Experimental investigation on mechanical and vibration characteristics of Flax/CNSL composite laminates

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Abstract. Natural fiber reinforced composite materials are most increasingly used as sustainable structures in engineering industries due to their vast availability and eco-friendly nature. In this regard, an emphasis is given in the present work to the use of natural fiber in structural composite material in place of synthetic fibers for structural applications. In the present study, the mechanical properties and free vibration characteristics of a pure green composite laminate were experimentally evaluated. For complete understanding of the behaviour of green composite material, a second laminate is prepared using synthetic resin. Two types of composite laminates were fabricated by hand layup method. In the pure green laminate, natural flax fiber is embedded in cashew nut shell liquid (CNSL) resin and for the second laminate epoxy resin is used as matrix. The flax fiber is preferred due to its high mechanical strength among all the natural fibers. Alkaline treatment is done for the natural flax fiber before fabrication to remove impurities and also improve the surface adhesion. Both the laminates were tested for mechanical properties and free vibration characteristics according to ASTM standards. The experimentally evaluated tensile, flexural properties and modal frequency values of two types of laminates are reported and discussed.

1. Introduction
Fiber-reinforced polymeric (FRP) composite materials are now commonly used in aircraft, automotive and machine tool structures due to their inherent property of high strength/stiffness to weight ratio [1]. However the composite structures used in the above applications are experiencing considerable mechanical vibration during their service. Hence, understanding and evaluation of the free vibration characteristics of these composite structures becomes more important. Increase in demand for environment friendly materials promotes the natural fibers and resins in place of synthetic fibers like glass and carbon and epoxy resin used in FRP composite structures [2]. Cashew nut shell liquid (CNSL) is one of the most promising natural biopolymers which has been extensively used in the application of composite material. Flax fibre reinforced polymer composites have attracted much attention from manufacturers of FRP materials due to its better mechanical strength among natural fibers [3]. The main
objective of this study is the usage of the natural fiber and bio-resin for making FRP laminates in place of synthetic counterparts and thereby promoting environment friendly material. In addition, green composites made of natural fiber embedded in bio-resins are also preferable for commercial applications [4–8].

Many studies have been carried out in the recent past on evaluation of the mechanical properties of FRP materials made of flax fibers with synthetic resin. Nonetheless the study on evaluating mechanical properties of flax fiber embedded in bio-resin matrix is very minimal. Nisini et al [9] evaluated the mechanical and impact properties of hybrid composite laminates made of carbon, basalt and flax fibers and the authors found that the intercalation of basalt with flax fibers between carbon fiber is beneficial for flexural and inter-laminar strength. Cihan et al [10] studied the static and dynamic properties of woven flax/glass hybrid composites and they observed that hybridization of flax with glass fibres increases the damping property. Cristiano Fragassa et al [11] experimentally investigated the mechanical and impact properties of vinyl ester based flax/basalt hybrid composite laminates and they reported that basalt/flax fibre hybrid laminates having basalt fibres as outer layers offered a good performance. Adrien Couture et al [12] evaluated the mechanical properties of composites made of flax fiber reinforced in polylactic acid resin and they revealed that high impact strength could be achieved for unidirectional flax-paper reinforced composites compared to unreinforced polylactic acid resin.

The structural stability of the natural composite materials used in various applications may be evaluated through vibration and damping analysis. In the recent years, many researchers have contributed towards the evaluation of vibrational characteristics of natural fiber reinforced polymer composite materials through experimental modal analysis. Yashwant S Munde et al [13] reviewed the vibration damping properties of natural fiber-reinforced composites evaluated by experimental and numerical methods. F. Duc et al [14] revealed the mechanical and damping properties of unidirectional and 2/2 twill flax fibre reinforced with thermoset, thermoplastic and polylactic acid composites. They found that the composites reinforced with flax fiber showed improved damping with respect to composites reinforced with synthetic glass and carbon fiber. Libo Yan [15] investigated the effect of fiber surface treatment with 5 wt. % NaOH solution on mechanical and vibration characteristics of flax and linen fiber reinforced composites. The author found that alkali treatment of natural fibers enhanced the mechanical properties like compressive strength, in-plane shear strength and specific impact strength of both flax/epoxy and linen/epoxy composites. The present work emphasizes the use of natural fiber and natural matrix in fabrication of FRP composite in lieu of synthetic fiber and resin. Flax natural fiber is preferred due to its high mechanical properties among natural fibers. Mechanical properties and free vibration characteristics of flax fabric reinforced with CNSL resin and epoxy resin composite laminates were evaluated experimentally and the results were discussed.

2. Fabrication of flax fiber reinforced composite laminates

Flax fiber is chosen as the reinforcement since it has higher mechanical strength among all the natural fibers. The 12 layers of flax fabric with size of 300x300 mm were procured, out of which 6 layers were used for flax/epoxy (NS) laminate, and remaining 6 layers were used for flax/CNSL (NN) composite laminate. Both the composite laminates were fabricated by hand layup method [16]. The natural flax fiber was alkali treated in 5% of NaOH solution before fabrication to improve its surface properties. The fiber volume fraction for both NN and NS laminates is preferred as 0.2.

The NS type composite laminate was prepared using epoxy resin (LY556) premixed with HY951 hardener in 10:1 ratio by volume as matrix. Once the fibers are stacked the pressure is applied over the stock for 24 hours and post cured in an oven at 60°C for 1 hour. The NN type composite laminate was prepared with CNSL resin matrix. Formaldehyde is used as catalyst for CNSL resin in the 4:1 ratio while preparing NN laminate. After arranging all the layers of flax fibers by hand layup method, it was cured in an industrial oven for 125°C for about 6-8 hours. Figure 1 shows the image of the two types of flax fiber reinforced composite laminates, NS and NN, fabricated by hand layup method. Table 1 shows the symbol, specimen description, dimensions and photographs of the two types of composite laminates prepared by hand layup method.
Table 1. Symbol, specimen description, dimensions and mass density of two types of composite laminates prepared by hand layup method

| Symbol | Specimen description       | Dimensions (mm) | Mass Density Kg/m³ |
|--------|----------------------------|-----------------|-------------------|
| NS     | 6 layered Flax/Epoxy laminate | 250 x 250 x 2.7 | 1324              |
| NN     | 6 layered Flax/CNSL laminate | 250 x 250 x 2.0 | 929               |

3. Evaluation of mechanical properties of flax fiber reinforced composite laminates

The tensile properties of two types flax fiber composite laminates are evaluated as per ASTM D3039 standard [17]. Composite specimens were cut from the cured composite laminates according to ASTM standard for tensile test as shown in Figure 2. The standard size of the tensile test specimen is 250 mm × 25 mm × t mm where t is the thickness of the specimen. The tensile tests were conducted on INSTRON 3382® universal testing machine with the cross-head speed of 5 mm/min and the results were reported.

ASTM D 790 standard test method is used for evaluating the flexural properties of flax fiber reinforced composite samples [18]. This method includes provisions for measuring maximum flexural strength, and flexural modulus. The standard dimensions of the flexural test specimen are 127 mm × 12.5 mm × t mm where t is the thickness of the specimen. Figure 3 shows the standard size specimen of NS and NN laminates cut for flexural test. The flexural tests of composite samples were conducted on SHIMAD2U-AUTOGRAPH® testing machine with uniform feed rate of 1.2 mm/min.

4. Free vibration study of flax fiber reinforced composite laminates

Figure 4 shows the schematic diagram of experimental setup used for free vibration study [19]. Impulse excitation technique is used for vibration measurement of composite samples. The completely cured
natural composite laminates were cut into the standard size of 250 mm x 25 mm x t mm where t is the corresponding thickness of the composite specimen. Modal analysis of the flax fiber reinforced composite specimen is carried out in cantilever end condition. A three-dimensional accelerometer (B&K Type 3273A2) is attached at the free end of the specimen to measure the vibration response due to the given excitation. Impact hammer with force transducer (B&K Type 5800B4) is used for exciting the specimen near the fixed end. The vibration response captured by the accelerometer and the excitation force applied to the specimen are amplified by the signal analyser and forwarded to the computer system having FFT analyser (RT Pro software). In the post processing, the frequency response function (FRF) plot for the two types of laminates considered were plotted using FFT analyser [20].

![Figure 3. Photographs showing the standard flexural test specimen of NS and NS laminates](image)

![Figure 4. Schematic diagram of experimental setup for free vibration test](image)

5. Results and discussion

5.1. Tensile Strength
The two types of flax fiber reinforced composite laminates NS and NN were fabricated by hand layup method. Tensile tests were conducted on universal testing machine to evaluate tensile strength and modulus. Comparison of the stress-strain plots of the two different laminates preferred is shown in Figure 5. It is observed from Figure 5 that the NS laminate has high tensile stress as expected. Also NN laminate possesses considerable tensile stress compared with the counterpart which is beneficial for structural applications. During tensile test, both NS and NN composite laminates are equally loaded axially, but the variation in axial strain between the two different types of matrix caused the variation in the tensile strength. The natural CNSL resin offers less tensile strength than the synthetic epoxy resin. Table 2 shows the tensile stress and modulus values evaluated experimentally for the two types of flax fiber reinforced composite laminates considered. The NS laminate has tensile strength of 75.343 MPa and the corresponding value for the NN laminate is 27.23 MPa which is around 40% of NS laminate.
Figure 5. Comparison of Stress-Strain Graph for NN and NS laminates

Table 2. Comparison of Tensile Strength and Modulus of NS and NN Laminates

| Specification | Tensile Stress (MPa) | Tensile Modulus (GPa) |
|---------------|----------------------|-----------------------|
| NS            | 75.34                | 4.14                  |
| NN            | 27.23                | 1.91                  |

5.2. Flexural Strength

The load-deflection curves under flexural test of the two different flax fiber reinforced composite laminates, NN and NS are shown in figure 6. Flexural property of a FRP composite laminate is largely controlled by the strength of peripheral layer of laminate which is in direct contact to bending load [21]. The ample variation in the trend of flexural plots of NN and NS laminates shown in figure 6 confirms that the nature of matrix controls the flexural property. Table 3 shows the comparison of flexural strength and modulus of two types of flax fiber reinforced composites laminates, NN and NS. From Table 3 it was observed that there is considerable variation in flexural strength of NN and NS composite laminates. Among the NN and NS samples, NS laminate has high flexural strength than NN composite laminate. This increased flexural strength of NS laminate is because the laminate with synthetic matrix provides more resistance to flexural loading than the natural resin matrix. The weaker bonding strength between flax fiber and the CNSL matrix than that of the fax fiber and epoxy matrix may also cause the variation in mechanical properties. The NS composite laminate has flexural strength of 106.55 MPa and the corresponding values for the NN laminate is 41.07 MPa that is around 40% of NS laminate.

From the experimentally evaluated results, it is revealed that the NN laminate has about 40% of tensile and flexural strength of NS laminate which is beneficial for structural applications. Further the mechanical strength of NN laminate can be sufficiently increased by the addition of filler materials as proposed by S. Prakash et al [22].

5.3. Free Vibration Characteristics

Free vibrational characteristics of the NN and NS composite specimens were evaluated by impulse excitation technique and the FRF plots are shown in Figure 7. Vibrational properties like modal frequencies are investigated based on the FRF plot obtained experimentally. From Table 4, it is evident that the modal frequency values of the NS laminate are comparatively higher than NN laminate in all three successive modes. The resonant frequency set attained for NS laminate shows higher range than NN laminate for all modes because the modulus of epoxy resin is higher than modulus of CNSL resin. It reveals that the two different matrix composition of epoxy and CNSL resin reinforced by flax fiber
layers influences significantly its vibration characteristics. NN composite laminate has about 70% modal frequency values of NS laminate at successive modes which is beneficial for structural applications.

![Figure 6. Comparison of Stress-Strain Graph for NN and NS laminates](image)

**Table 3.** Comparison of Flexural Strength and Modulus of NS and NN Laminates

| Specification | Flexural Stress (MPa) | Flexural Modulus (GPa) |
|---------------|-----------------------|------------------------|
| NS            | 106.55                | 4.319                  |
| NN            | 41.07                 | 2.989                  |

![Figure 7. Comparison of FRF Plots of NS and NN Laminates](image)

**Table 4.** Comparison of Modal Frequency Values of NS and NS Laminates

| Sample | Mode I | Mode II | Mode III |
|--------|--------|---------|----------|
| NS     | 13     | 89      | 211      |
| NN     | 10     | 60      | 145      |
6. Conclusions

Mechanical and vibration characteristics of flax fiber reinforced composite laminates with two different matrices such as epoxy and CNSL resin were evaluated experimentally. The influence of two different matrices on the mechanical properties was investigated for six layered composite laminates. The experimental results showed that flax/CNSL laminate (NN) is having about 40% of tensile and flexural strength of flax/epoxy laminate (NS). The NS composite laminate has increased mechanical properties than NN composite laminate because the synthetic epoxy resin matrix has higher bonding strength than natural CNSL resin.

From the free vibration study, the modal frequency values of NS and NN laminates are evaluated. It is observed that the modal frequency values of NS laminate is considerably higher than NN laminate in all three successive modes. This characteristic behaviour is due to the higher modulus of the epoxy matrix than CNSL matrix. The experimental results showed that Flax/CNSL composite having nearly 50% of mechanical properties and 70% of dynamic stiffness could be a viable alternate for Flax/Epoxy laminate.

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