Properties and Characterization of Tamarind Nut Shell Powder Filled Jute and Hemp Fibers Reinforced Hybrid Polymer Composites

A. Felix Sahayaraj
KIT: Kalaignar Karunanidhi Institute of Technology
M. Muthukrishnan
KIT: Kalaignar Karunanidhi Institute of Technology
M. Ramesh (mramesh97@gmail.com)
Kalaignar Karunanidhi Institute of Technology https://orcid.org/0000-0002-8401-2521

Research Article

Keywords: Jute/hemp fibers, Tamarind nut shell powder, Hybrid composites, Mechanical properties, Characterization, Void content

Posted Date: July 9th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-684490/v1

Abstract

The main aim of this work is to investigate the effect of hybridization and the influence of tamarind nut shell powder (TNSP) on the properties and characterization of jute and hemp plant fibers reinforced composites by varying weight % of fibers. The composites are fabricated through the compression molding method and the properties such as tensile strength, tensile modulus, flexural strength, flexural modulus, Shore-D hardness, void content, and interlaminar shear strength (ILSS) of the hybrid composites are evaluated. The characterization studies such as Fourier transform infra-red (FT-IR) spectroscopy, water absorption behavior and scanning electron microscopy (SEM) analysis are also conducted. The results indicated that the hybrid composite samples 40:0 (jute: hemp) have the highest tensile, flexural, impact strengths as well as ILSS values. The void content of 20:20 (jute:hemp) composites was reduced owing to the good adhesion and compatibility of both the fibers with the matrix material.

1. Introduction

Composites have very good potential to replace conventional materials like steel, wood, and metallic elements due to their lightweight, high specific strength, stiffness, availability, and economically cheap [1–3]. Polymer-based composites are widely utilized in several applications, including sports goods, motor boats, airplanes, missiles, space-craft, shipping, computer peripherals, naval and automotive components [4–7]. Natural fibers have become increasingly common as reinforcement material for both thermosetting as well as thermoplastic polymers in recent days [8, 9]. These fibres are carbon neutral and can absorb the equal amount of CO_2 when they produce [10]. Moderate strength, lower density, resistance to corrosion, low thermal expansion coefficient, less energy consumption for manufacturing, and low cost for production are all advantages of polymer composites with natural fiber as a reinforcement [11].

The researchers show tremendous interest in natural fibers reinforcement in light of their low production costs, low equipment requirements, and high strength-to-weight ratio when compared to synthetic fiber reinforcements [12]. Plant-based natural fibers serve as biodegradable reinforcement materials to replace petroleum-based synthetic fibers [13, 14]. Pysical and mechanical properties of plant fibers are largely determined by their physical structure and chemical composition, which includes fiber structure, moisture content, fibrils angle, cellulose content, and cross-section. In a study, the volume fraction of fiber shows the very good impact on both mechanical as well as physical characteristics of the composites [15]. The mechanical properties of several plant based fibres reinforced composites were studied by Arputhabalan et al [16]. From the results, they found that the jute fibre composites possess the maximum strength and good adhesion with polymer matrix.

Considerable amount of biological solid waste is gathered in the form land fill, garbages, etc and this causes environmental pollution. To minimize this pollution, the solid waste is coverted or modified into filler materials, can be mixed into polymer matrices and used for biocomposite preparation [17]. The hemicelluloses content, xyloglucon in the TNSP making it suitable filler material for bio-based composites [18]. The eco-friendly composites were fabricated by adding TNSP as nanofillers for packaging applications and making of other value added products [19, 20]. Few researchers have modified the TNSP with insitu generated copper/silver nanoparticles by thermal assisted processes and suggested this nano-fillers to the preparation of antibacterial bio-nanocomposites [21, 22]. TNSP/silver nanoparticles composites were prepared by using regeneration and solution casting methods [23]. The mechanical properties, FT-IR spectroscopy, XRD and SEM studies of these composites are studied and found that these composites showed good mechanical as well as actibacterial properties.

In comparison with other plant fibers, both jute and hemp fibers have high mechanical, physical and thermal properties [24]. Hemp and jute have many advantages, including lightweight, good tensile strength, high stiffness, recyclability, and biodegradability. Jute fiber has high proportion of cellulose and hemp fiber conducts heat, blocks ultra-violet rays and having anti-bacterial characteristics. Hemp fiber contributes heavily towards for the load-bearing applications when reinforced with polymer matrices. Hemp fiber based polymer composites has high frictional resistance as well as low friction coefficient, which provides better wear properties [16, 25]. Changing the volume of jute and hemp fibers in epoxy matrix has been studied by Vimalanathan et al. [26], and found that the mechanical properties have both positive and negative effects.

The hemp/jute fibres reinforced hybrid composites showed better tensile, flexural, and impact strengths, as well as specific gravity and hardness when compared with either hemp or jute fiber reinforced composites [27]. Graphite filler incorporated jute and hemp fibers hybrid polymer nano-composites were developed with 30°, 45° and 90° fibre directions. The developed hybrid nano-composites were subjected to different mechanical loading, specific gravity test, moisture absorption and hardness tests. It was noted that the elongation, mechanical strengths, hardness, specific gravity are high at 90° orientation, compared to 30° and 45° orientations. Finite element modelling was done and found that the the results are highly correlated with experimental results. Hybrid hemp/kevlar and jute/kevlar based epoxy composites are developed by using hand layup technique as well as vacuum bagging process. The properties such as tensile, compression and flexural strengths of these hybrid composites are studied. A relationship between the hemp/kevlar and jute/ kevlar hybrid composites has been established quantitatively. From the results it is concluded that hemp fiber gave more directional properties when compared to jute and vice-versa in the transverse direction [28]. The jute-hemp fibres reinforced hybrid composite materials were prepared by hand lay-up techniue and the mechanical properties of these composites are evaluated. The experimental and finite element method results of the hybrid polymer matrix composites are compared and found that they have closer values [29].

In this present experimental work, jute and hemp plant fibers reinforced hybrid epoxy composites are manufactured through compression molding technique by varying weight % of fibers. The properties such as tensile strength, tensile modulus, flexural strength, flexural modulus, hardness, void content, ILSS, FT-IR spectroscopy, water absorption behavior and SEM analysis experiments are carried out and the results are analyzed in detail.

2. Materials And Methods

2.1 Materials

The jute and hemp plants are harvested from Alandurai village located at the sub-urban of Coimbatore District, Tamil Nadu, India. The fibers were separated from the outer part of the plant stem by means of water retting and mechanical extraction process. The tamarind nuts were taken out from the fruits, washed, dried under hot sun for 4 days and powdered. The epoxy polymeric resin (LY 556) and hardener (HY 951) are supplied by M/s. Kovai Seenu Chemicals, Coimbatore, Tamil Nadu, India.

2.2 Composite fabrication

To prepare samples for testing, the jute and hemp fibers were cut into 30 cm lengths. The laminate is made up of four layers, each with jute and hemp fibers alternately arranged. The TNSP is mixed with the epoxy resin was first applied to the aluminum foil cover. The jute fiber is the first layer, followed by an epoxy resin, TNSP and hardener combination, and finally hemp fiber on top of the resin. After the resin had dried, the subsequent layers were filled. Developed composites were hold for 60 min at 130°C with a pressure of 30 bar before being removed from the mold. The fabricated laminate can only be 300 x 300 x 5 mm in size (Fig. 1a).

3. Testing And Characterization

3.1 Tensile, flexural and impact tests

Computerized universal testing machine (UTM) of model ROELL Z100 was employed to perform the tensile test. The samples used had a length of 250 mm and a width of 25 mm as per ASTM D 3039 standards [30]. Experiments are carried out at a 20 cm/min crosshead speed. The flexural test was performed on a same UTM following ASTM D 790 requirements [31] at a crosshead velocity of 10 mm/min. The samples used had measurements of 125 x 12.7 mm. The low velocity charpy impact test was used to examine the impact energy values of hybrid composites. The impact test samples were 60 mm x 12 mm x 5 mm in size, in accordance with ASTM D 256 standards [30]. Five samples were checked in each case for all the tests and results were recorded. The typical fractured tensile, flexural and impact test specimen are shown in Fig. 1 (b-d). The experimental tensile and flexural test results are given in Table 1 and the impact test results are given in Table 2.

Table 1 Tensile and flexural test results

S. No	Fiber content (%)		Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)
	Jute	Hemp				
1	0	40	22.43	1.145	57.11	5.811
2	10	30	25.51	1.489	64.56	7.250
3	20	20	26.34	1.734	81.24	8.124
4	30	10	30.55	2.123	82.65	8.765
5	40	0	36.24	2.427	87.60	8.960

3.2 Hardness test

Hardness is one of the essential mechanical property which is defined as resistance to scratch or indentation. The mean hardness value (average of two indentations) of the developed composites was tested with the help of Shore D durometer. The test specimens are prepared in accordance with ASTM D 2240 standards. To obtain proper reading, the thickness of the specimen to be taken as ten times greater than the depth of the indentation [32]. The hardness results of the composite samples are given in Table 2.

3.3 Inter-laminar shear strength

Shear failure is one of the worst mode of failure in fiber reinforced polymer composites. The resistance offered by the sample against shear loading is analyzed by ILSS method. This measures the strength between the layers, and provides in-plane shear modulus of the specimen [32]. Before testing, the ILSS samples are kept in the temperature around 80°C – 120°C for 5 h in a furnace and then cooled constantly at 1°C/min. A cross-head velocity of 5 mm/min was manitained during the test. The ILSS was calculated using the following Eq. (1) and the values are tabulated in Table 2.

$$\text{ILSS} = F/\pi dl \qquad (1)$$

where F = ratio of force measured and force required to de-bond, d = diameter of the sample and l = fiber length embedded in the matrix.

Table 2
ILSS, impact test, and hardness test results

S. No	Fiber content (%)		ILSS (MPa)	Impact strength (J)	Hardness (Shore-D)
	Jute	Hemp			
1	0	40	2.51	1.25	73.15
2	10	30	2.96	1.61	75.58
3	20	20	3.27	1.83	81.02
4	30	10	3.32	2.16	81.98
5	40	0	3.52	2.35	87.05

3.4 Water absorption test

The samples were soaked in the distilled water for 120 h at room temperature and were used to measure the moisture absorption % of jute/hemp fiber incorporated hybrid composites. The standard ASTM D 570 was used to prepare the test specimens [33]. After the necessary amount of time had passed, the samples were taken away from the water and rubbed with a soft cloth, and then dried for some time. Then the samples were weighed to evaluate the water absorption behavior of composites. The water absorption of the samples is evaluated by dividing the increased weight of the specimens by the initial weight and given in Table 3.

Table 3
Water absorption test results

S. No	Fiber content (%)		Immersion duration (h)	Weight (g)		Water absorption (%)
	Jute	Hemp		Before immersion	After immersion	
1	0	40	120	41.50	46.63	45.74
2	10	30	120	44.72	49.74	48.84
3	20	20	120	40.17	45.32	44.43
4	30	10	120	38.24	42.18	41.27
5	40	0	120	42.86	44.26	43.29

3.5 Void content of composites

The ability to estimate the quality of composites requires knowledge of void content present in the material. The voids can be developed within composite during stacking process due to moisture content dissolved gas formation while resin fiber interaction. Even though, voids are inevitable in composites, particularly those made using the compression molding technique. Voids in the composites increase the cross-sectional area which results in poor mechanical properties. The void in composites was calculated using the ASTM D 2734-94 process. The void content (V) of the developed samples was measured with theoretical and experimental densities and given in Table 4.

$$V = (T_d - M_d) / T_d \qquad (2)$$

T_d represents theoratical composite density and T_d represents the experimental density.

Table 4
Void content of the hybrid composite samples

S. No	Fiber content (%)		Density		Void content (V)
	Jute	Hemp	Theoretical (T_d)	Experimental (M_d)	
1	0	40	1.228	1.196	2.605
2	10	30	1.222	1.180	3.437
3	20	20	1.288	1.251	2.873
4	30	10	1.308	1.280	2.141
5	40	0	1.348	1.332	1.187

3.6 FT-IR analysis

FT-IR spectroscopy is a method which is used to classify the chemical consitituents in the samples by passing infra-red spectra. To examine the chemical composition and constituents of jute and hemp fibers, FT-IR analysis is carried out in this experiment. To achieve an infra-red spectrum, the KBr disc sample preparation method was used. Fibers are mixed with potassium permanganate in the specified ratio, then pelletized under vacuum condition in the mixer. Between 4000 cm^{-1} and 400 cm^{-1}, FTIR spectra are observed.

3.7 SEM analysis

SEM is a characterization technique used to analyze the structure of broken surfaces caused by mechanical and physical loading. The morphological representations of the developed composites are examined with aid of SEM [34]. To investigate the interfacial characteristics of developed composite and the structure of fractured surfaces, SEM analysis was performed on the composite samples. Before morphological analysis, a small portion of the sample was placed aluminum stub, in order to create conductivity silver coating was applied on the sample. The SEM micrographs were taken using standard imaging techniques.

4. Results And Discussion

4.1 Tensile and flexural test result analysis

Jute and hemp fibers hybrid composite samples were tested by appling tensile and flexural loads. Table 1 presents the tensile and flexural strengths as well as modulus of prepared hybrid composites of jute and hemp fibers. As given in the table, the tensile strength is high (36.24 MPa) for the sample with 40 % of jute fiber reinforcement. From this it is observed that, raising the proportion of jute fibers in the composites shows better tensile strength as compared to other hybrid combinations. Tensile strength of only hemp fiber reinforced composites is 22.43 MPa, while 10% jute and 30% hemp reinforced composites have a strength of 25.51 MPa. With a modulus of 8.960 GPa, the flexural strength value of the 40% jute fibers and 0% hemp fiber (87.60 MPa) is found to be higher. The flexural results of composites fabricated with 0% jute and 40% hemp fibers were the lowest (57.11 MPa). The analysis of the tensile and flexural test results are explained in Fig. 2. From the figure it is clearly noted that the strengths and modulus of these fibers reinforcements are found to differ linearly by varying jute fiber weight %. The hybrid composite's tensile and flexural strengths were found to be higher at 40 % jute fiber combination. Due to the reinforcement of jute fibers in the composites the tensile as well as flexural strength are increased when compared to hemp fiber reinforcement. Figure 2 clearly indicates jute fiber addition to epoxy matrix material increases the both strengths as well as moduli of hybrid composites.

4.2 Impact test result analysis

The analysis of energy absorbed during impact loading is presented in Fig. 3. The figure shows that the jute fiber adds a lot of strength to the material, the 40:0 (jute: hemp) composites tend to have a higher impact value than other developed composites. Impact strength of the composite increases because jute fiber has higher cellulose content, when compared to other plant fibers. The impact energy absorbed is increased with the higher jute fiber percentage because more energy is needed to break the fiber/matrix bonding. The figure further reveals that the hybrid composite samples with 0% jute and 40% hemp fibers exhibited low impact strength due to the porosity and spiral angle of fibers.

4.3 Hardness test result analysis

The reinforcement of natural fiber in the epoxy which enhances the hardness of the composites developed. Hardness results are given Table 2 and the comparisons are explained in Fig. 3. From the figure it is known that the hardness (Shore-D) of 40% jute fiber reinforced composites is maximum (87.05) and 40% hemp fiber reinforced composites having the lowest hardness of 73.1. This improved crack propagation which is also due to the excellent bonding between the reinforcement and epoxy resin. Due to this stress adjacent, laminate got deformed, which can lead to failure along the midplane if the gap between successive layers is large enough.

4.4 ILSS test result analysis

The ILSS of jute/hemp fibers reinforced hybrid composite samples is presented in Fig. 3. From the table it is evident that the range of ILSS is in between 2.51 and 3.52 MPa. From the results it is noted that the 40:0 (jute:hemp) hybrid composite has the highest ILSS of 3.52 MPa among all hybrid composites analyzed in this study, as a result of increased jute fiber volume fraction and 0:40 (jute: hemp) hybrid composites, has the minimum shear strength of 2.51 MPa. This is because of the influence of the bonding strength at the interface of the fibers and matrix. As a consequence, it's necessary to assess the ILSS using a test in which the composite laminate fails in a shear mode.

4.5 Water absorption test result analysis

Lingo-cellulosic fiber's highly polar and hydrophilic nature makes it difficult to make natural fiber-reinforced hybrids, resulting in poor bonding with the matrix material and mechanical properties were reduced due to the increased moisture content. As a result, the test was conducted for jute and hemp fibers hybrid composite materials with various volume fractions and water absorption behavior were investigated, and the results are presented in Table 3. The percentage moisture absorption of the samples are calculated and the values are plotted in Fig. 3. The figures clearly denotes that the water absorption level is high in the 20% jute and 20% hemp fiber hybrid composites and low in the 40% jute and 0% hemp hybrid composite samples. The water absorbance level is increased with higher hemp fiber reinforcement and jute fiber reinforcement in the epoxy matrix produces a lower water absorption.

4.6 FT-IR spectroscopy analysis

Spectral analysis of the jute and hemp fibers samples was done using the Shimadzu FTIR-8400S machine and results are presented in Fig. 4. The experiment was conducted to find out the the functional groups in the fibers. The interaction of the –OH groups and hydrogen stretching vibrations are characterized by a long absorption band ranging from 3842 cm^{-1} to 3726 cm^{-1}. In the jute fiber sample, the hydrogen stretching frequency ranged from 2978.09 cm^{-1} to 2885.51 cm^{-1}. The peaks at 2360.87 cm^{-1} show C-H stretching bonds found in consitituents of plant fibers. The 1743.65 cm^{-1} bands refer to the C = O stretching and the spike shown at 1512.34 cm^{-1} for the samples suggests C-O bending. The structure of cellulose is associated with the band at about 671.23 to 424.34 cm^{-1}. The band at 2360.87 cm^{-1} represents the C-O bonding due to the availability of wax and pectin on the fiber surface.

4.7 SEM morphology analysis

Cracks, fractured surfaces, and fiber orientation of the hybrid composite materials are observed using SEM micrographs. The SEM images of the hybrid composite specimens underwent to different types of loading are shown in Fig. 5. The micrographs display the fiber fractures caused by mechanical loading (Fig. 5a-c). The surface of the samples gets roughened due to hardness, as seen in the micrograph presented in Fig. 5d. Since the fiber-matrix adhesion has improved, the fiber pull-out has decreased. Fiber fracture and delamination are also normal due to the fiber pull out (Fig. 5e). Bad roughening of the surface may be caused by the removal of water content from the fiber surface (Fig. 5f). This means that the fiber and matrix are well-bonded during the interphase. Composite with improved flexural strength and modulus is due to fiber concentration, which provides resistance to fiber fracture. The maximum strength was reported for the sample 40% of jute fiber having good interfacial bonding strength, less intra fiber delamination according to the findings from SEM images.

5. Conclusion

The mechanical strengths, hardness, void content, ILSS and FT-IR spectra of jute and hemp fibers strengthened TNSP filled hybrid composites fabricated by compression moulding process are tested experimentally. The effect of hybridization and influence of TNSP on the physical and mechanical properties of the composites are investigated. The following conclusions are arrived from the results:

- The tensile strength of the 40:0 (jute:hemp) composite samples are 34.24 MPa, which is significantly higher than the other tested samples.
- According to the results, the composites with 40% jute fiber and 0% hemp fiber have the highest flexural strength value of 87.60 MPa.
- The composites maximum impact strength as well as ILSS values are 2.35 J and 3.52 MPa for the 40:0 (jute: hemp) composite sample.
- Jute/epoxy with 40:0 ratio sample shows the maximum Shore-D hardness (87.05 Shore-D) compared to other hybrid samples.
- Due to the excellent interfacial bonding strength of jute fibers with epoxy resin, the void content is better except 20:20 (jute: hemp) hybrid composites.
- Water absorption level is also high in the 20% jute and 20% hemp fiber hybrid composites and low in the 40% jute and 0% hemp hybrid composite samples.
- Fiber matrix adhesion is increased, resulting in decreased fiber pull out, according to SEM image analysis of the broken surfaces of the hybrid composite specimens.

References

1. Belouadah Z, Rokbi M, Ati A (2020) J Nat Fib. https://doi.org/10.1080/15440478.2020.1856273
2. 2. Jin Y, Gwak Y, Gerhardt RA (2020) Adv Compos Mater 29(3):235
3. Ramesh M (2016) Prog Mater Sci 78:1
4. Anwary M, Kumar P, du Toit LC, et al (2018) Artif Cells Nanomed Biotechnol 46:1074
5. Asghari F, Samiei M, Adibkia K, et al (2017) Artif Cells Nanomed Biotechnol 45(2):185
6. Kausar A, Rafique I, Anwar Z, et al (2016) Polym Plast Technol Eng 55(7):704
7. Ramesh M (2018) Prog Mater Sci 102:109
8. Panda R, Tjong J, Nayak SK, et al (2017) J Nat Fib 14(5):747
9. Vimal R, Subramanian KHH, Ashwin C, et al (2015) Mater Today: Proc 2:2918

10. Ashik KP, Sharma RS (2015) J Miner Mater Character Eng 3:420
11. Premnath AA (2019) J Nat Fib16(5):718
12. Sathishkumar GK, Ibrahim M, Mohamed Akheel M, et al (2020) J Nat Fib. https://doi.org/10.1080/15440478.2020.1848723
13. Chokshi S, Parmar V, Gohil P, et al (2020) J Nat Fib. https://doi.org/10.1080/15440478.2020.1848738
14. Ramesh M, Deepa C, Kumar LR, et al (2020) J Ind Text https://doi.org/10.1177/1528083720924730
15. Thakur VK, Thakur MK, Gupta RK (2014) Int J Polym Anal Character 19(3):256
16. Arputhabalan J, Karunamoorthy L, Palanikumar K (2020) Polym Polym Compos https://doi.org/10.1177/0967391120973508
17. Ashok B, Hariram N, Siengchin S, et al (2020) J Biores Bioprod 5(3):180
18. Sahoo R, Sahoo S, Azizi S (2017) Manipal J Medi Sci 2(2):32
19. Kumar TSM, Rajini N, Jawaid M, et al (2018) J Nat Fib 15:11
20. Kumar TSM, Rajini N, Tian HF, et al (2017) Int J Polym Anal Charact 22:415
21. Ashok B, Feng TH, Natarajan H, et al (2019) Int J Polym Anal Charact 24:548
22. Li JY, Zhang JM, Natarajan H, et al (2019) Int J Polym Anal Charact 24:421
23. Mamatha G, Rajulu AV, Madhukar K (2019) Int J Polym Anal Charact 24:219
24. Ramamoorthy SK, Skrifvars M, Persson A (2015) Polym Rev 55:107.
25. Inbakumar JP, Ramesh S (2018) Trans Can Soc Mech Eng 1–6:280
26. Vimalanathan P, Venkateshwaran N, Srinivasan SP, et al (2018) Int J Polym Anal Character 23(2):99
27. Sowmya C, Ramesh V, Karibasavaraja D (2018) Mater Today: Proc 5:13309
28. Suresha KV, Shivanand HK, Amith A, et al (2018) AIP Conf Proc 1943:020109
29. Babu CA, Kalam SA, Kumar PR (2017) Int J Eng Develop Res 5:217
30. Ramesh M, Deepa C, Niranjana K, et al (2021) J Nat Fib, https://doi.org/10.1080/15440478.2021.1921660
31. Chaudhary V, Bajpai PK, Maheshwari S (2018) J Nat Fib 15(1):80
32. Ramesh M, Bhoopathi R, Deepa C et al (2019) J Chin Adv Mater Soc, 6(4):640
33. Toubal L, Zitoune R, Collombet F, et al (2018) J Nat Fib 15(1):39
34. Ramesh M, Deepa C, Tamil Selvan M et al (2020) J Nat Fib, https://doi.org/10.1080/15440478.2020.1764443

Figures

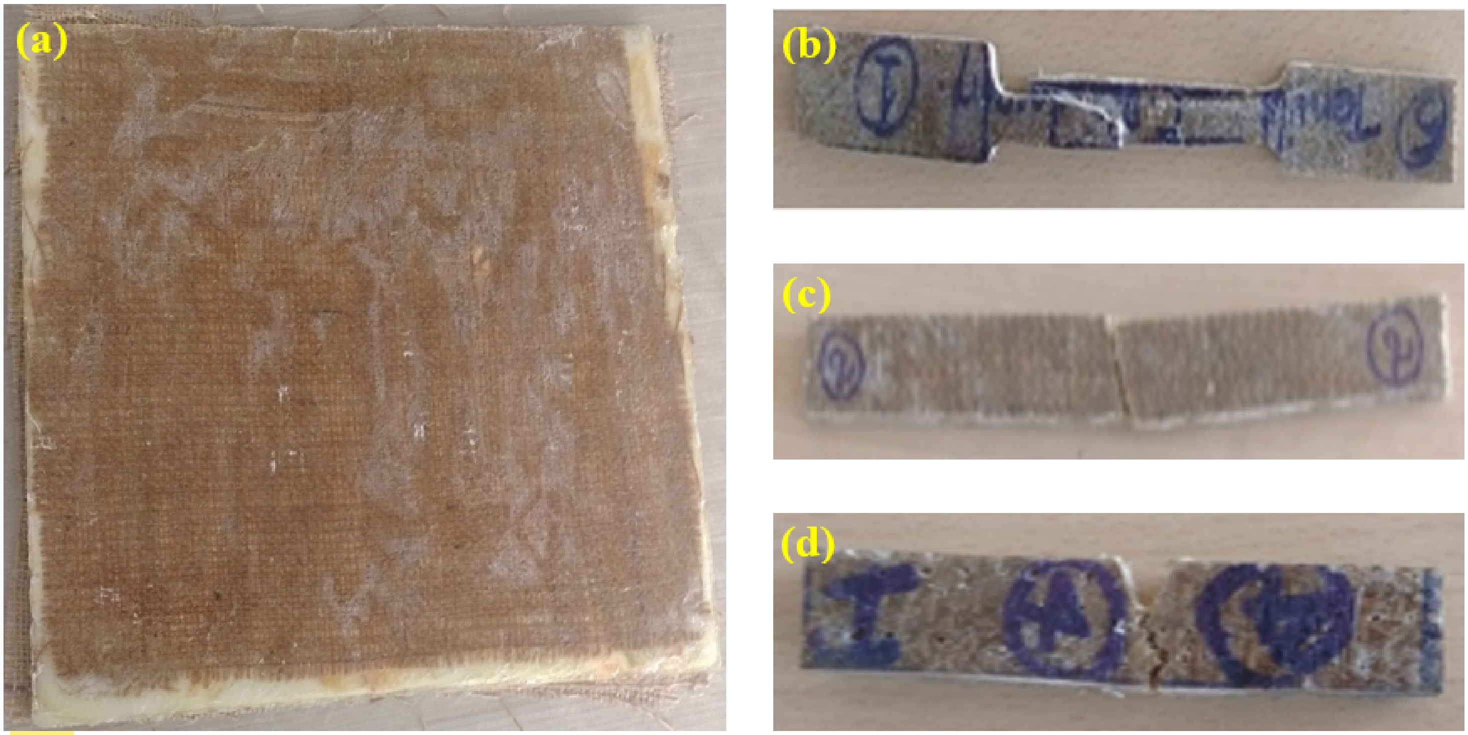

Figure 1

The typical (a) fabricated hybrid composite laminate, (b-d) fractured tensile, flexural and impact test specimens

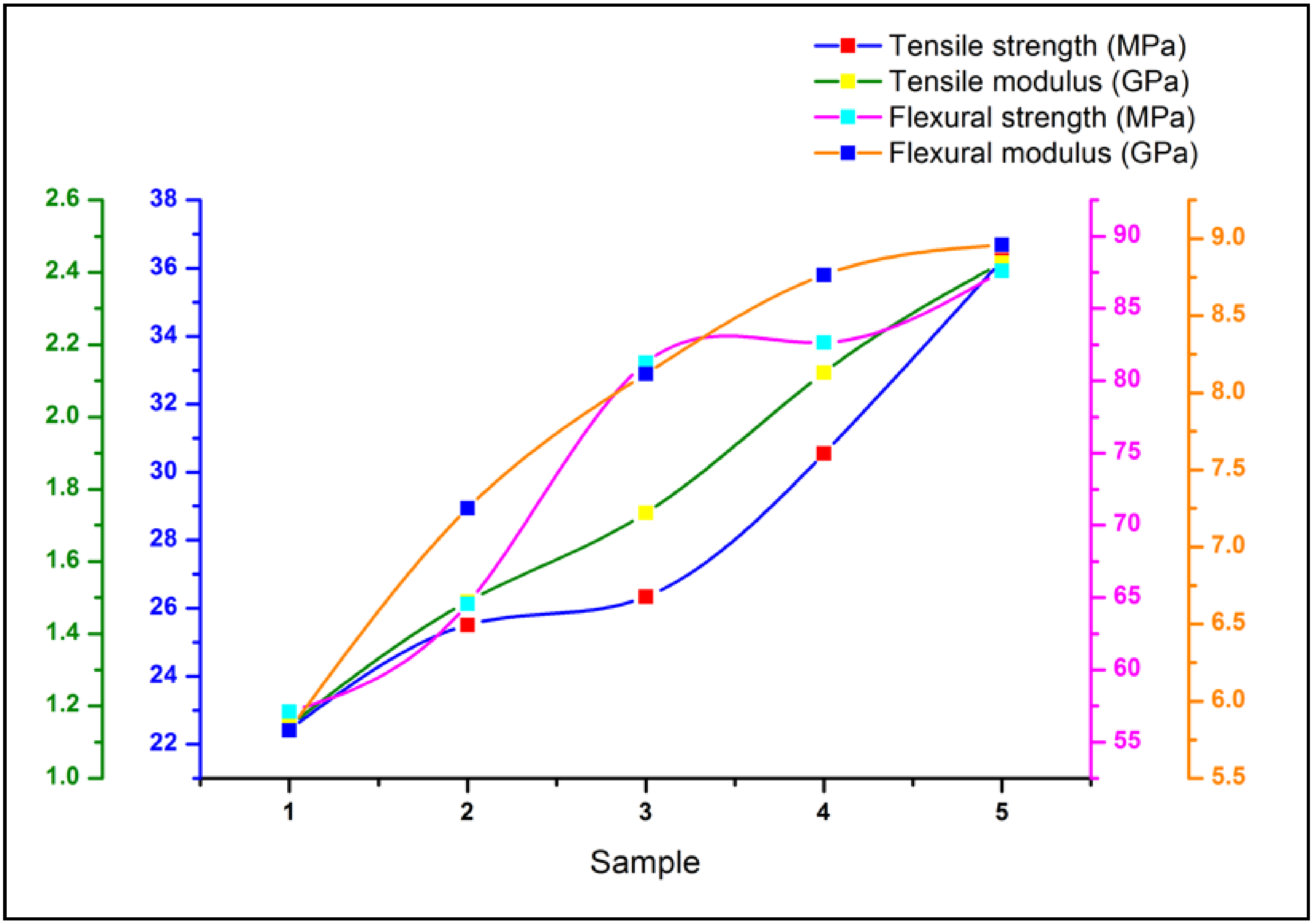

Figure 2

Tensile and flexural test results of hybrid composites

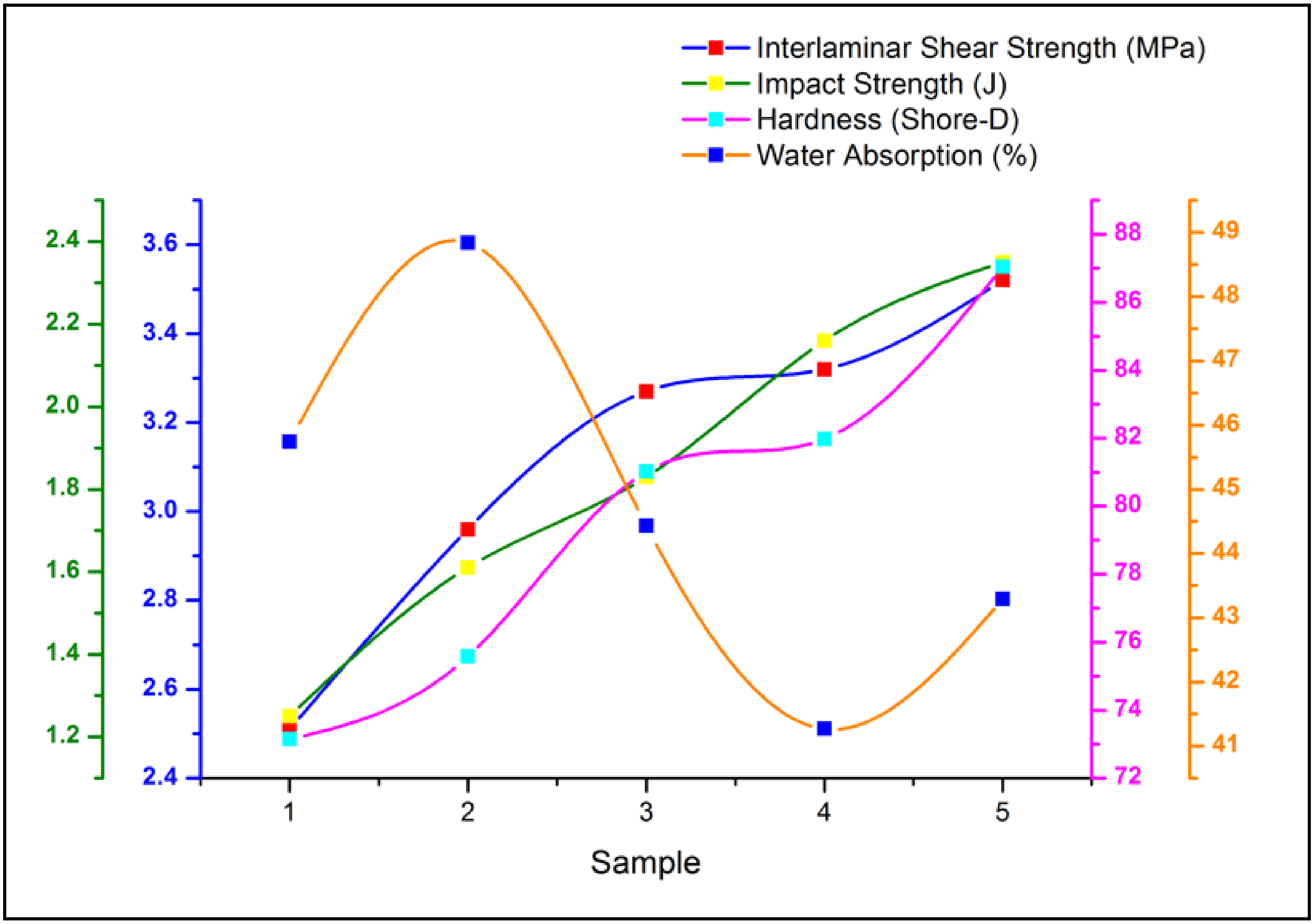

Figure 3

ILSS, impact strength, hardness and water absorption test results of hybrid composites

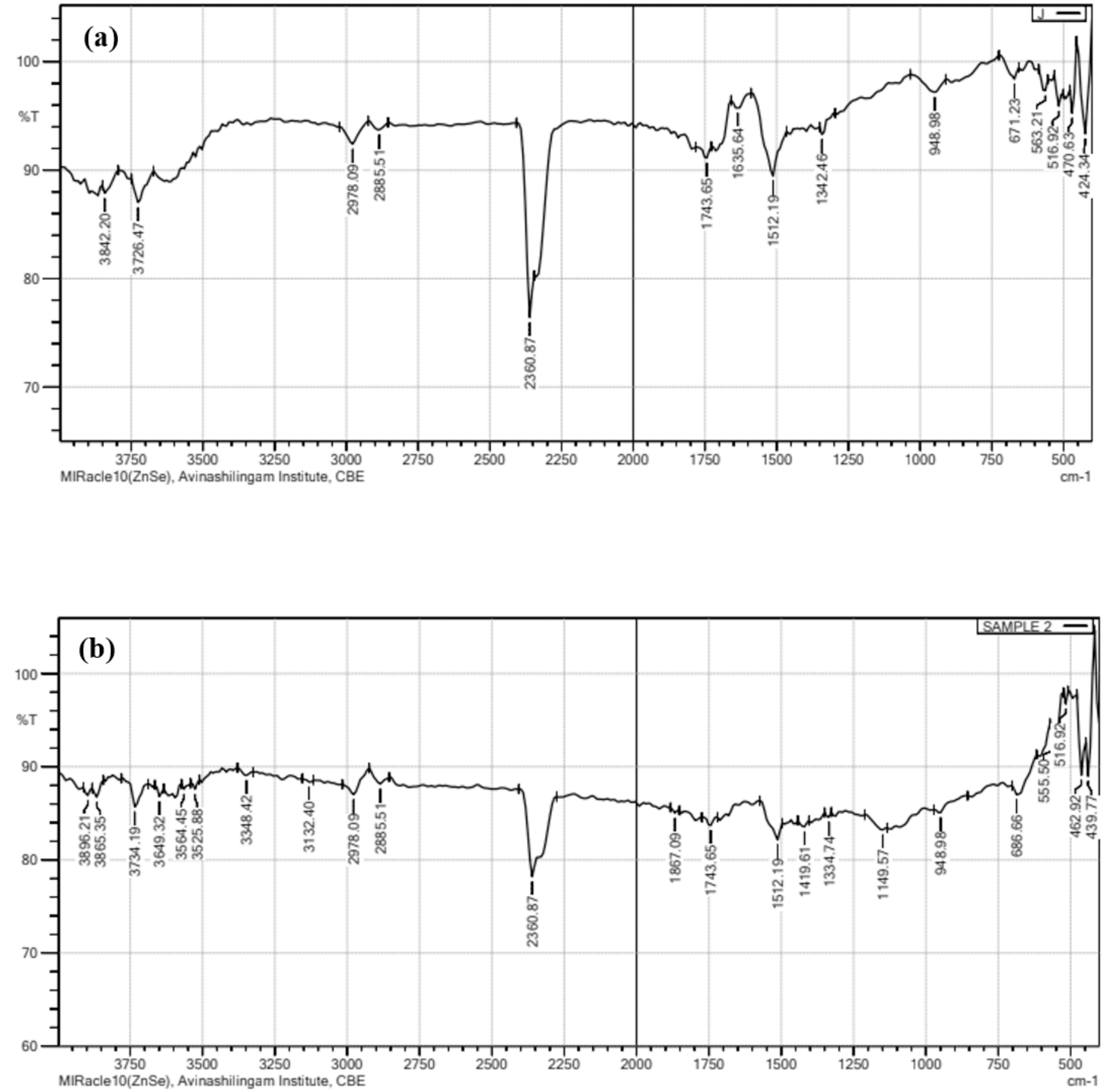

Figure 4

FT-IR spectrum of (a) jute and (b) hemp fiber samples

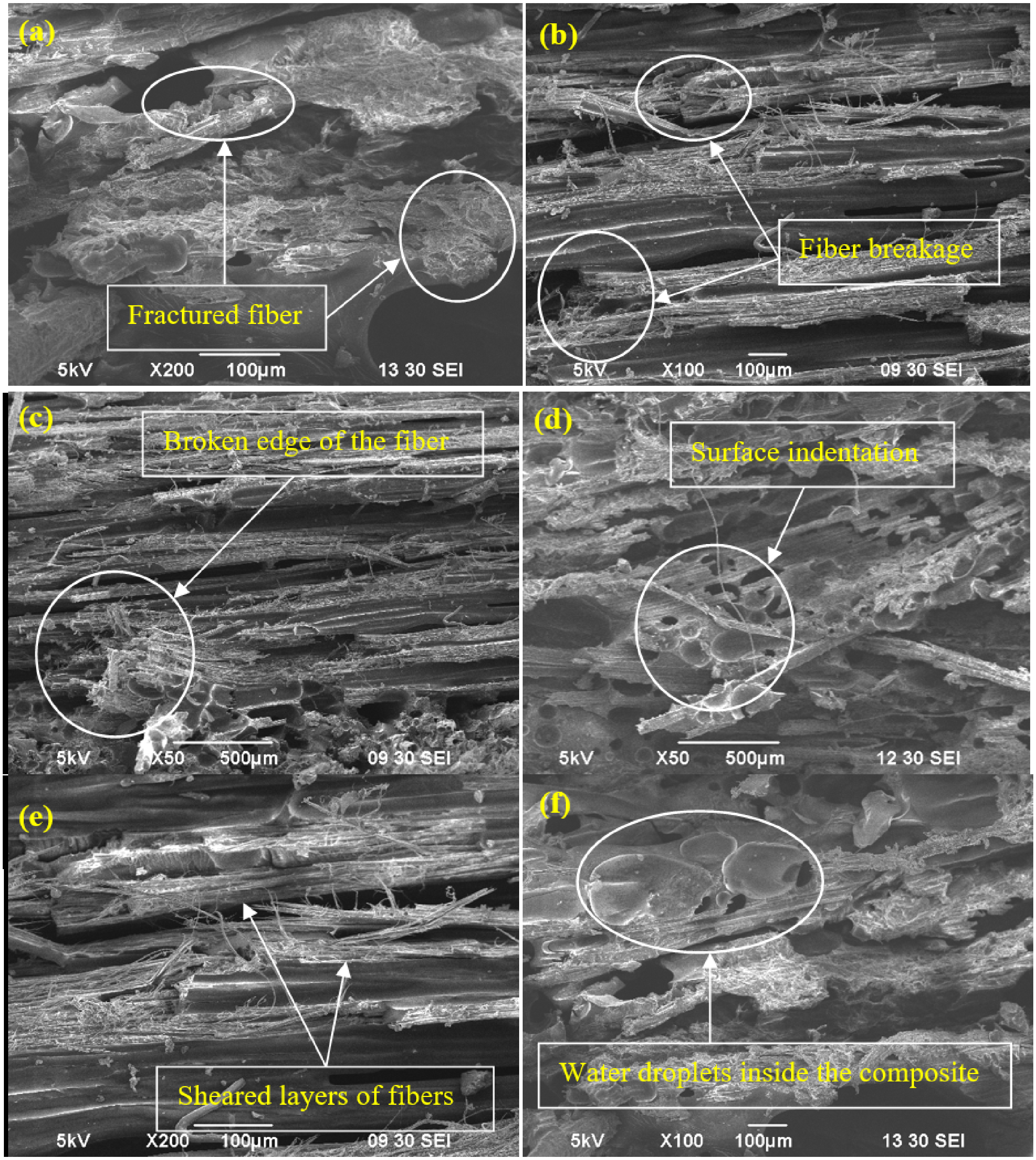

Figure 5

SEM micrograph of the jute/hemp composite specimens subjected to (a) tensile; (b) flexural; (c) impact; (d) hardness; (e) ILSS; and (f) water absorption tests