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Natural fabric sandwich laminate composites: development and investigation

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Abstract. **In this work, eco-friendly natural fabric sandwich laminate (NFSL) composites are formulated using jute and linen-fabric-reinforced epoxy with different layer ratios (5:0, 4:1, 3:2, 2:3, 1:4 and 0:5) by hand layup system. Different mechanical attributes (tensile, flexural and impact) of the NFSL composites are quantified. Thermal stability and water absorption behaviour of the NFSL composites are also assessed. A scanning electron microscope (SEM) and optical microscope are used for qualitative analysis of NFSL composites' interfacial properties. Two layers of jute and three layers of linen sandwich laminate have registered peak values in tensile and impact properties. The five layers of linen laminate composite have exhibited high flexural strength, been proven to have good thermal stability and furthermore shown better water absorption behaviour than any other laminate composites.**

Keywords. **Natural fabrics; jute; linen; sandwich laminate; mechanical properties; fractographic analysis.**

1. Introduction

Owing to ecological necessities and strict regulations, incorporating natural fibres in the place of synthetic fibres becomes inevitable for the manufacturers to accomplish new composite materials originated from renewable sources. Natural fibres play an important role in capturing carbon di-oxide from the environment by means of carbon sequestration. The natural fibres as reinforcement in polymer composites can offer impressive technical and ecological characters. Nowadays, researchers are cogitating to develop green composites from natural fibres. In this regard, myriads of studies are being carried out with different natural fibres replacing the widely used man-made fibres [1–3]. Natural fibres offer multifarious merits when compared with metals and ceramics and play a vital part in formulating complete biodegradable composites, which are key substances to check ecological issues. In the automobile industry, conventional glass fibres are supplanted by natural fibres due to their light weight and less cost [4]. Fibre incorporation in a composite is an imperative parameter that influences the mechanical properties of the composites.

The materials scholars are on the run to explore the possibility of introducing natural fibres as reinforcement in polymer-based composites. A few material specialists have indicated how natural fibres have surprising mechanical properties that yield them great hope as reinforcement in polymer matrix composites. For the possible application in interior automotive panels a biocomposite made of biodegradable bark cloth was developed by Rwawiire *et al* [5]. Pineapple leaf fibre reinforced phenol formaldehyde (PF) composites were studied by Mangal *et al* [6]. Yousif *et al* [7] discussed the suitability of betelnut fibre for tribological applications. Hadjadj *et al* [8] conducted a study on alfa cellulose fibres, which are successfully utilized as reinforcing components because of their attractive electrical trends. Anbukarasi and Kalaiselvam [9] investigated the luffa-fibre-reinforced epoxy composites and Ridzuan *et al* [10] researched about the Pennisetum purpureum fibres. In addition to the above-mentioned natural fibres, flax [11], banana [12], sisal [13], hemp [14] and coir [15] are well accepted as reinforcements for natural-fibre-based polymer matrix composites.

Jute fibre is a potentially viable reinforcement for composite because of high specific strength and modulus, minimal cost, low density, no health hazard, easy accessibility, renewability and less energy necessity for processing [16]. The mechanical properties of jute/epoxy composites were studied by Gassan and Bledzki [17]. An investigation on the surface properties and interfacial adhesion of jute fibre/epoxy composites was done by Doan *et al* [18]. Santulli *et al* [19] study revealed that the hybridization with jute fibres can considerably improve both the tensile and flexural properties of wool-fibre-reinforced epoxy composites. According to Boopalan *et al* [20] the sisal fibre soaks up more water than the jute fibre, thus decreasing the mechanical properties of the composite.

The drive to utilize the lamination process is the blend of best characteristics of the constituent layers keeping in mind the end goal to acquire a material with definite characteristics

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not obtained with a single material [21]. Manicaria fabric plays a major role in helping develop a green composite lamina, an attractive blend of mechanical properties and eco-friendly quality [22]. The bamboo fibre laminates have the ability to replace glass-fibre-reinforced composites in the application as skin material in sandwich structures [23]. Lightweight laminate composites are fabricated using kenaf and polypropylene (PP) fibres [24]. The enhancement in mechanical properties has led to the increased interest in textile reinforcements, which are more prominent than their non-woven counterparts [25]. Grewia tilifolia fabrics are proven to be a promising reinforcement for polymeric matrix [26].

In recent days, the demand for apparel use of linen fabric has considerably increased due to its different qualities [27]. Research on tensile strength of linen-reinforced composites was done by Gu and Liyan [28]. Buchert *et al* [29] analysed the surface chemistry of linen fabric. Yan *et al* [30] investigated the composite material made of linen-fabric-reinforced epoxy resin. The foremost reason to prefer epoxy resin as matrix is its outstanding mechanical and dynamic strength [31]. Interfacial properties such as fracture behaviour, fibre pull-out and fibre–matrix interaction of the composite samples are investigated using a scanning electronic microscope (SEM) [32].

From the above literature it is observed that the natural fibres and their laminates have played an imperative part in fabricating polymer matrix composites. In this research work, an attempt has been made to develop eco-friendly natural fabric sandwich laminate (NFSL) composites using jute- and linen-fabric-reinforced epoxy resin. The effects of the reinforcements on the mechanical attributes (tensile, flexural and impact), thermal property and water absorption behaviour of the NFSL composites are assessed. A SEM and optical microscope are utilized for detailed study of the morphology of fractured surface of the NFSL composites.

2. Experimental

2.1 *Materials and method*

Jute fabric, linen fabric, epoxy resin (LY556) and hardener (HY951) are used to formulate the NFSL composites. The methodology in the manufacturing of NFSL composites employs a glass plate mould measuring 400 mm × 300 mm and thickness 6 mm. In order to prevent the adhering of composite to the mould a release gel is splashed on the mould surface. A thin plastic sheet is placed at the top of the mould after applying release gel. Reinforcement as fabric is cut according to the mould dimensions and placed above the plastic sheet. The epoxy resin mixed with hardener in the ratio 10:1 is poured onto the surface of fabric, which is already placed on the mould. The epoxy is consistently spread with the aid of a brush. Another layer of reinforcement in the form of fabric is then placed on the epoxy resin surface and a roller is used to remove any air trap and extra epoxy in the composite. Again thin plastic sheets are placed at the top of the stacked layers. Release gel is splashed on the plastic sheet and then a weight of 25 kg is kept over it for 24 h [32] for curing, which is done at room temperature. The procedure is repeated for every layer of epoxy and reinforcement till five layers of six different NFSL composites with different layer ratios of jute and linen fabrics (5:0, 4:1, 3:2, 2:3, 1:4 and 0:5) are obtained. Figure 1 summarizes the flow of fabrication steps of NFSL composites.

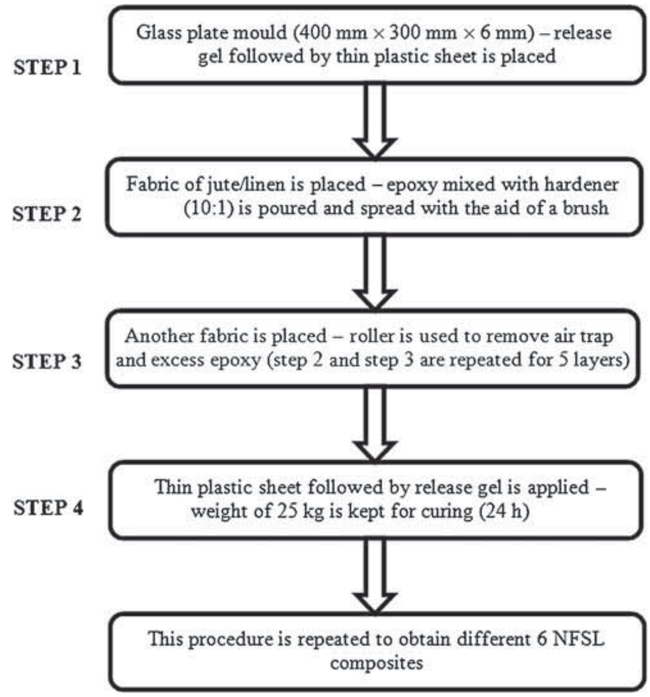

Figure 1. Flowchart of fabrication steps of NFSL composites.

2.2 *NFSL composite structure*

In four layers of jute fabrics and one layer of linen fabric (J4-L1), the linen fabric is kept as the middle (third) layer. In three layers of jute fabrics and two layers of linen fabrics (J3-L2) the first, third and fifth layers are jute fabrics. In two layers of jute fabrics and three layers of linen fabrics (J2-L3) the first, third and fifth layers are linen fabrics. In one layer of jute fabric and four layers of linen fabrics (J1-L4), the jute fabric is kept as the middle (third) layer. The NFSL composites thus formulated are tabulated in table 1 with respect to their codes, volume fractions and densities. Figures 2 and 3 show a schematic representation of NFSL composite and some of the formulated sandwich laminates, respectively. An optical microscope (Model: AXIO SCOPE A1, Make: CARL ZEISS, Germany) is used to study the cross-section of the NFSL composite. Figure 4 shows an image of jute and linen fibres in NFSL composite.

2.3 *Mechanical characterization*

After formulation, the NFSL composites are subjected to different mechanical tests with their corresponding ASTM

Table 1. Codes, volume fractions and densities of the NFSL composites.

NFSL composite	Codes	Volume fraction (%) Jute	Linen	Epoxy	Density (g cm^{-3})
5 Layers of jute fabrics	J5-L0	16	0	84	0.83
4 Layers of jute and 1 layer of linen fabric	J4-L1	14	2	84	0.77
3 Layers of jute and 2 layers of linen fabrics	J3-L2	11	5	84	0.72
2 Layers of jute and 3 layers of linen fabrics	J2-L3	8	8	84	0.66
1 Layer of jute and 4 layers of linen fabrics	J1-L4	4	12	84	0.61
5 Layers of linen fabrics	J0-L5	0	16	84	0.55

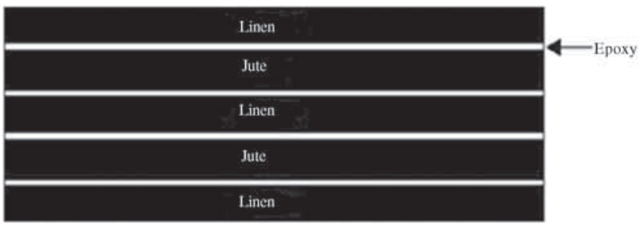

Figure 2. Schematic representation of NFSL composite.

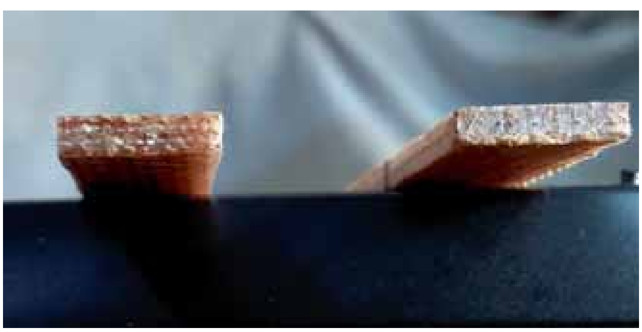

Figure 3. Sandwich laminates.

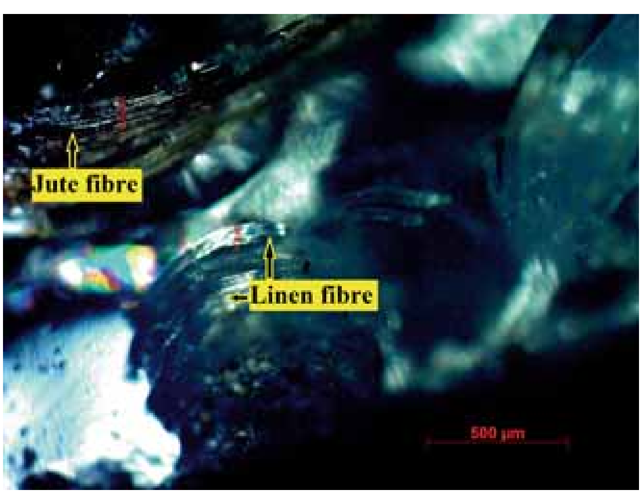

Figure 4. Optical microscope image of jute and linen fibres in NFSL composite.

standards. The tensile test is carried out using a Universal Testing Machine (Make: Fuel Instruments and Engineers Pvt. Ltd. India) in accordance with ASTM D638 with cross-head speed of 3 mm min^{-1} as per nominal dimension of 115 mm $\times$ 19 mm $\times$ 3.44 $\pm$ 0.35 mm. Standard ASTM D790 is used for performing flexural test (three-point bending) in the same machine at the same cross-head speed as per nominal dimension of 70 $\pm$ 7 mm $\times$ 12.7 mm $\times$ 3.44 $\pm$ 0.35 mm. The Izod impact test is performed in an impact testing machine (Make: Fuel Instruments and Engineers Pvt. Ltd. India) according to standard ASTM D256 as per nominal dimension of 63.5 mm $\times$ 3.44 $\pm$ 0.35 mm $\times$ 12.7 mm. In order to assess the mechanical attributes of the NFSL composite, three specimens are tested under each category of the NFSL composite. The mechanical attributes, throughout the investigation, are reported in terms of mean $\pm$ standard deviations.

2.4 *Fractographic study*

The fractography study of the fractured surfaces is carried out using a SEM (Model: EVO MA15, Make: CARL ZEISS, Pvt. Ltd. UK) at room temperature with an accelerating voltage of 15 kV. It is to be noted that the specimen surfaces are vacuum coated with a thin layer of gold prior to analysis for obtaining good conductivity.

2.5 *Thermal characterization*

The thermal stability of NFSL composite is evaluated using a thermogravimetric analyser (Model: TG/DTA 6200, Make: SII NANO Technology, Japan) under nitrogen atmosphere at a flow rate of 140 ml min^{-1}; 5–6 mg of each sample is placed on an alumina crucible and heated from ambient temperature to 600°C at a heating rate of 20°C min^{-1}. Thermogravimetric analysis (TGA) is used to measure the loss of weight in a material as a function of temperature (or time) under a controlled atmosphere in order to determine the thermal stability and decomposition. In this analysis, the temperature of a sample is gradually raised in a furnace as its weight is measured on an analytical balance that remains outside the furnace. In TGA, if a thermal event involves loss of a volatile component then a mass loss is observed. The weight of the sample is plotted against temperature (or time) to illustrate thermal transitions in the material such as degradation.

2.6 *Water absorption test*

For the water absorption test, the test is performed in accordance with ASTM D570. The specimens are weighed in dry condition and are immersed in a water bath maintained at ambient temperature for 1 h and the specimens are delicately dried by applying pressure on both sides with a paper towel and are weighed again [32]. The water absorption of the composites after immersion is calculated by the weight increased with respect to the dry weight using an electronic balance machine (SHIMADZU (AUW220D)) with an accuracy of 0.01 mg. The percentage increase in weight of the samples is calculated using the formula [21]

$$\text{TA}\ (\%) = \frac{M_\text{i} - M_\text{s}}{M_\text{s}} \times 100, \quad (1)$$

where TA (%) is the absorbed water content, M_s is the mass of the dry specimen and M_i is the mass of the specimen after immersion.

3. Results and discussion

3.1 *Mechanical characterization*

3.1a *Mechanical properties*: The tensile strength of the NFSL composites is presented in table 2. The graph in figure 5 depicts the variation of the tensile properties of the different composites. The 8 vol% of jute and 8 vol% of linen (J2-L3) sandwich laminate presents superior tensile property. The 8 vol% of jute and 8 vol% of linen sandwich laminate possesses the highest tensile strength of 36.07 MPa. It exhibits the maximum tensile strength 34% higher than that of 16 vol% of jute (J5-L0) laminate composite and 20% higher than that of 16 vol% of linen (J0-L5) laminate composite.

The flexural properties of the NFSL composites are summarized in table 2. The flexural strength of the composite is enhanced by the introduction of linen fabric. There is a significant increase in the flexural strength of the composites as the layer of linen fabric increases. The trend of the flexural strength is depicted in figure 6. The flexural strength of the pure linen fabric/epoxy (J0-L5) laminate composite, which has 16 vol% of linen, is 41% more than that of the pure jute fabric/epoxy (J5-L0) laminate composite, which has 16 vol% of jute. The flexural strength is controlled by the strength of the extreme layer of reinforcement [33,34]. The upper and lower layers of the fabrics are subjected to compression and tension, respectively [1], and they are chiefly accountable for the flexural strength of the sandwich laminate [35]. The sandwich 8 vol% of jute and 8 vol% of linen (J2-L3), 4 vol% of jute and 12 vol% of linen (J1-L4), 16 vol% of linen (J0-L5) laminates have linen fabrics on the top and bottom layers. While J0-L5 has linen fabrics on all layers, J1-L4 has jute fabric on the third layer and J2-L3 has jute fabrics on the second and the fourth layers. The presence of linen fabrics on the first, second, fourth and fifth layers makes

Table 2. Mechanical properties of the NFSL composites.

NFSL composite	Tensile strength (MPa)	Flexural strength (MPa)	Impact energy (J)
J5-L0	26.90 ± 1.00	26.37 ± 0.57	4.33 ± 1.15
J4-L1	30.19 ± 0.91	28.16 ± 0.71	6.00 ± 1.00
J3-L2	33.13 ± 0.93	29.42 ± 0.58	7.33 ± 0.57
J2-L3	36.07 ± 0.95	30.68 ± 0.69	8.00 ± 1.00
J1-L4	30.86 ± 1.02	35.58 ± 0.71	6.33 ± 0.57
J0-L5	30.17 ± 0.79	37.11 ± 0.50	5.67 ± 1.15

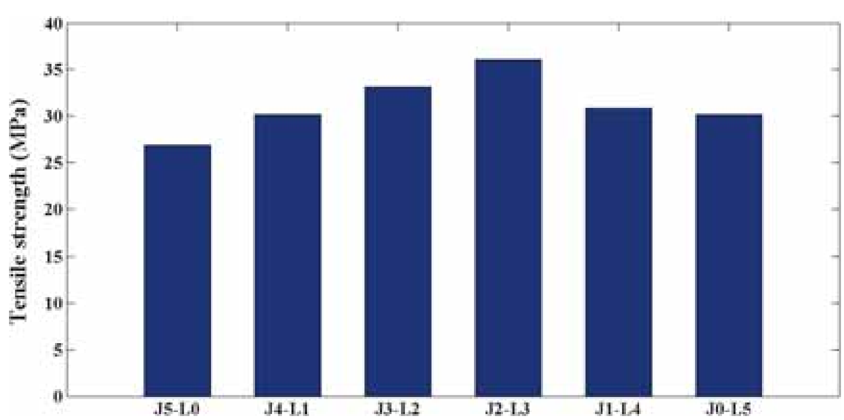

Figure 5. Tensile strength of the NFSL composites.

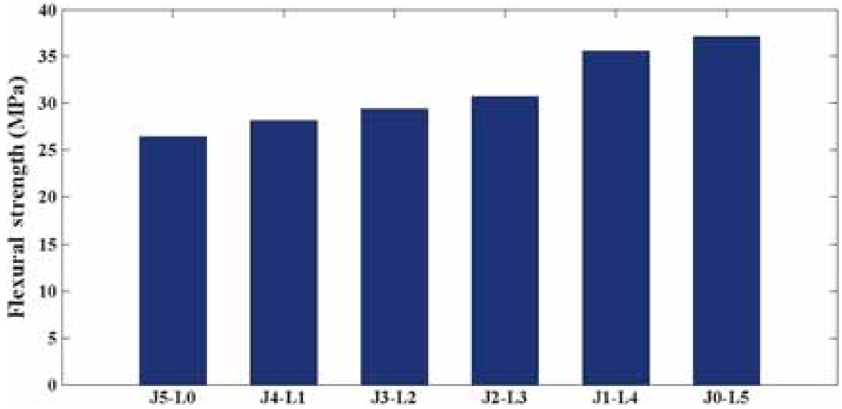

Figure 6. Flexural strength of the NFSL composites.

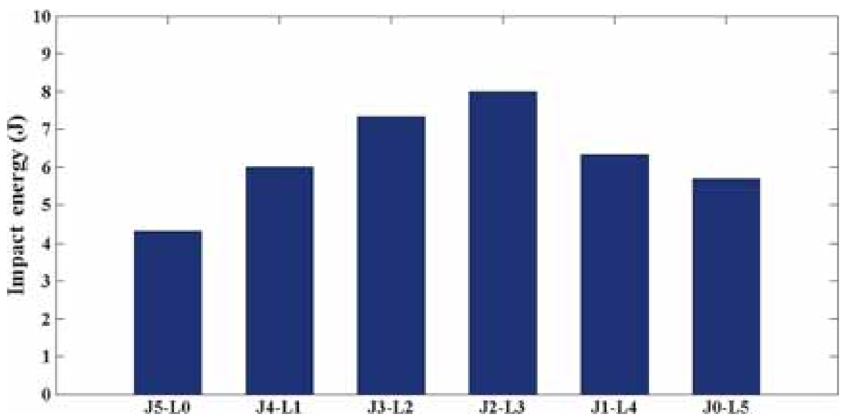

Figure 7. Impact energy of the NFSL composites.

J1-L4 almost at par with J0-L5 when it comes to the maximum flexural strength. J2-L3 has linen fabric only on the third layer, apart from the outermost layers. It is to be noted that the flexural strength of the composite is enhanced by the presence of linen fabrics, which have resulted in the maximum flexural strength value of 37.11 MPa in 16 vol% of linen (J0-L5) laminate.

The impact properties of the composites are squarely associated with the overall toughness of the composite materials [35]. The impact property of the fibre-based polymer matrix composites relies on the nature of the matrix, fibre and interfacial bonding between them [36]. In addition, the strength and structure of the individual fibre constituent are also largely responsible for the impact strength of the composites [37]. The impact energy of the NFSL composites is listed in table 2. The 8 vol% of jute and 8 vol% of linen (J2-L3) composite possesses the maximum impact energy of 8 J. The impact energy for 8 vol% of jute and 8 vol% of linen laminate composite is 85% higher than that of the 16 vol% of jute (J5-L0) laminate composite and 41% higher than that of the 16 vol% of linen (J0-L5) laminate composite. The variation in the impact energies of the different composites is depicted in figure 7.

3.1b *Fractographic analysis*: The SEM micrographs in figure 8a–c illustrate the distinct tension-fractured regions of the 8 vol% of jute and 8 vol% of linen (J2-L3) sandwich laminate composite. The micrographs very evidently point out that there is more breakage of fibres and a few voids present on account of fibre pull-out; this explains that there is enough interaction between the fibre and epoxy matrix, indicating a strong fibre/matrix bonding in the 8 vol% of jute and 8 vol% of linen composite [21,32]. The SEM micrographs in figure 9a and b give a picture of the morphology of the fractured surface of the 8 vol% of jute and 8 vol% of linen sandwich laminate composite after impact fracture. The impact testing of the NFSL composite has resulted in significant matrix debris and due to impact loading damage, its presence is found in all of the fracture micrographs [15].

3.2 *Thermogravimetric analysis*

As per TGA results of NFSL composites, the change in weights with respect to temperature is depicted in figure 10. The thermal stability of the composites is highly influenced by the onset temperature of degradation, where above this temperature, composites decompose and a mass loss begins

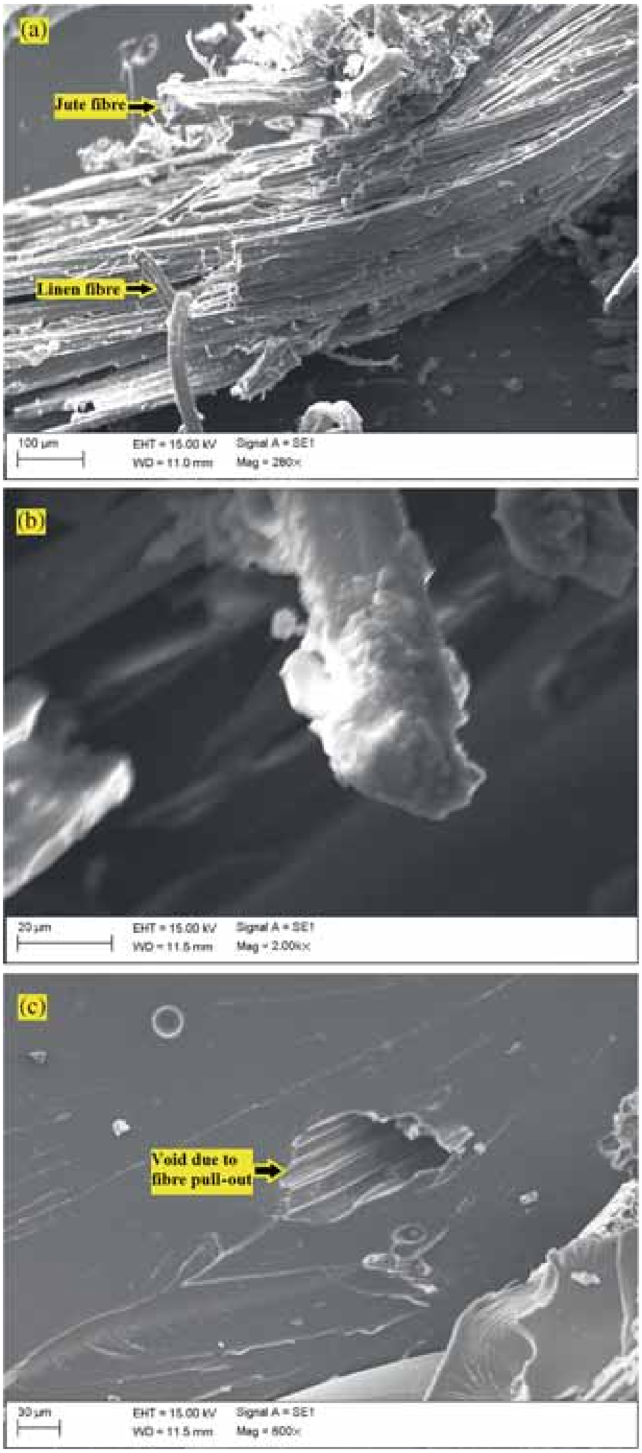

Figure 8. SEM micrographs of J2-L3 laminate composite after tensile test: (**a**) fractured surface, (**b**) fractured fibre and (**c**) void due to fibre pull-out.

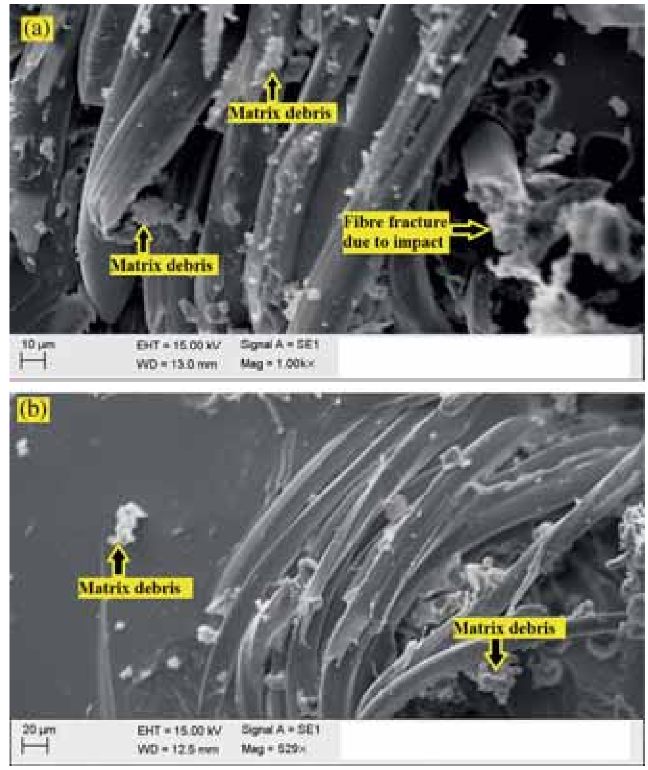

Figure 9. (**a** and **b**) SEM micrographs of fracture surface of J2-L3 laminate composite after impact test.

[9,38]. From the TGA result it is observed that the loss of water and moisture has led to initial weight loss [39]. The onset temperature of 16 vol% of jute (J5-L0) laminate composite is 248.7°C. When rise in temperature persists, the composite tends to lose its weight due to degradation and volatization of epoxy along with the fibres [32]. Up to 600°C the final residue of this composite remains stable. The onset temperature of 14 vol% of jute and 2 vol% of linen (J4-L1) laminate composite is 251°C and the final degradation occurs at 518.7°C. The onset temperature of 11 vol% of jute and 5 vol% of linen (J3-L2) laminate composite is 251.4°C and the final degradation occurs at 541.2°C. The onset temperature of 8 vol% of jute and 8 vol% of linen (J2-L3) laminate composite is 251.6°C and the final degradation occurs at 524.4°C. The onset temperature of 4 vol% of jute and 12 vol% of linen (J1-L4) laminate composite is 251.9°C and the final degradation occurs at 495.3°C. The onset temperature of 16 vol% of linen (J0-L5) laminate composite is 254.1°C and up to 600°C the final residue of this composite remains stable. As a result, the 16 vol% of linen (J0-L5) laminate composite is considered to be thermally stable for it possesses the highest onset temperature among the distinct NFSL composites.

3.3 *Water absorption characteristic*

The water absorption characteristic for each one of the six NFSL composites is calculated by weight increment for laminate immersed in water bath maintained at ambient temperature. The water absorption quantity dwindles as the linen volume fraction percentage increases in the NFSL composites. Figure 11 displays the trend in water absorption behaviour of all the six NFSL composites.

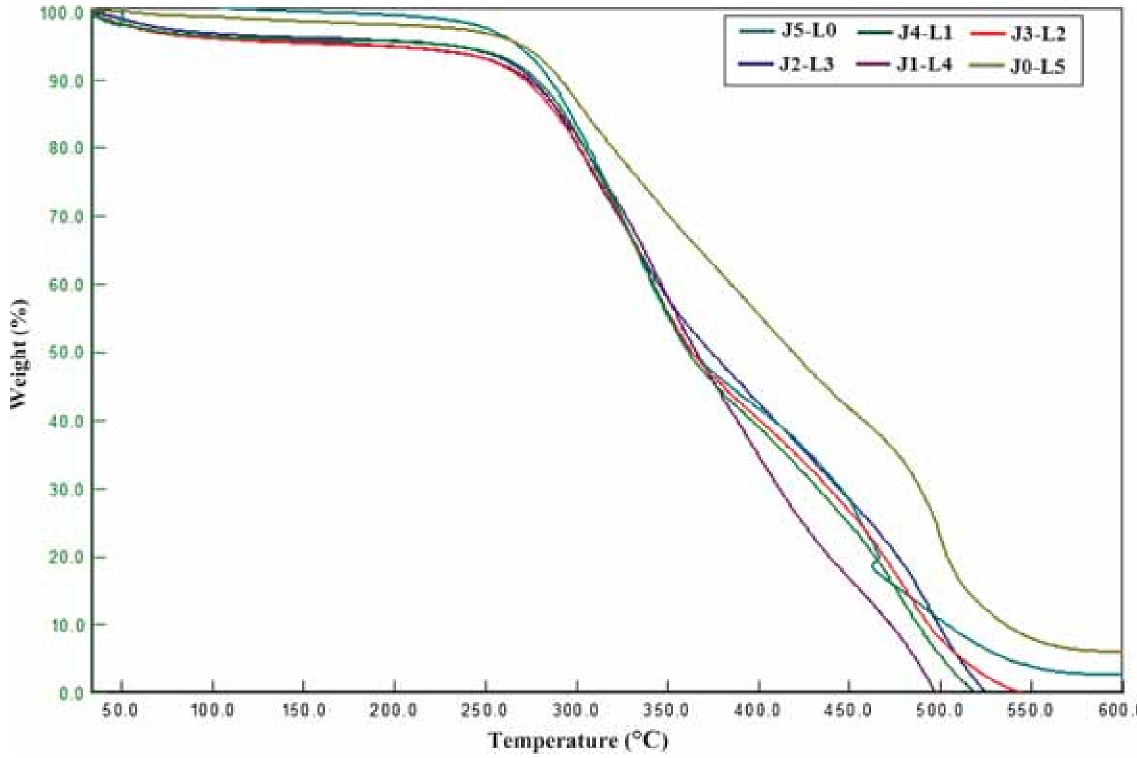

Figure 10. Thermogravimetric curves for NFSL composites.

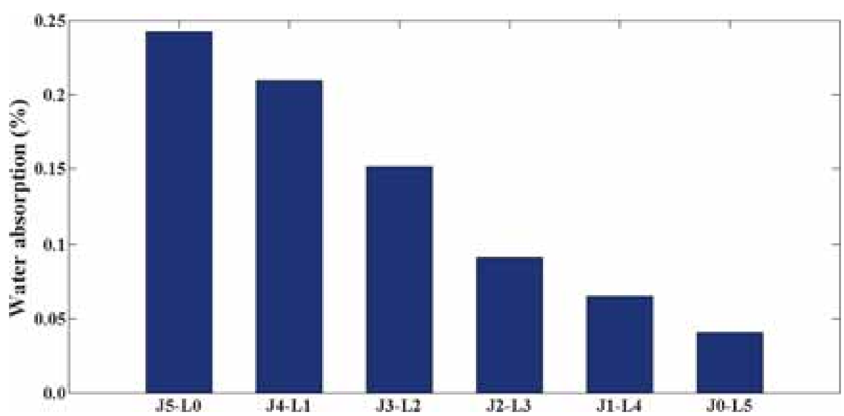

Figure 11. Water absorption characteristics of the NFSL composites.

4. Conclusions

An investigation regarding mechanical attributes, thermal stability and water absorption behaviour is conducted for eco-friendly NFSL composites made of jute- and linen-fabric-reinforced epoxy and the following conclusions are based on it:

- The sandwich laminate that has 8 vol% of jute and 8 vol% of linen (J2-L3) presents superior tensile property and great impact strength, an asset for engineering applications.
- The flexural strength of 16 vol% of linen (J0-L5) laminate is recognized as better than that of any other laminates and can be used in the automobile floor applications.
- In thermal study, 16 vol% of linen (J0-L5) laminate is found to be better than any other laminates, since the maximum onset temperature is observed in this laminate and from water absorption study it is ascertained that 16 vol% of linen (J0-L5) laminate has low water absorption quality; therefore this laminate can be used in the interior automobile panels where strength is not considered as a crucial factor.

References

[1] Shadrach Jeya Sekaran A, Palani Kumar K and Pitchandi K 2015 *Bull. Mater. Sci.* **38** 1183

[2] Nabi Saheb D and Jog J P 1999 *Adv. Polym. Technol.* **18** 351

[3] Hristozov D, Wroblewski L and Sadeghian P 2016 *Composites Part B* **95** 82

[4] Ahmad F, Choi H S and Park M K 2015 *Macromol. Mater. Eng.* **300** 10

[5] Rwawiire S, Tomkova B, Militky J, Jabbar A and Kale B M 2015 *Composites Part B* **81** 149

[6] Mangal R, Saxena N S, Sreekala M S, Thomas S and Singh K 2003 *Mater. Sci. Eng. A* **339** 281

[7] Yousif B F, Lau S T W and McWilliam S 2010 *Tribol. Int.* **43** 503

[8] Hadjadj A, Jbara O, Tara A, Gilliot M, Malek F, Maafi E M and Tighzert L 2016 *Compos. Struct.* **135** 217

[9] Anbukarasi K and Kalaiselvam S 2015 *Mater. Des.* **66** 321

[10] Ridzuan M J M, Abdul Majid M S, Afendi M, Aqmariah Kanafiah S N, Zahri J M and Gibson A G 2016 *Mater. Des.* **89** 839

[11] Garkhail S K, Heijenrath R W H and Peijs T 2000 *Appl. Compos. Mater.* **7** 351

[12] Pothan L A, Oommen Z and Thomas S 2003 *Compos. Sci. Technol.* **63** 283

[13] Joseph P V, Rabello M S, Mattoso L H C, Joseph K and Thomas S 2002 *Compos. Sci. Technol.* **62** 1357

[14] Keller A 2003 *Compos. Sci. Technol.* **63** 1307

[15] Harish S, Peter Michael D, Bensely A, Mohan Lal D and Rajadurai A 2009 *Mater. Charact.* **60** 44

[16] Debiprasad G, Kousik D, Palash P and Subhankar M 2012 *Int. J. Textile Sci.* **1** 84

[17] Gassan J and Bledzki A K 1999 *Compos. Sci. Technol.* **59** 1303

[18] Doan T-T-L, Brodowsky H and Mader E 2012 *Compos. Sci. Technol.* **72** 1160

[19] Santulli C, Sarasini F, Tirillò J, Valente T, Valente M, Caruso A P, Infantino M, Nisini E and Minak G 2013 *Mater. Des.* **50** 309

[20] Boopalan M, Umapathy M J and Jenyfer P 2012 *Silicon* **4** 145

[21] Braga R A and Magalhaes Jr P A A 2015 *Mater. Sci. Eng. C* **56** 269

[22] Porras A, Maranon A and Ashcroft I A 2016 *Composites Part A* **81** 105

[23] Sukmawan R, Takagi H and Nakagaito A N 2016 *Composites Part B* **84** 9

[24] Shibata S, Cao Y and Fukumoto I 2006 *Polym. Test* **25** 142

[25] Pothan L A, Mai Y W, Thomas S and Li R K Y 2008 *J. Reinf. Plast. Compos.* **27** 1847

[26] Jayaramudu J, Siva Mohan Reddy G, Varaprasad K, Sadiku E R, Ray S S and Varada Rajulu A 2014 *Fiber. Polym.* **15** 1462

[27] Kan C W, Yuen C W M, Lam Y L and Chan C K 2009 *Fiber. Polym.* **10** 325

[28] Huang G and Liyan L 2008 *Mater. Des.* **29** 1485

[29] Buchert J, Pere J, Johansson L S and Campbell J M 2001 *Textile Res. J.* **71** 626

[30] Yan L, Chouw N and Yuan X 2012 *J. Reinf. Plast. Compos.* **31** 425

[31] Guduri B R, Rajulu A V and Luyt A S 2006 *J. Appl. Polym. Sci.* **102** 1297

[32] Boopalan M, Niranjanaa M and Umapathy M J 2013 *Composites Part B* **51** 54

[33] Jawaid M, Abdul Khalil H P S and Abu Bakar A 2010 *Mater. Sci. Eng. A* **527** 7944

[34] Munikenche Gowda T, Naidu A C B and Chhaya R 1999 *Composites Part A* **30** 277

[35] Narendar R, Priya Dasan K and Nair M 2014 *Mater. Des.* **54** 644

[36] Rahman M R, Huque M M, Islam M N and Hasan M 2008 *Composites Part A* **39** 1739

[37] Alavudeen A, Rajini N, Karthikeyan S, Thiruchitrambalam M and Venkateshwaren N 2015 *Mater. Des.* **66** 246

[38] Milanese A C, Cioffi M O H and Voorwald H J C 2012 *Composites Part B* **43** 2843

[39] Narendar R and Priya Dasan K 2014 *Composites Part B* **56** 770