Chapter 15
Mechanical Properties of Flax-Cotton Fiber Reinforced Polymer Composites

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1 Introduction

A natural fiber composite material consists of natural fibers and polymeric resin which are glued together under optimum operating conditions. A proper knowledge on the properties of reinforcing fiber, polymeric matrix, the process of fabricating the composite material, and proper bonding at the interface is a crucial aspect which contributes a lion's share in determining the properties of the material [1]. In general, a variety of natural fibers are available for the use of reinforcement. Among them, flax fiber proves to be the best in terms of mechanical properties, acoustical, and vibration properties. The most notable aspect of a flax fiber reinforced composite is that the composite material weight is less than that of glass fiber reinforced composite material [2].

Omkar Nath et al. [3] tested the behavior of polymer composites reinforced with jute-cotton fiber embedded in a polyester resin. The results of the various testing carried out revealed that input parameters such as fiber loading and fiber orientation are the critical parameters which have to be concentrated upon. Adding to this, the water absorption rate of the composite gradually elevates in accordance with fiber loading.

Sabinesh et al. [4] conducted experimental investigation on the behavior of cotton fiber reinforced isophthalic polyester composites under tension and flexural conditions. A range of fiber fractional volume of the reinforcing fiber was considered. The author reported that the tensile behavior of the composite material increases with

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an increase in the fiber fractional volume. Menderes Koyuncu et al. [5] explored on the potentiality of the cotton fabric as a possible reinforcement in composite material and the effect of alkali treatment on composite material properties. The results revealed that the modification of the fabric by means of alkali treatment enhance the mechanical property significantly when compared with the untreated fabric. The studies also suggested that the cotton fabric can be utilized as potential reinforcement in composite material.

Pickering et al. [6] reviewed the recent developments in natural fiber composites and their mechanical performance. It was postulated that mechanical behavior of the natural fiber composites are in par with glass fiber. Ajith Gopinath et al. [7] experimented on the mechanical properties of natural fiber reinforced composite material with jute fiber as the reinforcement and two different polymeric matrices, namely epoxy resin and polyester resin. The reinforcing fiber was chemically modified by using proper quantity of sodium hydroxide solution. The behavior of the prepared composite material was explored by subjecting the material to destructive testing. The author concluded that the strength of jute-epoxy composite material was superior to that of jute-polyester composites indicating a poor bonding in the interfacial region of the latter.

Cai et al. [8] explored the process of fiber modification and its influence on the interfacial bonding and the resulting composite material properties. Abaca fibers and epoxy resin were considered as the reinforcement and matrix, respectively. The abaca fibers were subjected to NaOH treatment. A varied concentration of NaOH was utilized for this purpose. It was concluded that the interfacial bonding was superior at a low concentration of chemical treatment when compared to a higher concentration. Also, the chances of fibrillation to occur are more at elevated levels of NaOH concentration.

Yahaya et al. [9] experimented on the layering pattern of the fiber on the behavior of the composite material. Kevlar and kenaf fibers were reinforced in the epoxy matrix. Two different sequences of layering of the reinforcing fibers were followed. In the first sequence, kenaf fiber was considered as the skin layer, and in the other, kevlar was the skin layer. The fabricated composite samples were tested for their mechanical properties, and the test results showed some significant trends. The composite material with kevlar as the skin layer possessed superior tensile and flexural strength, whereas the impact strength was not satisfactory. On the other hand, the behavior in the kenaf reinforced sample was in contrast. It was concluded that the behavior exhibited by the material depends on the layering sequence of the reinforcement.

Sood et al. [10] reviewed the effect of fiber treatment on the flexural properties of natural fiber reinforced composite materials and postulated that alkali treatment of natural fibers along with the inclusion of coupling agents improves the flexural behavior. The review also suggested that the treatment of the matrix material with the aid of coupling agents can enhance the overall characteristics of the composite material. Fragassa et al. [11] explored on the mechanical behavior of flax and basalt fiber embedded in a vinyl ester. Composite samples were destructively tested so as to evaluate the behavior of the material during the application of mechanical loading conditions. The test results concluded that in a hybrid natural fiber reinforced composite material, the bonding between the different fibers and the matrix material is a crucial aspect that has to be concentrated upon. The good bonding between the different fibers and the matrix material can ameliorate the mechanical properties of the composite material.

Ku et al. [12] studied the tensile behavior of a range of natural fiber composites. It was concluded that the tensile properties of a natural fiber reinforced composite material depends largely on the interfacial adhesion between the reinforcement and the matrix material. In addition to this interesting aspect, the author evidenced that as the fiber content increases the tensile strength of the composite follows the same trend up to an optimum level and then follows a decreasing trend. Ramesh et al. [13] experimented on the characteristics and fabricating techniques of flax fiber reinforced polymer matrix composites. An intensive exploration of the features of the flax fiber composites was made, and it was revealed that the modulus of elasticity of the flax fiber followed a decreasing trend with an elevation in the flax fiber diameter. This shows that an optimum fiber diameter is essential to achieve a satisfactory modulus value. It was also suggested that modification of the fiber surface has a negative influence on the thermal conductivity and diffusivity to a great extent.

Aruchamy et al. [14] fabricated and experimented on the mechanical properties of woven natural fiber reinforced polymeric composites materials. Cotton and bamboo fibers were weaved as a single fabric mat and embedded in the epoxy resin. Hot press compression molding technique was employed for the fabrication. Analysis of the mechanical behavior and interfacial relationship was carried out as per American standard specifications. The author highlighted that tensile behavior of the prepared sample follows an increasing trend for a certain fiber weight percentage, after which there was a gradual dip in the tensile strength, which is an important observation. The same trend was observed in the case of flexural properties as well. The result also revealed that the hybridization of fibers weaved in a single fabric would yield better results compared to the non-hybridization of fibers.

Boopathi et al. [15] explored the various mechanical and physical characteristics of untreated and chemically modified Borassus fruit fiber. Alkali treatment of the reinforcing fiber using sodium hydroxide solution was performed. The influence of alkali treatment on the fiber was studied. The test results revealed that the fiber-matrix interface was enhanced on alkali treatment of the fiber. Also, the alkali treatment of the fiber led to the formation of a strong hydrogen bond, which ameliorates the fiber's properties and could be used as reinforcement in a composite material. On a similar note, Tran Huu Nam et al. [16] evaluated the influence of alkali treatment on the behavior of coir fiber reinforced poly (butylene succinate) resin. It was evident that the chemical modification of coir fiber in a suitable alkali medium leads to the formation of strong mechanical interlocking between the reinforcement and the matrix material. This contributes to superior strength under tension.

Ramesh et al. [17] experimented on the characteristics of natural fiber composite material reinforced with sisal-jute-glass fibers in a polymer matrix. Composite samples were fabricated by the conventional hand lay-up technique. The fabricated composite material was tested according to the ASTM standards. The test results concluded that the combination of sisal, jute fiber, and glass fiber improved the overall mechanical property.

Ghosh et al. [18] prepared a natural fiber composite material using banana fiber as the reinforcing material and vinyl ester was distributed over the reinforcing material. The influence of the volume fraction of the fiber on the characteristics of the material was evaluated. The fabricated composite samples were according to the ASTM standards and were subjected to mechanical testing following the same guidelines. Based on the evaluation made, it was highlighted that an increase in the volume fraction of the reinforcing fiber, there was an unexpected dip in the tensile strength, which subsided and followed an increasing trend.

The amount of moisture absorbed by a composite material pose a vital role in determining the mechanical behavior and the application area of the composite material. Yamini et al. [19] experimented on the characteristics of the composite material with coir and aloe vera fibers as the reinforcing fiber embedded with epoxy resin. The composite material was prepared as per the American standards. The samples were tested for the quantity of moisture being absorbed and reported that the composite material absorbs more moisture due to the presence of more number of microvoids. The same phenomenon was also evidenced by Venkateshwaran et al. [20], wherein the formation of microvoids during the fabrication of the composite sample has a more considerable influence on the overall mechanical behavior of the composites. Hence, researchers prefer compression molding than the conventional technique of fabrication. The notable aspect in compression molding is the possibility of formation of microvoids is very minimal because of the distribution of the matrix material being uniform throughout. Hence, the mechanical behavior of the fabricated sample is precise. Also, the interfacial adhesion is one step ahead compared to those in the conventional hand lay-up technique of fabrication.

In a natural fiber composite material, the property of resistance to vibration and energy-absorbing capability is greatly influenced by the order in which the fibers are laid. This is evidenced by the experiment conducted by Senthil Kumar et al. [21]. This feature also contributes to the overall characteristics of the natural fiber composite, which is evident from the investigations made by Sathiskumar et al. [22]. Dhaka et al. [23] experimented on the influence of fiber volume fraction on the moisture absorption and the overall mechanical properties of the fabricated composites. The investigations revealed that the interfacial adhesion decreases with an elevation in the fiber volume fraction. As a result, there is a dip in the flexural properties of the composite. As the volume fraction of the reinforcing material increases, the cellulose content of the fabricated composite material increases. As a result, moisture-absorbing capacity of the composite material is increased.

Kushwaha et al. [24] experimented on natural fiber composites with bamboo fiber being reinforced with a polymeric resin. The fibers were subjected to chemical modification by pre-impregnation. Mechanical and water absorption properties were determined by subjecting the material to the required testing. The test revealed that pre-impregnation had a positive influence on the overall mechanical characteristics and the water-absorbing properties of the composite material. Hristov et al. [25] studied and made a comparison on the influence of aging on the strength retention capability of flax fiber reinforced composite material with glass fiber reinforced composite material. Adequate samples were fabricated. The fabricated composite samples were subjecting to varied environmental conditions for different durations. Then, the samples were subjected to mechanical loading to have a quantitative measure of the strength. The results posed that flax fiber reinforced composite material possesses a good strength retention property than the glass fiber reinforced composite material. Adding to this, flax fiber reinforced composite material proved to be environmentally friendly than that of glass fiber reinforced composite material.

Since the combination of cotton and flax as a single fabric mat has not been studied, this experimental work deals with the fabrication and evaluation of the behavior of the flax-cotton fiber reinforced polymer composite under different conditions of loading. The behavior of the material thus obtained will be correlated with the interfacial images.

2 Materials and Methods

2.1 Materials

Based on the literature studies carried out, flax and cotton fibers are used as the reinforcement in the current experimental work. Flax and cotton fibers possess superior mechanical properties. Hybridization of the reinforcement is performed by weaving both the reinforcing fibers into a single fabric mat. A fabric mat consists of two sets of thread or fiber which are woven together. They are technically termed as the weft and warp. The weft is a set of fibers placed horizontally, and the warp is a set of fibers placed vertically at the time of weaving using a power loom or handloom. Proper selection of the loom is significant; this decides the properties of the fabric mat. A power loom is preferred than the handloom due to a faster rate of production. Here, flax fiber is placed on the weft direction and the cotton fibers in the warp direction.

Moving on to the matrix phase, finely blended epoxy resin and hardener mixture are used as the polymeric matrix. Faster and more comfortable process of curing makes epoxy to top the list. Thorough mixing of the resin and the hardener under optimum condition is essential. The hardener acts as a catalyst and enhances the curing process. Curing is the most critical step, which is to be concentrated upon else the interfacial adhesion will be in vain.

2.2 Fabrication Method of the Composite Samples

Compression molding method was employed for the fabrication of the sample. Though the cost of fabricating by the conventional hand lay-up technique is less, the formation of microvoids and uneven distribution of the resin makes the hand lay-up

Table 1 ASTM standards and test specimen dimensions [26–29]

S. No.	Name of the testing	ASTM standards	Dimensions of the test specimen (in 'mm')
1	Tensile testing	ASTM D3039	250 × 25 × 3
2	Flexural testing	ASTM D790	127 × 13 × 3
3	Impact testing	ASTM D256	66 × 13 × 3

technique less preferable when compared to compression molding. A notable aspect of compression molding is that the rate at which curing is done is tremendously high when compared to the hand lay-up process, which makes the compression molding technique even more preferable than its competitor.

The main requirement in compression molding is that the reinforcement should be of the same size and shape of the mold. The size of the mold used in the present experimental work is 300 mm × 300 mm. Hence considering the permissible allowances, the woven fabric mat was cut as a perfect square shape of 270 mm × 270 mm. The number of layers of the fabric to be used depends on the sample's thickness as per the ASTM standards. Accounting to this fact, 14 layers of the woven fabric was used with epoxy matrix coated in between the fabric.

On completing the fabrication process, a proper check on the curing process was done by visual inspection. The test specimens were prepared in accordance with the American standards. The dimensions of the test specimen are tabulated below (Table 1). The dimensional sketch of the test specimen is shown from Figs. 1, 2 and 3.

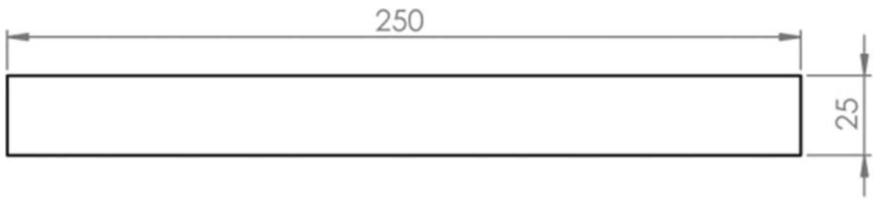


Fig. 1 Dimensional sketch of the tensile test specimen as per ASTM D3039

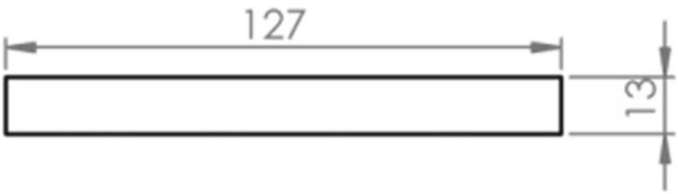
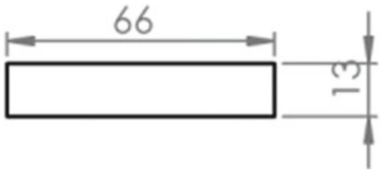


Fig. 2 Dimensional sketch of the flexural test specimen as per ASTM D790

Fig. 3 Dimensional sketch of the impact test specimen as per ASTM D256



3 Mechanical Testing of the Composite Samples

On the successful preparation of the specimens, the mechanical tests were carried out. Tensile and the bending tests were performed using different fixture setups in a computer-controlled universal testing machine (UTM). Prepared test specimen was placed along the longitudinal direction in between the fixtures of the UTM. Load was applied as a pulling load, which created induced internal stress within the specimen and under the peak load or the maximum load, and the maximum strength of the specimen was recorded. This can be interpreted as the maximum load where the composite specimen can withstand under pulling load conditions (Fig. 4).

Flexural strength of the composite sample prepared was measured using the UTM with a standard three-point bending test setup attached to it. This arrangement looks

Fig. 4 Tensile test setup with the composite specimen loaded on to the UTM

similar to that of a simply supported beam with a point at the center. As the specimen is rested horizontally on the supports of the apparatus, the load was applied at the center of the test specimen. As the ends of the sample were arrested, the applied load caused maximum deflection in the center portion of the composite sample. The load corresponding to the maximum deflection or the displacement was recorded. This can be interpreted as the maximum load where the composite specimen can withstand under bending conditions (Fig. 5).

Impact testing of the composite material is conducted to determine the maximum energy absorbed by the material due to sudden shock loads. A composite material should possess sufficient impact strength so as to use it in the automobile industry. The prepared composite test specimen was placed on the work holder of the Charpy impact tester. The impact testing sample was an un-notched sample and was placed vertically on the Charpy impact tester (Fig. 6).

During the process of testing the fabricated composite samples, the chances of error occurrence are more. The sources of the errors are always uncertain. To account for the errors that could arise during the testing, it is always preferred to have five test specimens for each of the above-mentioned testing procedures. The average value of the results shall be considered for further processing.

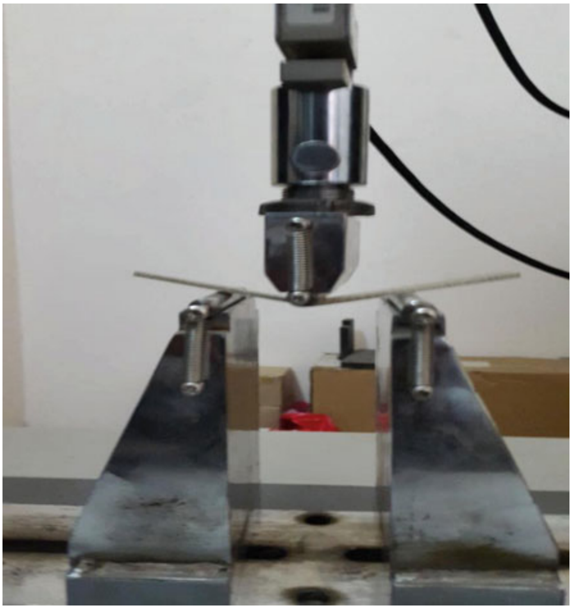


Fig. 5 Flexural test setup attached in the UTM with the composite specimen loaded

Fig. 6 Impact testing setup with the composite specimen loaded

4 Results and Discussion

The results of the mechanical testing carried out are tabulated below (Table 2). The detailed analysis is done subsequently (Fig. 7).

Table 2 Results of the mechanical testing

Sample No.	Ultimate tensile strength (MPa)	Flexural strength (MPa)	Impact strength (kJ/mm^2)
1	129.914	102.181	29
2	128.746	96.571	32
3	128.884	89.171	38
4	129.524	90.280	40
5	129.775	91.355	36
Average	129.368	93.911	35

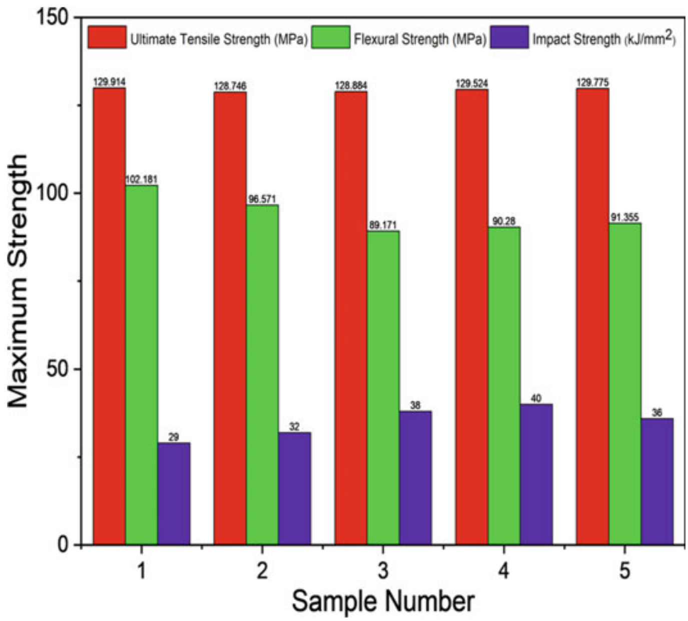


Fig. 7 Comparison of the results of the mechanical testing

5 Tensile Behavior

Factors such as the orientation of the fiber, fiber length, number of layers of the fabric material, the interfacial bonding, and the weaving pattern largely contribute to the tensile strength of the fabricated composite sample. In general, the maximum resistance offered by a material to external load is the ultimate tensile strength of that material, and this holds good for a natural fiber composite material as well. The average tensile strength and the average breaking load are recorded in Table 3 and Fig. 8, respectively. These values indicate that if the composite material is loaded beyond this threshold value will eventually lead to rupture, which is a sign of failure.

Table 3 Breaking load of the tested composite samples

Sample No.	Breaking load (N)
1	9743.55
2	9655.95
3	9666.30
4	9714.30
5	9733.12
Average	9702.64

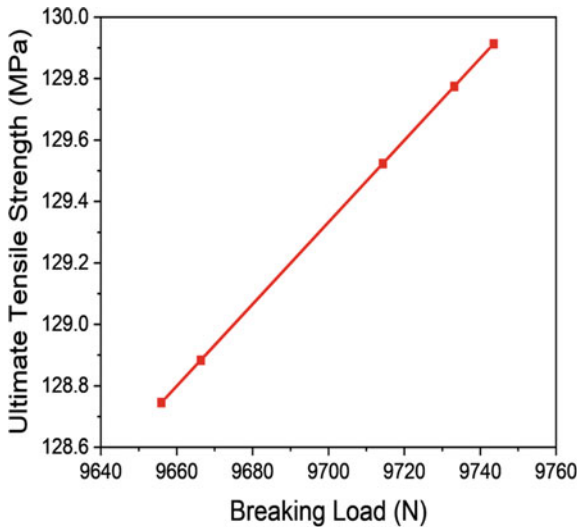


Fig. 8 Breaking load versus ultimate tensile strength

Knowledge about the mechanism of rupture is essential when applying the fabricated material to an industrial application. The reason for the rupture of the fabricated composite could be attributed to the weakening of the bonding between the reinforcement and the polymeric matrix. In the present experimental studies, as the fabricated material is loaded against the peak value of the internal resistance of the material, first, the matrix material, i.e., the epoxy resin, starts deteriorating. Hence, the interfacial adhesiveness gets gradually reduced. As a result of the loss of interfacial adhesiveness, formation of cracks in the form of microvoids takes place on the internal surface of the fabricated composite material and as the applied load increases the formed microvoids gets enlarged which is a sign of crack propagation, and at one particular point which is technically the UTS point, a peculiar phenomenon known as the fiber pull-out takes place which is a sign of complete failure of the fabricated material (Fig. 9).

As the test material is loaded in the longitudinal direction up to a particular amount of load, the fibers resist, but after the safe loading limit, the individual fibers in the longitudinal direction, i.e., the warp side, start expanding gradually. This can also be attributed to the weakening of the adhesive force. The weakening of the adhesive force gradually increases and the interfacial contact becomes loose. As a result, the warp set of fibers expands at a drastic rate, and this is termed as the % elongation of the composite material. Since the warp and the weft set of fibers were weaved in an interlocking manner, the weft set of fiber also loses its strength. At one particular point, a drastic pullover of the fiber takes place, and the corresponding load is known as the breaking load. Beyond this load, the material will surely fail under any operating circumstances (Fig. 10).

It can be interpreted from the plot (Fig. 11) that the maximum stress that the composite material can withstand is 129.914 MPa. On reaching this maximum stress

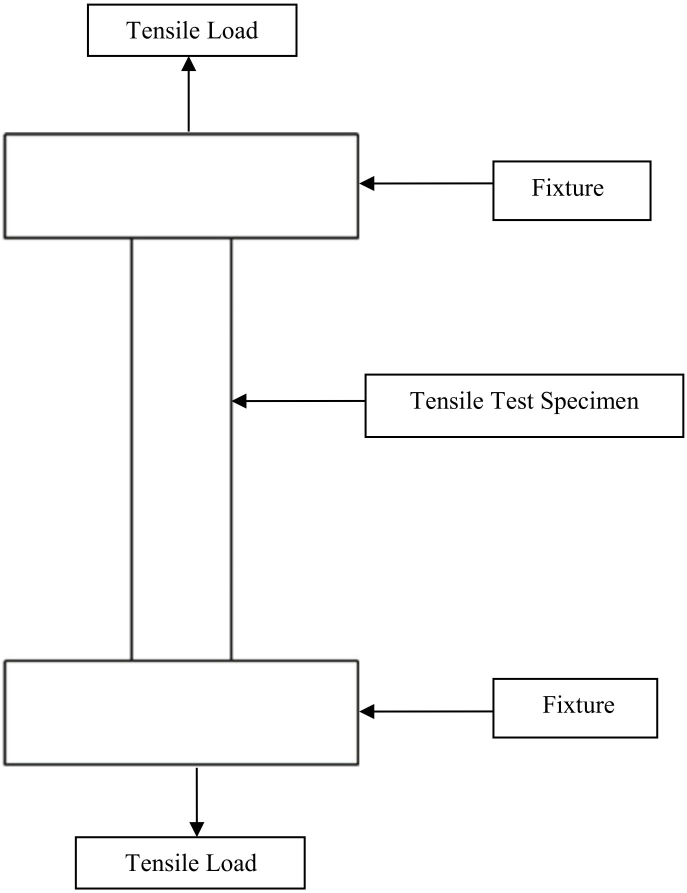


Fig. 9 Schematic representation of the test specimen for tensile testing

value, the fiber and the matrix get separated. Beyond this particular value, the material undergoes severe elongation, and the stress value dips drastically, which indicates that the material fails.

The debonding between the reinforcing material and the matrix is clearly indicated in the SEM image. Debonding is a phenomenon in which the adhesive loses its adhesiveness, and thus the interfacial contact between the reinforcement and the matrix becomes weak, paving its way to ultimate failure (Fig. 12).

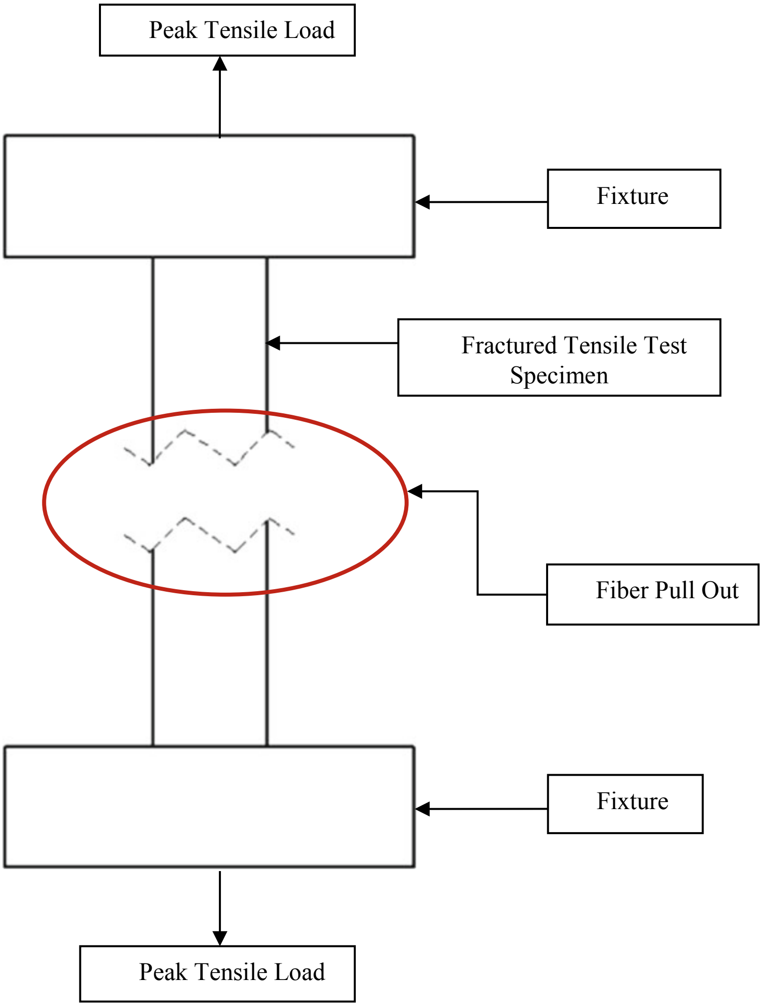


Fig. 10 Schematic representation of fiber pull-out

6 Flexural Behavior

Flexural strength of the composite material is a measure of the material to withstand bending loads. The flexural property of the material is equally important as that of the tensile property. A three-point flexure test attachment is attached to the UTM, and the test sample is placed on the supports. The load is given perpendicular to the fibers, i.e., in the transverse direction. As the material is loaded transversely, the failure mechanism in the flexural loading is a clear distinct featured when compared to the tensile testing.

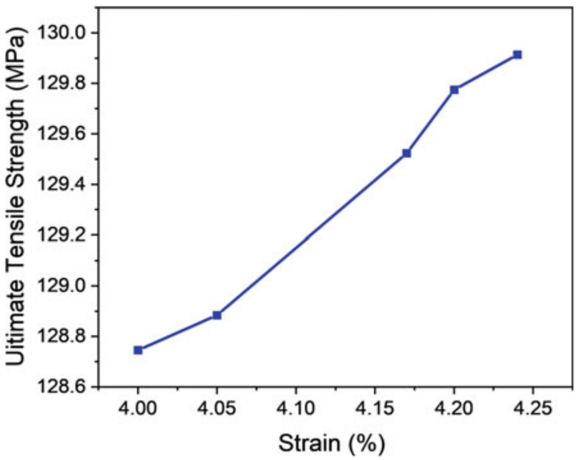


Fig. 11 Stress versus strain plot of the tensile tested sample

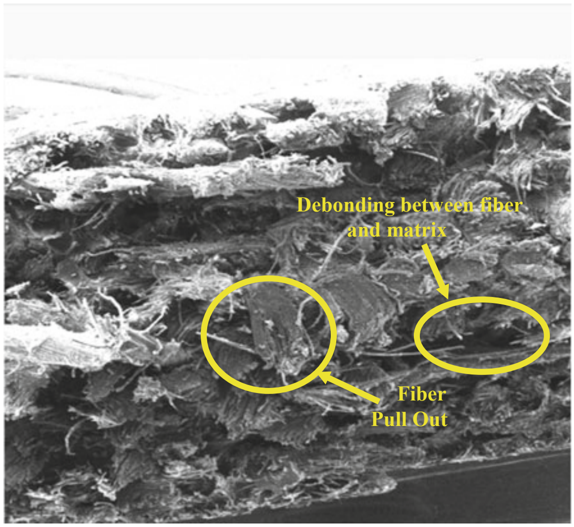


Fig. 12 Scanning electron microscopy image of the fractured tensile test specimen

In the current experimental work, the test specimens were tested for its behavior against a bending load, and the corresponding strength values are tabulated in Table 2. The average value of the flexural strength of 93.911 MPa indicates the maximum resistance that the fabricated composite material can offer to bend load beyond which the composite material will fail.

It is observed that the flexural strength of the fabricated composite material largely depends on the interfacial relationship. In order to establish a good interfacial relation, it is required that the resin should be uniformly distributed over the reinforcing fabric mat. In order to ensure proper and uniform distribution of the polymeric matrix, a

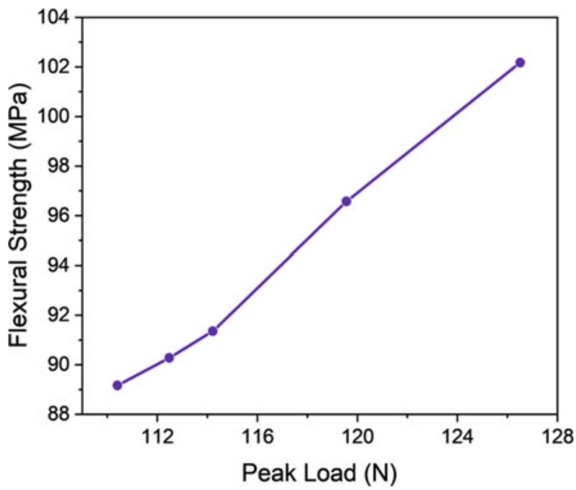


Fig. 13 Plot illustrating the maximum value of the load and flexural strength of the samples

pressure of 1500 psi was used in the compression molding setup during the fabrication of the composite (Fig. 13).

The failure mechanism in the flexural loaded sample varies that of the tensile loaded sample. In a flexural loaded sample, as the load increases gradually the formation of voids initiates. The size of the void initially being in the microscopic range propagates and thus leads to failure. An important aspect to be noted in a flexural test sample is that the microvoid propagates along the direction perpendicular to the applied bending load, which is the horizontal direction. As the load is applied transversely, the maximum bending displacement is observed in the bottom-most layer of the composite material. The SEM image in Fig. 14 clearly shows the presence of void in the composite sample. The propagation in the size of the void indicates the weakening of the interfacial strength; hence, the process of debonding between the fiber and the matrix takes place.

The flexural strength of the composite material also depends on the dimensional accuracy of the sample. In a three-point flexure test, a certain portion of the material will be overhanging away from the supports of the flexure attachment. So, the effective test area is the area within the supports. As this effective test area is vital, the dimensional accuracies at the time of sample preparation should be followed properly, failing, which will lead to erratic results, and the material selection process for an application will not be foolproof.

Adding to this, the type of fiber yarn shares an equal contribution to the final flexural strength of the composite. Based on the literature review made, it was evident that yarn of 30 s count proves to be beneficial, and hence the same count of cotton fiber and the flax fiber was used during the fabrication of the composite samples. The variation in the flexural strength values as recorded in Table 3 can be attributed to the uncertain minor errors that would have been aroused due to dimensional instability during the preparation of the test specimen. Hence, it is always safe to have a larger

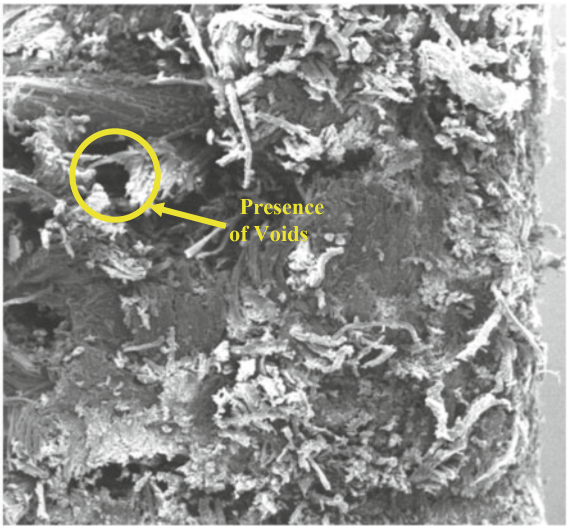


Fig. 14 Scanning electron microscopy image of the fractured flexural test specimen

number of experimental runs so that the overall value of a particular property could be asserted from its average value.

7 Impact Behavior

Determining the material behavior toward sudden shock load is important as most of the materials are subjected to impact loads in the practical scenario. The impact testing of the fabricated composite samples was tested using a Charpy impact tester. The impact strength of the fabricated composite sample is recorded in Table 2.

During an impact load condition, a material, in general, should absorb maximum energy possible before failure. This measure is significant in developing real-time products that are vulnerable to shock loads such as a spare part for an automobile. With reference to the present work, the values of the impact strength of the fabricated composites indicate that only a minimum amount of energy is absorbed before failure, which is a severe concern, and evaluating the cause for the same is important. The decrease in the impact strength can be attributed to the length of the fiber being pulled out during the destructive impact testing. Fiber pull-out is the common mechanism of failure in the case of a fiber reinforced polymeric composites (Fig. 15).

In the case of epoxy-based fiber composites, the length of the fiber pull-out is less owing to the fact that epoxy resin and hardener mixture when properly distributed over the reinforcement establishes a superior interfacial bonding. Hence, as the interfacing bonding is more, the length of the fiber pull-out is less and hence attributed to the decline in the impact property. This can be elevated by a perfect bonding between the

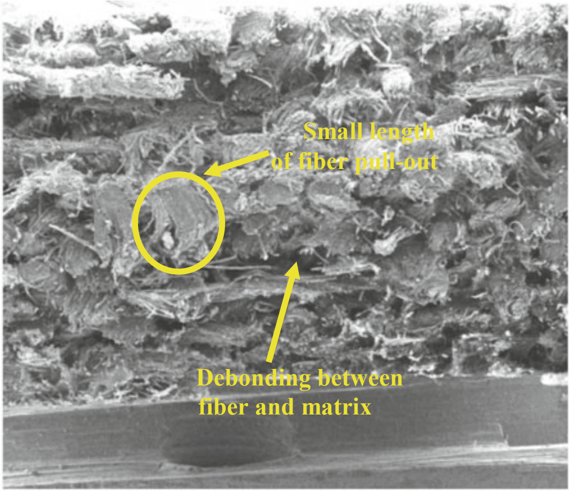


Fig. 15 Scanning electron microscopy image of the fractured impact test specimen

reinforcement and the matrix. Dimensional stability throughout the sample is very important in computing the impact properties of the composite sample.

8 Conclusion

In the present experimental work, flax-cotton fiber reinforced polymer composite material was fabricated by compression molding technique. Hybridization of the fibers was followed where the flax and the cotton fibers were weaved as a single fabric mat with the cotton fiber placed in the warp direction and the flax in the weft direction. Keeping the quality of the fabric mat as the top most priority, the fibers were weaved using a power loom.

Epoxy resin blended with a suitable hardener (HY951) mixed in an optimum ratio was utilized as the continuous phase (matrix). Mechanical testing of the prepared samples was carried out to evaluate the behavior of the material subjected to tension, flexural and impact load conditions. Taking the various errors that may arise during testing into consideration, the average of five test specimens was taken as the best fit for all the mechanical testing. The average tensile strength of the composite material was recorded at 129.914 MPa, the flexural strength at 93.911 MPa, and the impact strength at 35 kJ/mm^2.

The interfacial studies of the fractured samples were carried out. Based on the analysis of the mechanical testing and the SEM images, the following interpretations are noted, as shown below.

1. Interfacial bonding contributes a major share in influencing the mechanical characteristics of the fabricated material. The relationship between the reinforcement and the matrix material should be established properly. Many factors contribute

to a good interfacial bonding. Uniform distribution of the matrix tops the list of factors contributing to interfacial bonding. A wise selection of techniques of fabrication ensures a uniform distribution of the matrix. Hence, the compression molding technique was used for fabricating the composite samples. As a thumb rule, uniform distribution contributes to superior interfacial bonding and hence enhanced wettability property of the matrix. Wettability is an important property of a matrix that is used to establish and maintain proper contact with the reinforcement.

2. The next important parameter to be considered is the type of fiber yarn. In this context, the tenacity of the yarn and the count of the fiber yarn are important. This contributes an equal share toward the overall behavior of the fabricated material. It is always wise to use bleached yarn for the weaving of the fibers. Bleaching is a process in which the impurities present in the normal yarn are removed, and hence proper weaving of the fibers is possible. Chemical treatment of the fiber after weaving is also important as this modifies the surface roughness of the fiber and ensures superior contact with the matrix. Chemical modification using NaOH solution and silane treatment tops the chart.
3. Modification of the matrix material by the addition of polymer enhancing material has a wide scope in improving the properties of the composite material.
4. Dimensional stability of the composite material is an important factor to be taken care of. Dimensional instability may arise during the sample preparation for mechanical testing. Hence, the proper care should be given to ensure a constant property.
5. Proper selection of warp and weft side fibers is essential during hybridization. As previously stated, warp refers to the vertical side of the fabric, and the weft refers to the horizontal side of the fabric. Hence, it is wise to place a strong fiber in the longitudinal direction (warp) and the other in the transverse direction (weft). Proper interlocking between the warp and weft has to be ensured during the weaving of the fabric.

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