Characterization of the Mechanical and Vibration Behavior of Flax Composites with an Interleaved Natural Viscoelastic Layer

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Abstract. This study presents an analysis of the mechanical and vibration behavior of a flax fibre reinforced composites with and without an interleaved natural viscoelastic layer. Two types of elastic and viscoelastic cross ply laminates $[0_2/90_2]_s$ and $[0_2/90_2/NR]_s$ have been characterized experimentally using different mechanical and vibrational tests. The elastic laminate is composed of natural long flax fibre and greenpoxy resin while the viscoelastic laminate is composed of a natural viscoelastic layer and two elastic composites. First, both types of specimen composites were studied using uni-axial tensile tests under the same conditions. A comparison between the two composites behaviors has been realized. Then, Acoustic Emission (AE) has been often used for the identification and characterization of micro failure mechanisms and damage in laminates. Finally, experimental vibration analyses were carried out on the composites with and without an interleaved natural viscoelastic layer. Throughout a series of resonance vibration tests, the evolution of the Young modulus and the modal damping were evaluated. The effect of the viscoelastic layer on the mechanical and vibration behavior of the elastic composite has been investigated and analyzed. It has been shown that the viscoelastic layer improves with a significant way the modal properties of the flax fibre reinforced composite.

1 Introduction

Composite materials are increasingly used in various fields of application. Nowadays, the interest of environmental and ecological concerns in recent years has led to the development of biosourced composites. These types of materials have good mechanical performances sometimes better than those of synthetic fibre reinforced composites [1]. Several researchers of natural fibres have been studied [1–4]. Their results showed that these materials have many advantages such as their low density, their biodegradability and their relatively high specific mechanical properties. Hemp and Flax composites are the most studied in the two last decades [5]. Knowing that France is the first producer

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of flax, this type of natural fibre has been chosen to be investigated in this present work. Many researchers have studied the vibration behavior of flax composites [1, 3, 6]. They demonstrate that they possess very high modal properties.

However, the ability of viscoelastic materials to dissipate energy makes this type of material a good element in many areas of the industry. Thus, several works are interested in increasing the damping of composite structures by the insertion of viscoelastic layers on their materials [6, 7].

The aim of this study is to analyse the mechanical and vibration behavior of a flax fibre reinforced composites with and without an interleaved viscoelastic layer made of natural rubber (NR). Two types of elastic and viscoelastic cross ply laminates $[0_2/90_2]_s$ and $[0_2/90_2/NR]_s$) were studied.

Quasi static tensile loading was realized on the two types of composites. Moreover, the tests were monitored by acoustic Emission analysis (AE). This study has often been used for the identification and characterization of damage modes on classical composites [8] as well as on natural fibre composites [4]. The data obtained was processed and classified with NOESIS software [9]. The ‘K-means’ algorithm was used for unsupervised model recognition. This study make it possible to identify and characterize the various mechanisms of damage that occurred during the tests. Finally, the modal properties of the composites were also investigated and the effect of the insertion of the viscoelastic layer on the laminate was studied.

2 Implementation of the Composite

2.1 Materials Used

The materials considered in this study are elastic and viscoelastic laminated materials. The elastic composite laminates are composed of natural long flax fibres trated and manufactured by LINEO [2] and greenpoxy resin ‘SR GreenPoxy 56’ produced by Sicomin, while the viscoelastic composite laminates are composed of a viscoelastic layer of natural rubber confined between two elastic composites. The obtained laminates $[0_2/90_2]_s$ and $[0_2/90_2/NR]_s$ were tested with quasi static tensile loading and vibrational tests.

2.2 Method of Implementing the Composite

The laminate materials used in this study were made by vacuum molding process. The procedure consists in producing laminates by alternately laying layers of long flax fibres and layers of liquid resin. Different demolding fabrics are interposed on both sides between the molds and the composite in order to facilitate the demolding, and to ensure the homogeneity of the absorption of the resin. Then, the obtained laminates were introduced into a vacuum bag of 0.6 bar for at least 6 h until the total polymerization of the matrix. Hence, they could be demolded after 24 h.

The laminated sheets were manufactured with 8 fibre’s layers so as to obtain a total nominal thickness of 4 mm for the elastic composites and 5 mm for the viscoelastic one. The volume fraction was estimated between 38% and 45% for all the specimens.

The porosity in the material was calculated by comparing the measured density of the composite and its theoretical one calculated from the fibre volume fraction and that of the matrix. It has been estimated between 3 and 10%.

3 Study of the Tensile Behavior of the Composite

3.1 Experimental Setup

Axial tensile tests were performed on cross ply laminates $[0_2/90_2]_s$ and $[0_2/90_2/NR]_s$. The tests were carried out on specimens with the dimensions 250 × 25 × 4 mm^3 for the elastic composites and 250 × 25 × 5 mm^3 for the vicoelastic ones according to ASTM standard test standard D3039/D3039M. The specimens have been tested using a standard MTS hydraulic traction machine with a capacity of ±100 KN.

Figure 1 presents the results of the stress/strain curves for the elastic and viscoelastic laminates. The obtained results show that the evolution of the stress as a function of the strain present two phases separated by a bend. The first one is a short linear elastic domain and the second one presents a non linear part until break. The point of inflection is very visible on the curves; it occurs for a very low level of deformation (0.1%) and causes a significant loss of rigidity. This non linear behavior is very different from the one of synthetic fibres reinforced composites, It was also observed in the study conducted in the laboratory by Monti et al. for Lin/Helium composites [4]. Thus, the obtained non-linearity could be attributed to the intrinsic behavior of natural flax fibre and more specifically to the behavior of lignin and amorphous cellulose fibre due to shear stresses in the cell walls.

The comparison between the two types of laminated composites show that the first part of the stress/strain curves is identical for both types. Then, the breakage of the viscoelastic composites is obtained at very low strain level comparing with the breakage of the elastic specimens. In fact, the characteristics at break of the elastic

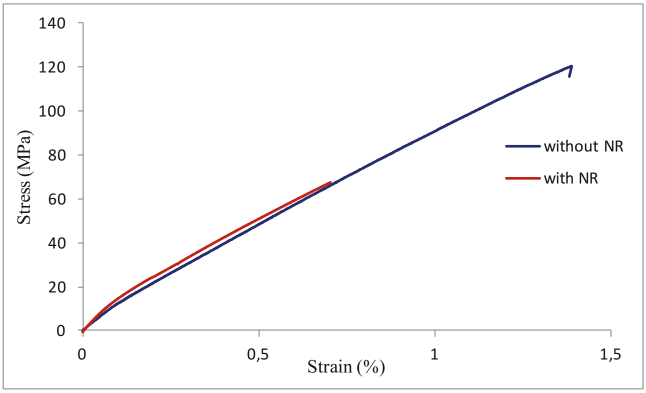


Fig. 1. Typical stress/strain curves of elastic and viscoelastic laminates

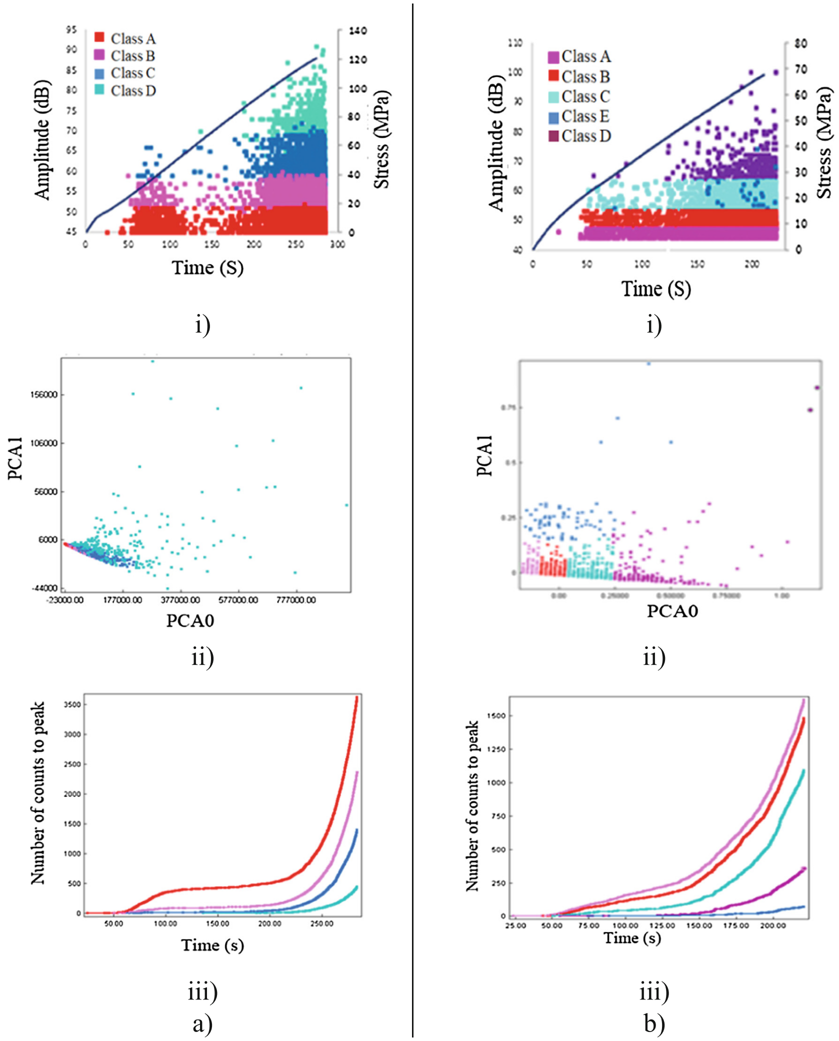
laminate is almost two times superior of those corresponding to the viscoelastic composites. The value of the tensile stress for the viscoelastic composite decreased by about 40% compared to that of the laminate composite, while the breaking strain increased by 50%. This decrease is due to the viscoelastic behavior of the natural rubber.

3.2 Damage Analysis by Acoustic Emission

In this part, and in order to analyze the damage mechanisms that appear during tensile tests, the various tests described above were repeated, and the monitoring of the damage was performed by acoustic emission (AE) using the Noesis software. The classification of the AE data was performed using an unsupervised model. Hence, a K-mean algorithm was used to classify and separate the different events into a k clusters based on five acoustic signal parameters: amplitude, rise time, number of counts to peak, duration and energy.

The results obtained from this classification methodology for the cross ply laminates $[0_2/90_2]_s$ and $[0_2/90_2/NR]_s$ are presented in Fig. 2. The results have been described by analyzing the superposition of the amplitudes of the AE signals as a function of time with the evolution of the applied stress (Fig. 2i). Then, the chronology and the appearance of the events of the different classes were studied by the analyze of the counts to peak as a function of time (Fig. 2ii). Finally, and to highlight the separation or overlap between the different classes, the acoustic signals were projected in the plane of two principal components (PCA) (Fig. 2iii). Four classes were obtained for the elastic composite (Fig. 2a). The signals of class A appear at very low stress level. Their appearance coincides with the end of the elastic part of the stress/time curve. This class possesses the lower values of amplitudes which vary between 45 and 50 dB. Classes B and C appear simultaneously during the test. Their appearance was detected at the beginning of the non linear phase of the stress/time curve. The amplitudes of the class B signals vary between 50 and 60 dB while those of the class C vary between 55 and 70 dB. According to the analyzes and the results founded in literature [4, 8], class A corresponds to matrix cracking, class B corresponds to the debonding fibre/matrix and class C corresponds to the delamination. Finally, the events of the Class D appear at the end of the test, just before the breackage of the specimens. The amplitudes of the signals of this class have the highest values, which vary between 70 and 95 dB. So this class is attributed to the fibre breakage.

Figure 2(b) present the results of the classification obtained for the viscoelastic laminate $[0_2/90_2/NR]_s$. The results present five classes. The comparison between the results of the elastic and viscoelastic laminates show that an additional class ‘E’is obtained for the viscoelastic laminate, which could concern a domage mechanism related to the viscoelastic layer. The amplitudes of these events’ classes vary between 55 and 85 dB. This class could be attributed to the debonding composite/viscoelastic layer.



i) i)

ii) ii)

iii) iii)

a) b)

Fig. 2. Analysis of acoustic emission data: (i) amplitude/ time, (ii) principal component analysis and (iii) chronology of occurrence of the different classes of composites: (a) $[0_2/90_2]_s$ and (b) $[0_2/90_2/NR]_s$.

4 Study of the Vibration Behavior of the Composite

The second part of this work is to investigate the dynamic properties of flax fibre reinforced composites with and without an interleaved natural viscoelastic layer. The composite specimens are supported horizontally in a clamping block. The excitation of the flexural vibrations of the beams was induced using an impact hammer and the beam response was detected by an accelerometer. The signals obtained from the acceleration transducer (PCB 352C23, model SN109866) and the force transducer (PCB 086B03, model SN5909) are analyzed by a dynamic signals analyser. Frequency response analyses were carried out to obtain the natural frequencies. Then, the damping factor was calculated using the Half Power Bandwidth (HPB) method used by Hammamiet al. [10] and Daoud et al. [6] Moreover, the young modulus E was calculated for every resonance mode by:

$$E = \frac{12\rho L^4 {\omega_n}^2}{h^2 \alpha_n^4}$$

The elastic and viscelastic cross ply laminates $[0_2/90_2]_s$ and $[0_2/90_2/NR]_s$ were carried out. The composite specimens were cut in different directions so as to obtain composites with stacking sequences of the type $[\theta_2/(90+\theta)_2]$ with different orientations of the fibres (Fig. 3). These laminates are labeled Cr-θ.

The modal analysis was carried out on the first four bending modes, according to the experimental analysis presented previously, on specimens of 25 mm width, a nominal thickness of 4 mm for elastic laminates and 5 mm for viscoelastic laminates and for three lengths (150, 200 and 250 mm). Different orientations of the fibres were studied: 0°, 15°, 30°, 45°, 60°, 75° and 90°.

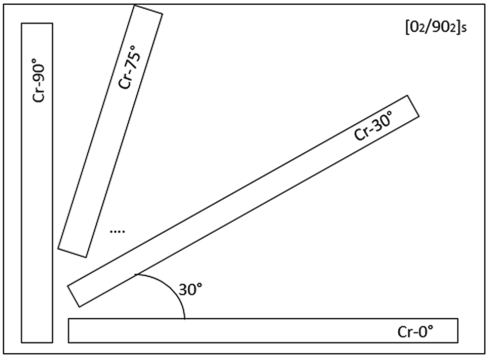


Fig. 3. Cross ply laminated specimens with different orientations

The evolution of Young modulus as a function of the frequencies for the different orientations is presented in Fig. 4.

It can be seen that the young modulus of the orientation 60° (Cr-60°) corresponding to a stacking sequence of the type ($[60_2/30_2]_s$) presents the least values and this for the elastic and viscoelastic composites. So, the specimens Cr-60° are the least rigid comparing to the other configurations of the cross laminates.

For a given orientation, the modulus E varies slightly with the increase in frequency for the elastic composite, while it decrease with a significant way for the viscoelastic laminates. This decrease is attributed by the viscoelastic behaviour of the natural rubber.

Hence, the insertion of the viscoelastic layer in the laminate increases its thickness and mass but decreases its rigidity in relative flexion. So, the modulus decreases drastically with the increase of the vibration frequency.

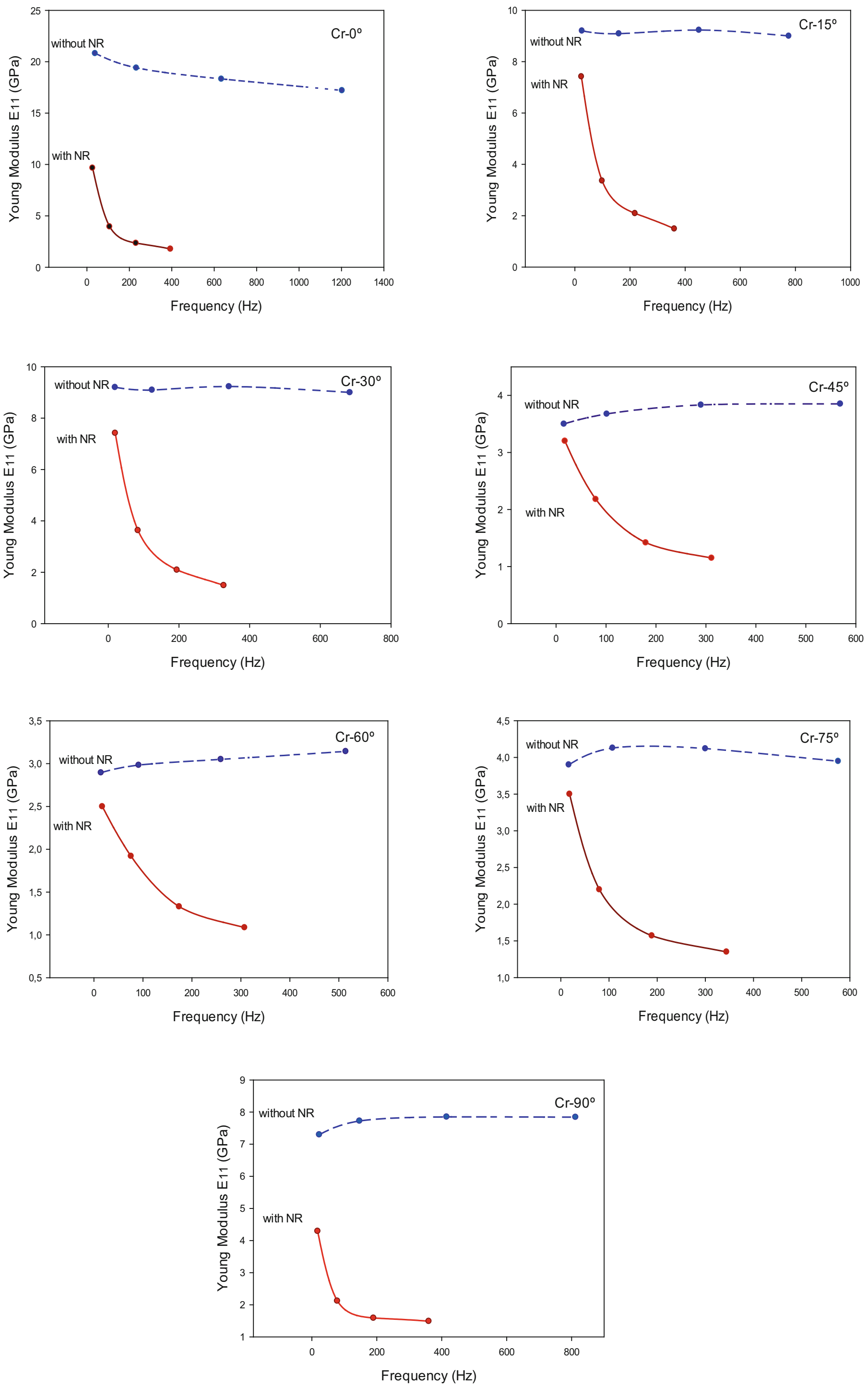
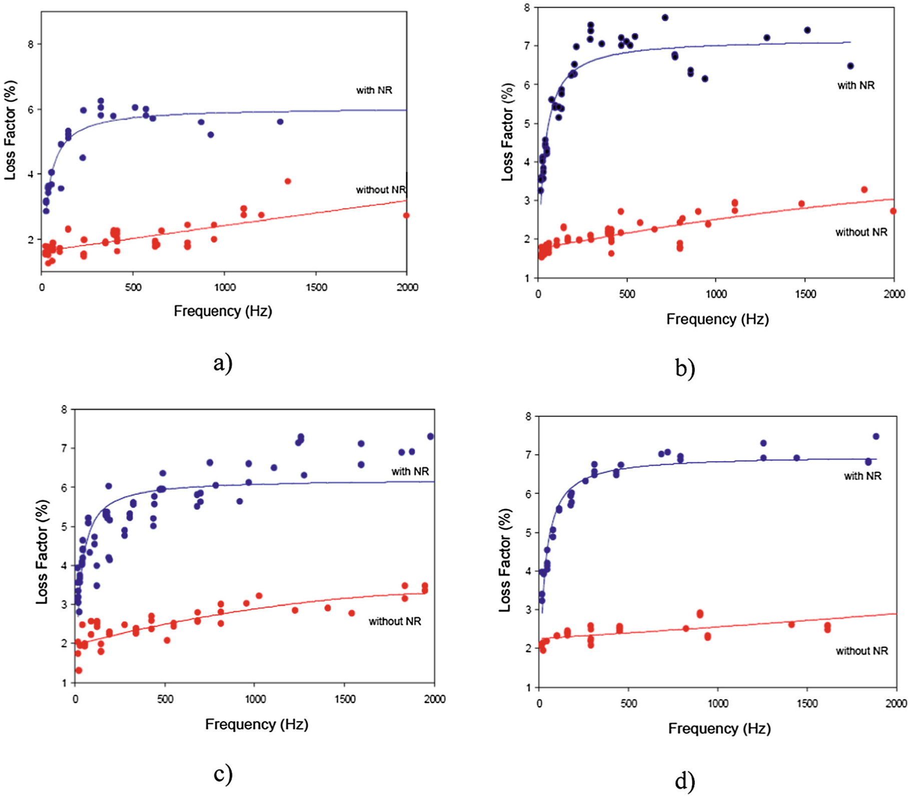


Fig. 4. Variation of the longitudinal Young's modulus E as a function of the vibration frequency for different orientations of the fibres

The effect of the insertion of the viscoelastic layer on the damping factor of flax compsoites was evaluated. The variations of this factor as a function of the frequency for the different stacking sequences and for the two studied materials (elastic and viscoelastic) are shown in Fig. 5. The figure show that, for a given stacking sequence, the damping increases as the frequency increases for the two laminates. This increase is much higher in the case of viscoelastic laminates.

The values of the damping factor for the elastic composite is between 1.5 and 2% for low frequencies and 3% for high frequencies (2000 Hz), while Ithe values corresponding to he viscoelastic laminate are in the order of 3% for low frequencies and could reach the 8% for high frequencies (2000 Hz). The integration of a viscoelastic layer in the cross ply laminates improves significantly its damping and thus its vibration behavior.



a)

b)

c)

d)

Fig. 5. Variation of damping factor versus frequency of elastic and viscoelastic cross laminates for different orientations: (a) Cr-0° and Cr-90°, (b) Cr-15° and Cr75°, (c) Cr-30° and Cr-60° and (d) Cr-45°.

5 Conclusion

This work focuses on the study of the mechanical and vibration behavior of a flax fibre reinforced composites with and without an interleaved natural viscoelastic layer. The composite materials have been characterized experimentally using different mechanical and vibrational tests. First, both types of composites were studied using uni-axial tensile tests. Acoustic emission (AE) has been often used for the identification and characterization of micro failure mechanisms in composites. The results showed that these composites have very high specific characteristics. It can be used for applications currently using composites reinforced with synthetic fibres such glass, carbon…. Next, experimental vibration analyses were carried out on the composites. It has been shown that the viscoelastic layer plays a major role in damping because it has a high level of energy dissipation. Therefore, it improves with a significant way the modal properties of the composite.

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