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Experimental evaluation on comparative mechanical properties of Jute – Flax fibre Reinforced composite structures

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Abstract. In the modern era, the world is facing unprecedented challenges in form of environmental pollution and international agencies are forcing scientists and materialists to look for green materials and structures to counter this problem. Composites based on renewable sources like plant based fibres, vegetable fibres are finding increasing use in interior components of automobile vehicles, aircraft, and building construction. In the present study, jute and flax fibre based composites were developed and tested for assessing their suitability for possible applications in interior cabin and parts of automobile and aerospace vehicles. Matrix system involves epoxy as resin and fibre weight fractions used were 45% and 55% respectively. Composites samples were prepared as per American society for testing and materials (ASTM) standard and were tested for individual fiber tensile strength, composite tensile strength, and flexural strength to analyse its behavior under various loading conditions. The results revealed that the Jute fibre composites possess enhanced mechanical properties over Flax fibre composites.

Keywords: composites; natural fibres; mechanical testing; Jute; flax; ASTM

1. Introduction

Natural fibres being renewable and environmental friendly in nature are attracting the focus of scientists, researchers, and materialists for their use in polymer composite reinforcements. There has been a dramatic increase in the usage of natural fibres such as fibre extracted from sisal, jute, coir, flax, hemp, and banana for making renewable and biodegradable composite materials. These natural fibres possess high /moderate strength, low density, recyclability, and thermal stability (Ramesh, Palanikumar, and Reddy 2013). Natural fibre composites being cost effective finds its application in interior parts of automobile vehicles, aircraft cabin, railway coach interiors, storage devices, building, and construction industry. Paulopecas *et al.* (Peças *et al.* 2018) have reported a detailed review article on natural fibre composites and their applications in industrial sectors. Bharath, K.N *et al*. (Bharath and Basavarajappa 2016) classified the various types of natural fibres and explored the applications of various natural fibres with a view of the various strength parameters. They also addressed need for emphasis on other criteria's such as environmental durability, embedded energy, fire resistance.

Gopinath, Senthil Kumar, and Elayaperumal (2014) reported an experimental study on mechanical properties of jute fibre reinforced composite and presented a detailed testing procedure to understand the behavior of composites under mechanical loadings. Effect of fibre length on mechanical properties of short jute fibre reinforced composite was presented by Himanshu *et al*. (Bisaria *et al.* 2015). In another study biswas *et al* reported investigation on physical and thermal properties of jute/ bamboo fibre reinforced unidirectional epoxy composites and have shown that jute reinforced composites shows enhanced physical and thermal stability over banana fibre composites (Biswas *et al*. 2015). Mohammad ali *et al* (Ali and Anjaneyulu 2018) studied the effect of fibre matrix volume fraction and fibre orientation on the design of flax fibre reinforced composite suspension system. Ravi Kumar *et al*. (Ravi Kumar and Hariharan 2019) presented a detailed experimental and microstructural evaluation on mechanical properties of natural fibre based biocomposites and indicated that natural fibre composites have potential to replace the glass fibre composites in specific applications.

Several other researchers (Cunedioglu and Beylergil 2014; Ray and Majumder 2014; Gurunathan, Mohanty, and Nayak 2015; Alizadeha and Dehestani 2015; Murthy, Aravindan, and Ganesh 2018) have reported the studies on potential application of natural fibre based composites as a viable replacement to the current man made synthetic fibres in structural sectors. Effect of stacking sequence of the bonded composite patch on repair performance was reported by Beloufa *et al*. They used 3D finite element analysis to understand mode-I and mode-II crack propagation in composites and shown that CRPF composite patches enhance the structural performance of the structure and prevent crack growth (Beloufa *et al*. 2016). Flexural behavior of reinforced concrete beam with carbon fibre reinforced polymer (CFRP) beam was investigated by Jiong et.al (Jiong-Feng Liang, Deng Yu 2017). They used four points bending test on composites samples. Results indicated that the behavior of reinforced concrete beams strengthen with near-surface mounted (NSM) carbon fiber-reinforced polymer (CFRP) pre stressed prisms enhanced

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Fig. 1 (a) Jute fibre. (b) Flax fibre

(i) JFRC (ii) Hand layup Mould (iii) FFRC

Fig. 2 (i) Jute fibre reinforced composite plate,(ii) Mould box, (iii) Flax fibre reinforced composite plate

the load carrying capacity. (Rajesh and Prasad 2013) studied the effect of fibre loading and alkali treatments on tensile properties of short jute fibre reinforced composite. Alves *et al* (Alves *et al*. 2009) reported study on the usage of natural fibre composites in ecodesign of automotive components and addressed the effects of factors affecting the performance of the composite components.

In the present study, the mechanical properties of jute and flax fibre reinforced epoxy composites are evaluated. Green composites are designed using hand lay-up technique and the properties such as tensile, flexural, and compression strengths are assessed to look for possible applications of these composites in structural Industry.

2. Material and experimental methods

2.1 Material selection

Fibres selected for composites fabrication are plant based fibres, i.e., jute and flax due to their low cost and rapid growth over a wide range of climatic conditions. Polymer used as matrix material is epoxy (LY556) and Araldite hardner (HY 951). Figure 1 (a) and Figure 1(b) show the chemically treated jute and flax fibre woven mats supplied by Go green Pvt. Industries Chennai.

2.2 Fabrication of composite

Hand layup technique is the most economical method and is used for the fabrication of Jute /epoxy and Flax /epoxy composite plates. Epoxy and a suitable hardener were mixed in the ratio of 10:1. The mixture was loaded inside a square mould box of dimensions 300 mm x 300 mm x 6 mm. Fibres were laminated using stacking sequence of [45/0] and are placed inside the mould box. Plates with fibre weight fraction of 45% and 55% were fabricated. Curing was carried out under a load of 50kg at atmospheric temperature.

Figure 2 shows the fabrication process and fabricated composite plates.

2.3 Samples preparation

Samples were prepared for different testings from the developed composites as per ASTM standards.

2.3.1 Individual fibre tensile testing

Individual fibres were tested as per ASTM D 3822 to assess their tensile strengths before reinforcing them into the polymer matrix. Twenty fibres of uniform diameters and 30 cm length were selected and tested on 10 kN universal tensile testing machine.

2.3.2 Tensile testing

The tensile test specimens were prepared according to ASTM D3039; the most common specimen for ASTM D3039 has a constant rectangular cross section, 50 mm wide and 200 mm long.

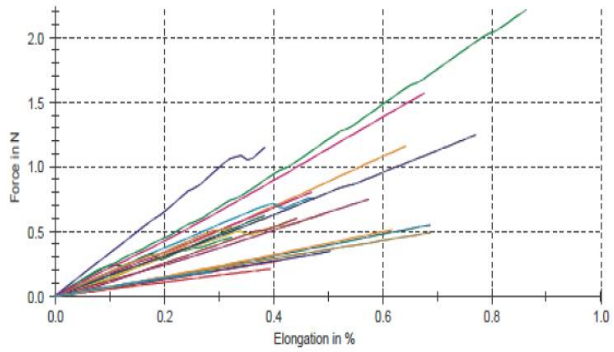

Fig. 3 Force vs strain for Jute individual fibre

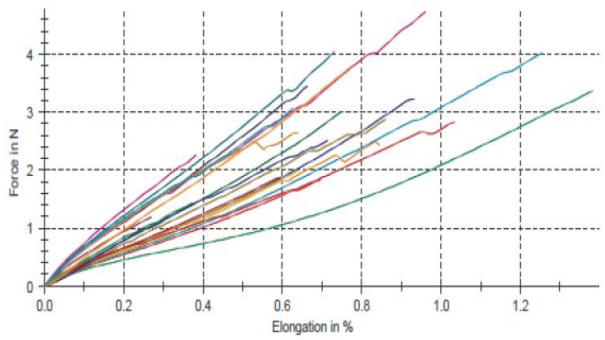

Fig. 4 Force vs strain for Flax individual fibre

2.3.3 Flexural testing

Flexural test was carried out by employing the three-point bending method according to ASTM D790. This test was conducted to study the behaviour and stability of material under bending load. Sample dimensions for flexural test were 120mm x 12mm x 6mm.

3. Results and discussion

3.1 Individual fibre testing

Twenty fibres of uniform length and diameters were selected and tested for tensile strength as per ASTM D 3822 standard. Individual fibres were subjected to tensile load in Universal tensile testing machine with grip to grip separation at the start position as 75 mm. Loading step was taken at the speed of 10 mm/min.

It is observed from figure 3 that the maximum elongation of individual jute fiber is about 0.85% and the average elongation of the individual fibre is found out to be 0.52%.The maximum tensile force that the single jute fiber can withstand is 2.2 N and the average tensile force that the single jute fiber could withstand is 0.75 N.

Figure 4 shows the tensile results for individual flax fibres, the maximum elongation of individual hemp fiber is observed about 1.3% and the average elongation of the individual fibers is found out to be 0.76 %. The maximum and average tensile force that a single flax fiber could withstand is 4.5 N and 2.83 N respectively.

Results indicate that on raw form flax fibres can withstand high tensile force as compared to jute fibres when subjected to the same tensile loadings.

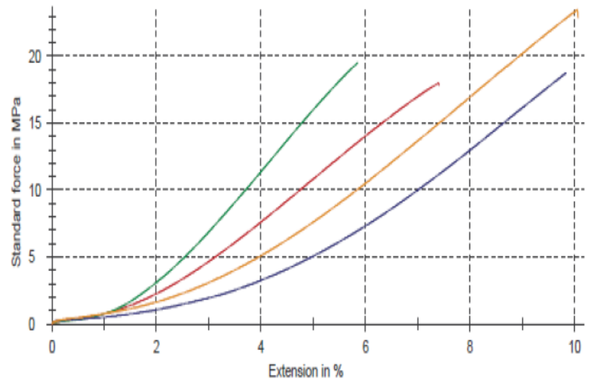

Fig. 5 (a) Stress vs strain for 45 % JFRC

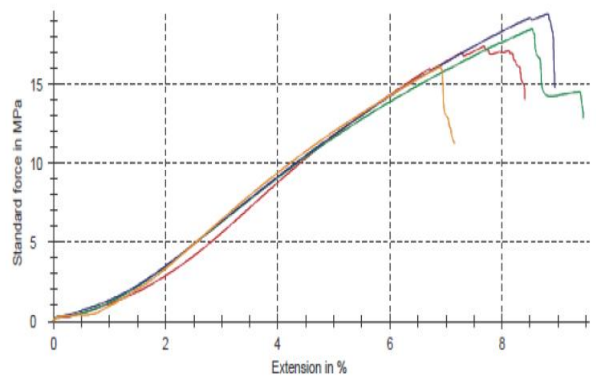

Fig. 5 (b) Stress vs strain for 45 % FFRC

3.2 Composite tensile testing

Both the composite's cut samples were tested for finding out their tensile strengths using 10 kN universal tensile testing machine as per ASTM D3039. Four samples for both jute fibre composite (JFRC) and Flax fibre composite (FFRC) were tested as per ASTM standards. Figure 5 (a) and (b) shows the variation of stress with strain for composites with fibre weight percentage of 45%.

Figure 5 (a) shows the variation of tensile stress of jute fibre composite (JFRC) with fiber weight fraction of 45%, it is clear that average tensile strength of composite is 19.9 MPa with an extension of 8.3 %. Figure 5(b) presents the stress variation with strain for flax fibre composite (FFRC). It is evident that maximum tensile strength is observed as 19.4 MPa with an extension of 8.9%. The average tensile strength observed to be 17.8 Mpa with a standard deviation of 1.45 MPa and the average elongation is found to be 8.5% with standard deviation of 1.0%. From results it is clear that jute fibre reinforced composites have shown an improved tensile strength over flax reinforced composites. Results have shown a promising agreement with the tensile results reported by Ajith et.al and Ramesh *et al* (Gopinath, Senthil Kumar, and Elayaperumal 2014; Ramesh, Palanikumar, and Reddy 2013).

Figure 6 (a) shows the variation of tensile stress of jute fibre composite (JFRC) with fiber weight fraction of 55% and Figure 6(b) presents the stress variation with strain for flax fibre composite (FFRC) with fibre weight fraction of 55%. It is evident that as the fibre content increases the tensile strength also increases.

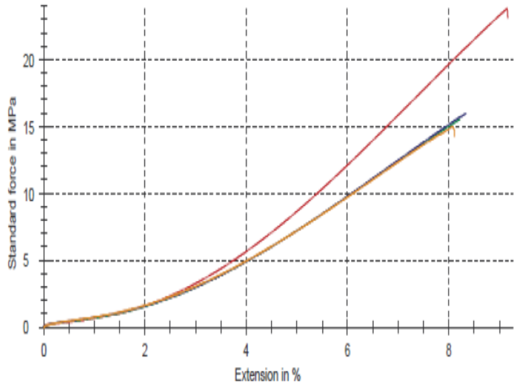

Fig. 6 (a) Stress vs strain for 55 % JFRC

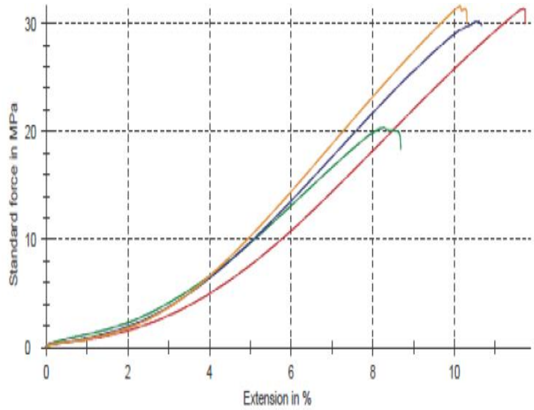

Fig. 6 (b) Stress vs strain for 55 % FFRC

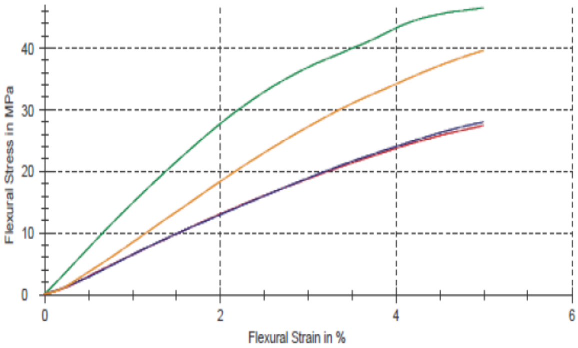

Fig. 7 (a) Flexural stress vs strain for 45 % JFRC

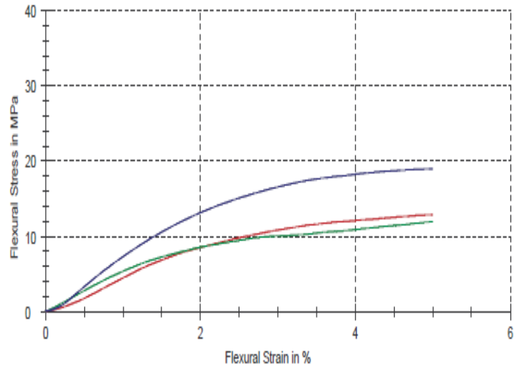

Fig. 7 (b) Stress vs strain for 45 % FFRC

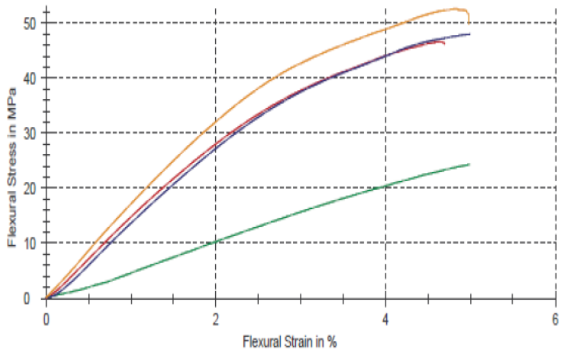

Fig. 8 (a) Flexural stress vs strain for 55 % JFRC

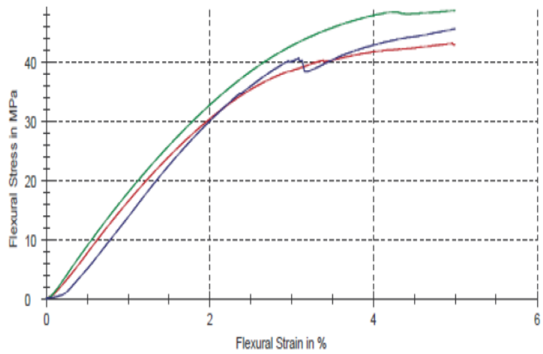

Fig. 8 (b) Flexural stress vs strain for 55 % FFRC

Table 1 Validation of the results

		Tensile strength (MPa)		Flexural strength(MPa)		Flexural modulus (GPa)	
Fiber weight fraction		45%	55%	45%	55%	45%	55%
Present	JFRC	20	24	35.4	43	0.76	1.1
Kaushik *et al*	JFRC	28	32	34	46	0.9	1.4
Elbadry *et al*	JFRC	30	-	36	-	0.8	-
Present	FFRC	17.8	28.4	14.6	43.5	0.43	1.25
Elbadry *et al*	FFRC	22	-	18	-	0.45	-

3.3 Flexural Test

The flexural test was conducted on both the composites specimens as per ASTM D790 standard. The test specimen was placed horizontally onto the three points of contact and then a force was applied on the top of the specimen through one point until the specimen fails.

Figure 7(a) shows the variation of flexural stress with strain for jute fibre composite (JFRC). Four samples were tested and it is observed that maximum bending stress found to be 46.5 MPa, with a maximum radius of curvature at 5%. The average bending stress is found to be 35.4 MPa with standard deviation of 9.3 MPa and average radius of curvature is 5 %. Figure 7(b) presents the bending stress variation with strain for flax fibre composite (FFRC). The average bending strength observed is 14.6 Mpa with a standard deviation of 3.83 MPa and the average radius of

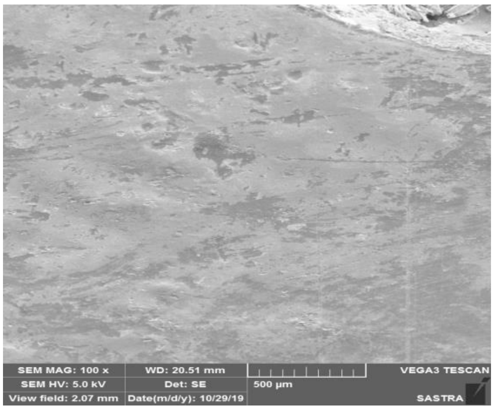

Fig. 9(a) SEM image of JFRC

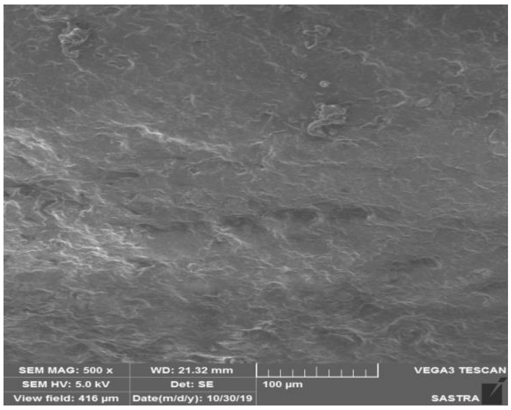

Fig. 9(b) SEM image of FFRC

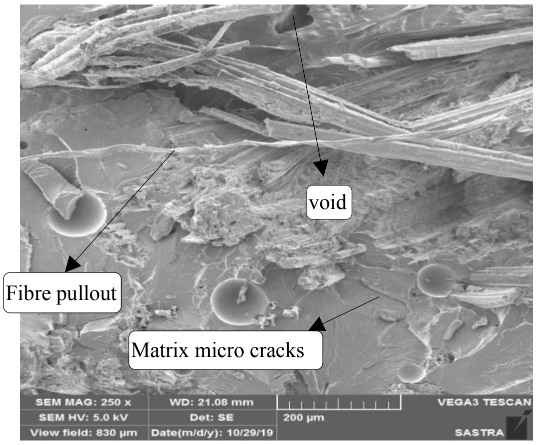

Fig. 10(a) SEM image of tensile test fractured surface of JFRC

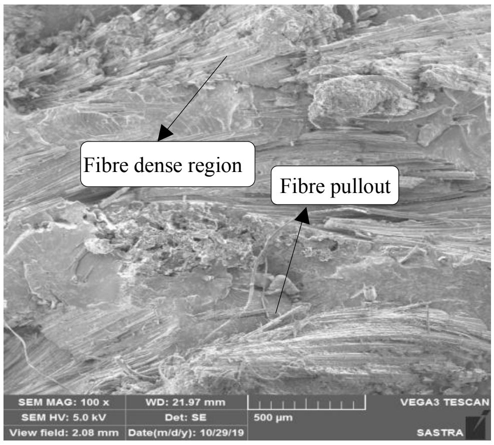

Fig. 10(b) SEM image of tensile test fractured surface of FFRC

curvature is found to be 5 %. From results it is clear that jute fibre composites have shown better flexural strength over flax fibre composites.

Figure 8 (a) shows the variation of flexural stress of jute fibre composite (JFRC) with fiber weight fraction of 55% and Figure 8(b) presents the flexural stress variation with strain for flax fibre composite (FFRC) with fibre weight fraction of 55%. It is evident that as the fibre content increases the tensile strength also increases. For high fibre content flax fibre composite shows equivalent flexural strength to jute fibre composite.

From Table 1 shows the validation of the results and it is clear that the results have shown a promissing agreement with the study carried out by Kaushik *et al* (Kaushik, Jaivir, and Mittal 2017) and Elbadry *et al* (Elbadry, Aly-Hassan, and Hamada 2012).

3.4 Micro-structural study of fractured surface

The surface morphology of the composite structure is studied through scanning electron microscopy (SEM). SEM images of the samples before and after the testing were taken to understand the behavior of composites under the influence of loads. All the specimens were coated with conducting material before taking the images. Figure 9 (a) and Figure 9(b) shows the surface morphology before fracture for jute fibre composite (JFRC) and flax fibre composite (FFRC). There is no visible sign of voids or micro cracks in the matrix and between matrix and fibre interface in the samples.

Figure 10(a) shows the scanning electron micrograph of tensile test fractured surface of JFRC, there is no visible sign of fibre breakage of fibre-matrix delamination. Figure 10(b) shows the scanning elctron microscopy image of fractured surface on FFRC, in this case there is no obserable void and delamination.

4. Conclusion

In this study, Jute-epoxy, Flax –epoxy composites were developed and tested for individual fibre testing, tensile, and flexural test to assess their suitability for possible application in interior of aircraft and automobile vehicles.

Based on the results, the following conclusions are drawn:

- Individual jute fibre in raw form can sustain higher tensile force over flax fibre under the same loading condition.
- Jute fibre composites have shown better tensile and flexural properties as compared to flax fibre composites.
- As the fibre content increases both the tensile and flexural strength also increases. In high fibre content region flax fibre composites have shown equivalent flexural strength.

- Scanning electron microscopy revealed that there is no visible sign of fibre-matrix crazing and delamination in both the composites.

The analysis presented in this research work would be helpful in further exploring the cultivability with improved mechanical properties, and sustainability of natural fibre based composites in industrial, domestic and structural applications.

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