0.8	3
Lignin (%)	3.3	2.5
Torque (rd/m)	62	64
Tensile strength (MPa)	45±5	43±7
Density(Kg/cm^3)	1.48	1.46-1.50
Youngs Modulus (MPa)	788±28	759±40
Yarns Fineness (tex)	4312± 513	4187 ± 396
% of Water	10	8

2.2. Preparation of fibers

Both hemp and flax fibers are cleaned with water to remove the dust particles on it and dried. Hemp and flax strands in the wake of retting the husks are compressed with a sled. These filaments are isolated from the brush when they tore out from the husks. Both hemp and flax filaments were looked over with a cotton checking outline for a few times at that point isolate stands. After that hemp and flax filaments are estimated for legitimate weight and length as per the die measurements and fibers are taken in the form of beds (as shown in Fig. 1) for the fabrication purpose.

Fig. 1 Hemp and flax fiber beds for fabrication

2.3. Weight fraction of the fibers

The weight fraction of both matrix and fiber is considered by using a fundamental relation between density, mass, and volume on the basis of hybridization. Rule of hybridization states that composites are prepared with two or more fibers are combined with one matrix material with 0.4Wf ratio. It clearly states that 40% of fibers and 60% of matrix (Glue) material. By varying the total percentage (40%) of fibers fraction total five different weight fractions of composites were fabricated, those are 40% hemp composite (40H/0F), 40% flax composite (0H/40F), 25% hemp and 15% flax (25H/15F), 20% hemp and 20% flax (20H/20F), and 15% hemp and 25%flax (15H/25F).

2.4. Preparation of epoxy and hardener

In order to prepare the proper resin solution for the fabrication of composites, we must follow the composition as per the rule of mixtures. That is, the weight proportions of both Epoxy and hardener as 10:2. The mixed resin solution has a viscosity range of 15 to 20 at a normal temperature. After proper mixing of resin with hardener, the glue is used for the preparation of composite plate. When we are using this resin solution proper care should be taken. The mechanical characteristics of epoxy and hardener are given in the following Tables 2 and 3.

Table 2

Mechanical characteristics of epoxy resin[15]

Property	Value
Viscosity at 25ºC	710±70 MPa
Density at 23ºC	1.15 ±0.01 g/cm^3
EP-Equiv. Weight	178 g/Eq
Volatile Content	0.4 %

Table 3

Mechanical properties of hardener [15]

Property	Value
Color	Colorless, Clear
Viscosity at 25ºC	10 MPa
Pot life at 80ºC	69 Min
Density	0.97-0.99 g/cm^3
Gel time at 80ºC	118 Min

2.5. Mould preparation

Mould material can be anything like wood, metallic and ceramic. The material used in this work is made up of wood. The dimensions of the mould used for fabrication is 150 mm × 150 mm × 12 mm and it has four corners (Fig. 2).

Fig. 2 Mould used for fabrication purpose

The hand lay-up modus operandi were used for the manufacture of composites. The top and bottom faces of the Mould covered with baking paper. It doesn't affect any properties of matrix material and isn't stick to that glue. The uniform load was placed on the top side of the mould; the function of this load is to distribute equal pressure and compress the fibers after application of epoxy resin to get the shape of the mould.

2.6. Fabrication of composites

The moulds, which are used for the fabrication purpose were cleaned and dried out before applying the glue. The mould covered with baking paper and fibers were placed homogeneously on that paper before applying the epoxy resin. In the wake of organizing the filaments, they were taken into consideration pressure for a couple of minutes in the form to get the state of the shape. Then epoxy resin is applied on the layers of fibers and compressed with a roller (Fig. 3) to get uniform distribution of the resin to avoid gaps in the layers of fibers and to get uniform shape as shown in Fig. 4. The composites were compressed at room temperature and a curing time of 20-24 h, the Compression is carried with an axial load of 6 kg.

Fig. 3 Roller on the fiber beds

Fig. 4 Composite specimens after fabrication

3. Testing of composites

3.1. Contact angle measurement

This test is used to find the weather the composite material is Hydrophilic or hydrophobic material. if the contact angle is less than 90 degrees it's called as hydrophilic material and if it is more than 90 it's called as hydrophobic material. The experiment set up used for this test is shown in Fig. 5 and it consists of adjustable holder *1*, camera Guppy F-503 B&W CMOS *2*, lenses *3*, specimen holder *4* and specimen *5*. The image is processed in the computer shown in Fig. 6.

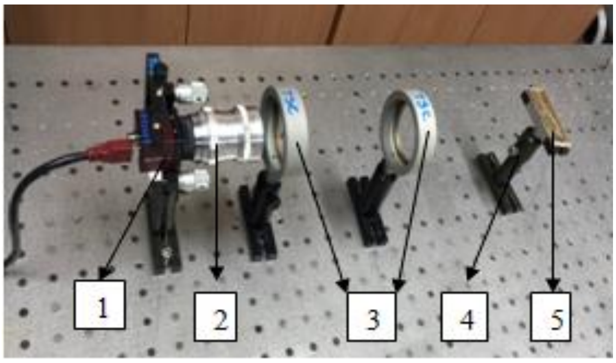

Fig. 5 Experimental setup for contact angle measurement

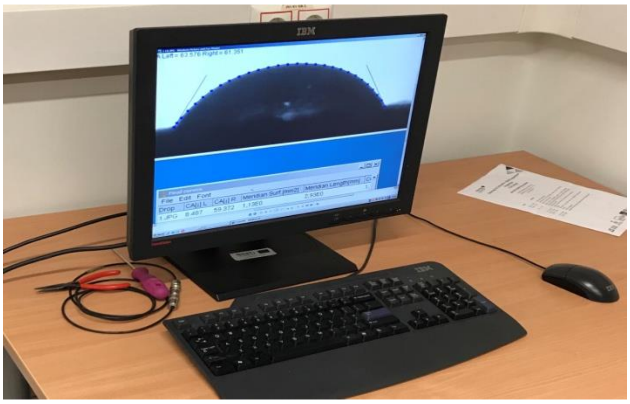

Fig. 6 Image processing in computer

3.2. Flexural strength

The Specimens were tested at a constant strain rate of 0.10 mm/min and speed of testing was calculated as 20 mm/min. each time five specimens are going to be tested on tinius olsen. Flexural strength is calculated as per ASTM standards. Composites which do not fail by the ultimate strain rate allowed for three-point bending test, it may be suitable for 4-point test. The main difference between these two tests is the point of application of load and failure criteria. In three-point bend test load acts at the midpoint and the stresses will be developed under the loading nose. Coming to the four-point bend test load acts at two points and stresses will be developed between these points. The formula used for this calculation is as follows:

$$\sigma_f = \frac{3PL}{2bd^2}\ \text{MPa}, \tag{1}$$

where: σ_f is flexural strength, P is maximum force, L is span length of the specimen, b is width of the specimen and d is thickness [16].

3.3. Flexural modulus

It is also called as tangent modulus of elasticity and usually calls it as elastic modulus. It is the ratio between stress and strain within the elastic limit and it is calculated by drawing a slope to the Force and displacement curve. The equation used for the calculation is as follows:

$$E_B = \frac{L^3 m}{4bd^3}\ \text{MPa}, \tag{2}$$

where: E_B is flexural modulus, L is span length, m is slope of tangent, b is width of the sample and d is thickness.

3.4. Interlaminar shear strength

Interlaminar shear strength of each composite is tested on tinius olsen and specimen dimensions are taken as per ASTM D 3846. It is explained by using the relation of the greatest shear load carried by the specimen divided by the area of the failure shear length simply area between the notches. The relation used for the calculation of interlaminar shear strength is as follows:

$$\sigma_S = \frac{P}{A}\,\text{MPa}, \qquad (3)$$

where: P is maximum load A is area of the failure shear [17]. Specimens used for these tests are shown in Fig. 7.

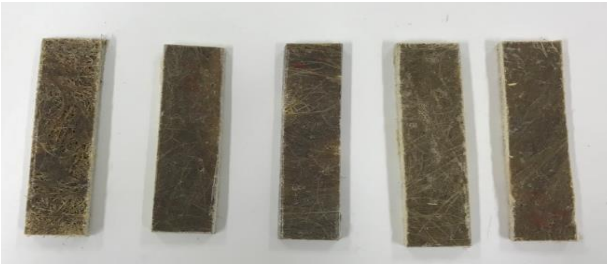

Fig. 7 Flexural test samples

Both flexural and interlaminar tests were done on Tinius Olsen H10K. It is suitable for tension, compression, shear, and flexure and other tests to a maximum load of 10kN. All interface options integrate with Horizon data analysis software. There are a total of 8 T-slots built into the machine to secure the test sample.

4. Results and discussion

4.1. Contact angle measurement

The contact angle measurement has been done with the help of experimental setup with image analysis software system ImageJ. The volume of dispensing drop kept constant from pipit to the composite surfaces is shown in Figs. 8 - 12.

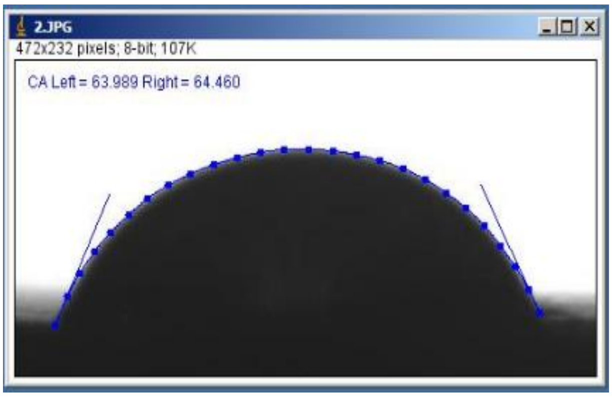

Fig. 8 Contact angle illustration of pure hemp composite

Fig. 13 shows the measured contact angle (θ) for various composite surfaces. From the measured values of contact angles, all composites shown less than 90º that means all composites are hydrophilic materials with water. And pure flax shown the maximum contact angle as 65.98º and 20H-20F shown the lowest contact angle as 56.95º. All hybrid composites shown the contact angle less than pure composites.

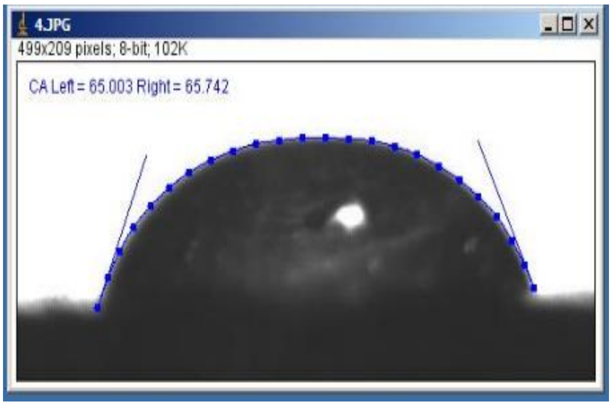

Fig. 9 Contact angle illustration of 15H-25F composite

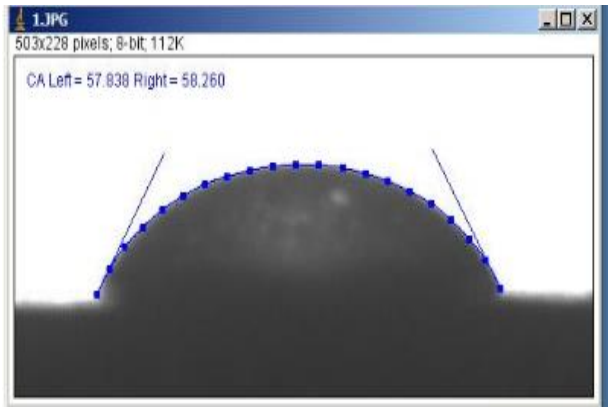

Fig. 10 Contact angle illustration of 20H-20F composite

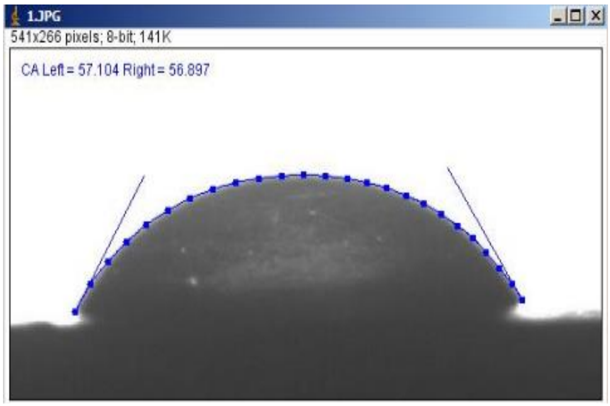

Fig. 11 Contact angle illustrations of 25H-15F composite

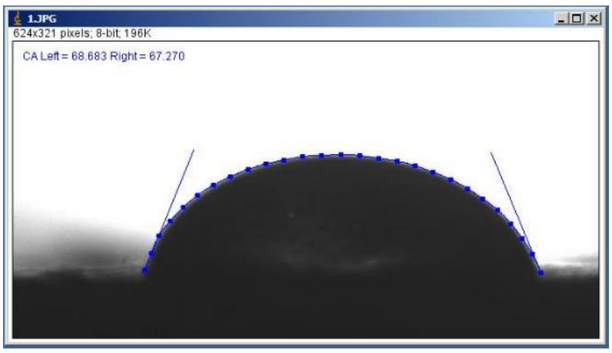

Fig. 12 Contact angle illustration of pure flax composite

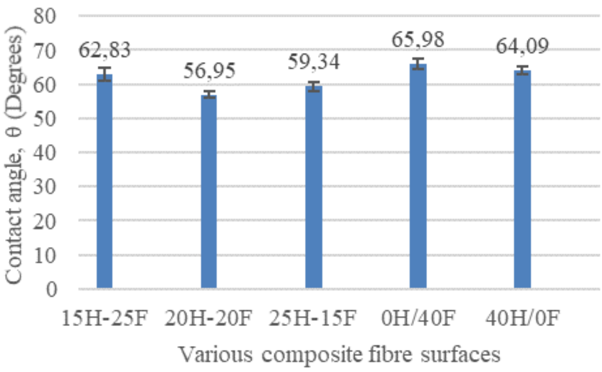

Fig. 13 Contact angle vs. composite fiber surfaces

4.2. Flexural strength test

The following results were taken from the three-point bending test conducted on tinius Olsen at speed rate of 20 mm/min, to calculate the properties such as flexural strength (MPa) and flexural modulus (GPa). The samples used for this test having the dimensions of 100 mm full length (80 mm span) 20 mm width and 5mm thickness. Total five specimens were tested each time and the outcomes are calculated as the average of those values to get the accuracy. The weight fraction of these composites used for testing 40H/0F, 0H/40F, 25H/15F, 20H/20F, 15H/25F. The results are shown in Table 4.

Table 4

Flexural properties of various composites

The % Weight fraction of composites	Break Load, N	Maximum displacement, mm	Flexural Strength, MPa	Flexural Modulus, GPa
40H/0F	266.27	4.92	63.90	2.60
15H/25F	321.07	5.62	77.06	2.92
20H/20F	279.58	5.22	67.10	2.88
25H/15F	353.33	5.30	84.80	3.30
0H/40F	272.00	4.73	65.28	2.74

Fig. 14 shows the relation between weight fraction of the composites and break load (N). Pure hemp and pure flax have shown as 266.27 N and 272.00 N, at break point. The composites 15H/25F, 20H/20F and 25H/15F values were observed as more than pure composites. 25H/15F shows the maximum load (353.33N) at the breakpoint when compared to the other composites.

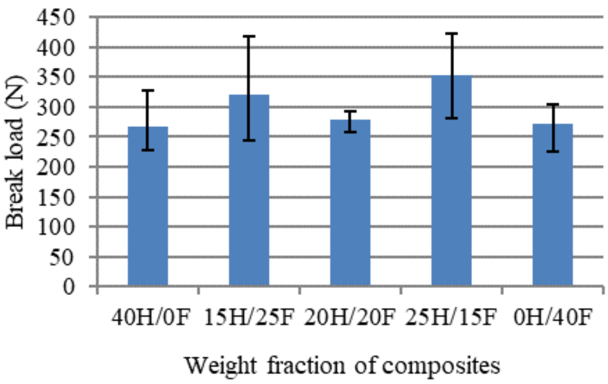

Fig. 14 Break load (N) vs. weight fraction of composites

The flexural quality of various composites with varying weight fractions have given away in Fig. 15. Pure hemp shows the lowest flexural strength of 63.90 MPa and flowing this pure flax shows that 65.28 MPa, which is second lowest, and coming to the hybrid composites all have shown improved results than pure composites and the values are almost close to each other. The hybridization effect is clearly visible in this case and 25H/15F shows the higher strength than every single other composite. This performance is interconnected to hybridization impact for both the fibers contribute superior flexural quality to the composites.

The above trend illustrates the flexural modulus (GPa) of various composites with varying weight fraction. It is evident from Fig. 16 all composites show a small variation in flexural modulus. Pure hemp has the lowest value as 2.6 GPa and remaining all shows close values there is no such difference and 25H/15F shows the maximum value as 3.3 GPa, this is very strong when compared to the other composites.

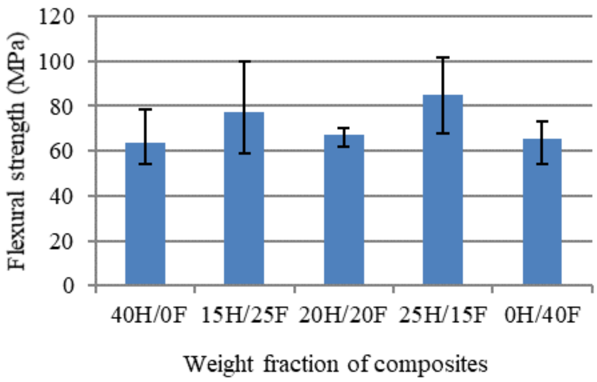

Fig. 15 Flexural strength vs. weight fractions of composites

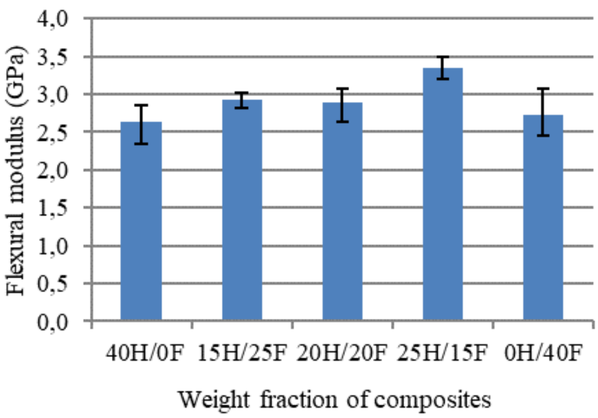

Fig. 16 Flexural modulus vs. weight fraction of composites

4.3. Interlaminar shear test

It is not possible to do this test with the 3-point bending test, because it promotes the breakdown of the composites. The notch depth of the specimen is taken as half of the thickness. Distance between the notches taken as 6.4mm from the centre of the specimen. The load applied in the transverse direction. The results are presented in Table 5 and Fig. 17.

The bar chart (Fig. 17) illustrates the Break load (N) of different composites (different weight fraction). It observed from the bar chart, pure flax shows the highest load as 1064 N and remaining all composites shows almost close to each other. The hybridization is not much affected, that we can observe from the above results.

Table 5

Interlaminar shear test results for various composites

Composites	Break Load (N)	Shear strength (MPa)
PH	528.14	6.50
PF	1064.00	13.09
15H-25F	549.06	6.76
20H-20F	604.94	7.44
25H-15F	534.39	6.57

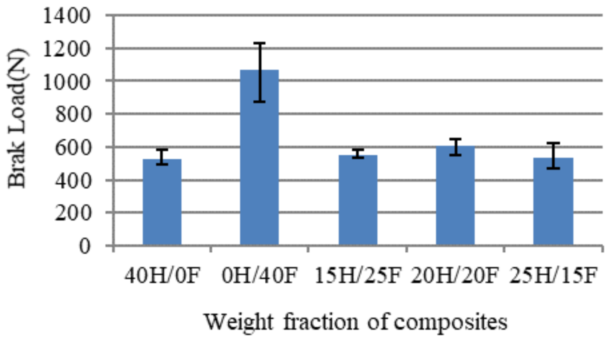

Fig. 17 Break load (N) vs. weight fractions of composites

Fig. 18 shows the trend of interlaminar shear force with respect to the varying weight fractions. Pure flax shows the highest interlaminar shear strength of 13.09 MPa and pure hemp shown that 6.50 MPa which is almost close to the hybrid composites. The hybridization effect is negligible, because there is no such variation in the results and 20H/20F shown the higher value than other composites except pure flax. This behaviour can be interrelated to the hybridization efficiency of the both (hemp and flax) fibers contributed to getting higher interlaminar shear strength.

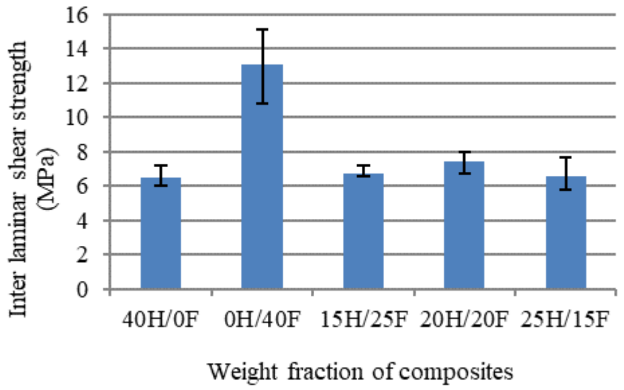

Fig. 18 Interlaminar shear strength vs. weight fraction of composites

5. Conclusions

The addition of two or more fibers under same matrix material will affect the mechanical properties of hybrid composites. Epoxy resin along with hardener was used as binding material and hand layup technique attempted for the fabrication process. Composites were fabricated on the basis of the rule of hybrid mixtures. The specifications of composites were taken from the ASTM standards for the testing purpose. After allowing the composites for testing, it is clear from the results, all hybrid composites shown improved properties when compared to the pure composites. All composites shown the contact angle less than 90º it means that it has hydrophilic surface contact with water and pure hemp and pure flax shown highest contact angle as 66 and 64 degrees whereas hybrid composites shown 55 to 60 degrees. The hemp/flax composites with a weight fraction of 25/15, shown the maximum flexural Strength as 84.80MPa and flexural modulus as 3.30GPa. Pure flax shown the highest interlaminar shear strength as 13.09MPa because of its cellulose content and more tensile in nature. All the hybrid composites shown intermediate results and close to each other. Because of its less weight, less density, high strength, and availability these composites can be used in biomedical applications.

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INVESTIGATION OF MECHANICAL PROPERTIES OF HEMP AND FLAX FIBERS HYBRID COMPOSITES

S u m m a r y

Hybridization process is one of the best ways to improve the materials properties. In this work, we prepared five different composites by using the same matrix materials. Composites were fabricated on the basis of the rule of hybridization (0.4Wf) mixtures. The materials used for this test were Hemp, Flax fibers and epoxy resin along with hardener was used as a reinforcement material. The fabricated composites were taken to the material testing to investigate the properties and comparison purpose. Three tests were conducted to examine the properties such as Contact angle measurement, Flexural test, interlaminar shear test. These tests were done on the basis of ASTM standards. The results shown that enhanced properties and hybrid composites shown improved flexural strength and interlaminar shear strength results when compared to the pure composites.

Keywords: hemp fiber, flax fiber, hybrid composites, flexural strength, interlaminar shear strength, contact angle.

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