STATIC AND DYNAMIC CHARACTERIZATION OF A WOVEN ECO-COMPOSITE YOUNG'S MODULUS AND ACOUSTIC EMISSION ANALYSIS

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The study describes the mechanical characteristics of polymer matrix composite reinforced with vegetable jute fibers such as Young's modulus variation according the orientation of the fiber. The jute manufacture fiber in warp and weft direction was associated by impregnation with a green liquid thermoplastic resin. Samples of stack laminated composite have been tested in static and dynamic analysis according the fiber orientations using acoustic emission monitoring. The obtained results for the dynamic tests have highlighted their approaches in relation to the static test. The acoustic emission data were processed using a global approach, in order to associate the acoustic signatures of the damage mechanisms during the test, and to understand their influence on the mechanical behavior of the material.

Keywords: Eco-composite; mechanical characterization; jute fiber; static and dynamic tests; acoustic emission.

1. Introduction

The new generation of biodegradable materials such as composite eco-materials is developed by many researchers in mechanical and civil industries applications to protect the environment [1]. They offer great potential to designers in a variety of areas that require both strength and lightness, including transportation, marine, nautical, aeronautical, aerospace, sports, heavy industry, civil and military. The mechanical, physical and chemical properties can change in the materials fibers and resins, which makes it possible to obtain suitable defined structures for applications.

Most of these materials require shaping by compression molding (press or vacuum). Among the different natural reinforcement materials such as jute fibers, flax, Alfa… are selected for their mechanical performance and availability [2, 3].

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Jute is available in abundance in the eastern part of India and Bangladesh, having high tensile strength and sensitivity to moisture and low thermal and electrical insulation properties [4], has also an advantage for the preparation of the eco-composite with hydrophilic resins [5,6] .

The mechanical properties of the composite jute / epoxy material such as tensile strength, flexural strength, impact strength and hardness are better by relative to a composite jute / polyester [7].

The mechanical properties of the composite based on short jute fibers of a length ranging between 2 and 3 mm with a proportion of 20% of fiber weight and 80% polypropylene resin were determined from the flexural strength testing, tensile, impact, elongation at break [8] where a significant decrease in bending strength is due to the impact caused by the damage. The impact resistance was carried out for the case of unidirectional laminates composite by many researchers [9]. The acoustic emission technique proves to be an effective means of understanding the mechanisms of damage that can lead to rupture [10].

The tensile behavior of a composite thermosetting composite reinforced by jute fibers, using the technique of acoustic emission have been studied to identify the main mechanisms of damage occurring at different scales and to quantify their effects on the mechanical behavior of the material. The acoustic activity is controlled by means of an algorithm that simultaneously takes into account the evolutions of the mechanical and acoustic energies within the material [11].

Experimental tests have been used to characterize the vibratory behavior of composites by applying impact excitations (Figure 3) [12]. In this context, several studies have been conducted to characterize composites reinforced by synthetic glass and carbon fibers [13-14] or by natural fibers of flax, jute, hemp, etc. [15-16].

The evaluation of vibratory and acoustic characteristics shows that natural fiber composites have very high modal properties compared to synthetic fiber composites [16-17]. It has also been shown that the high values of vibratory characteristics of eco-composites are induced by the intrinsic properties of natural fibers and essentially by their particular morphology. The hybrid polymer composite with jute fiber could be used in the industrial applications of automotive and consumer goods where the components are under the operation of moderate cyclic loadings [18].

In this paper we have developed an eco- composite based on jute fiber and green epoxy resin SR 56 to study mechanical properties in different orientations in static and dynamic analysis of Young's modulus by using an acoustic emission data in order to associate the acoustic signatures of the damage mechanisms during the test, and to understand their influence on the mechanical behavior of the material.

2. Materials and methods

2.1 Eco-composite preparation

The experimental study was carried out by using composite material woven jute fibers (surfacic weight of 390 g m^{-2}) and a green SR epoxy resin 56. The preparation of the composite is obtained by successive laminating warp direction oriented layers (O_2)s for four plies. We have considered a plate of dimensions 400 mm x 400 mm and a nominal thickness of 4 mm, molded under vacuum (0.6 bar depression) for 8 hours between the mold and the counter-mold after the insertion of various molding tissues using the so called bag technique. However, it allows the production in large series of small pieces potentially complex.

The green epoxy resin SR 56 is an epoxy resin of which 56% of the molecular structure is of plant origin supplied by Sicomin. The polymerization rate at room temperature makes it easy to produce a large number of samples. The sample cutting test was performed with a diamond saw blade in the direction of the warp and weft fibers, from plates, according to ASTM D 3039 norm.

2.2 Mechanical test

Static and dynamic modal tests were conducted considering the four-layer stratified composite in two orientations of jute fibers (warp and weft).

The static tensile tests were carried out on composite test samples measuring 200x20x3.5 (mm^3) using a machine equipped with a force sensor of 100 KN Capacity. The deformation was measured using an axial extensometer of 25 mm empty length and a stroke of 5 mm. All tests were performed at a speed of 2 $mm.min^{-1}$

Fig. 1. Tensile static test for eco-composite specimen

Table 1

Mechanical properties obtained from static tests in the warp and weft fibers direction

Fiber orientation	E (Young Modulus) GPa	σ_R (Ultimate stress) MPa
Warp fibers direction	7.437	73.984
Weft fibers direction	3.481	22.981

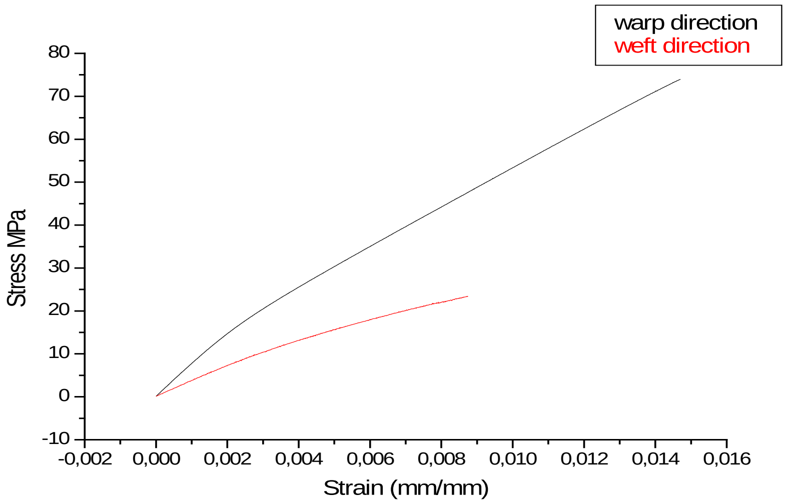
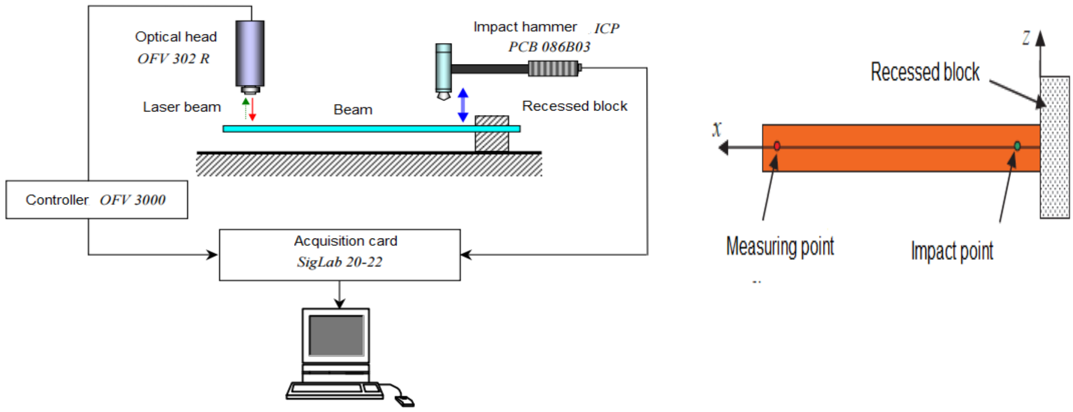


Fig.2. Stress-Strain curves of Eco-composites for both orientations of jute fibers

Experimental dynamic analysis in the case of impact excitation was performed on a specimen in a recessed / free configuration. The tests were carried out according to ASTM-E756. The measurements were carried out on the first four bending modes on beams of width equal to 20 mm, a nominal thickness of 3.5 mm and various lengths of 150, 175 and 200 m. The experimental device used is shown in the figure. 3a.

The specimen is held horizontally, recessed on one side into a mounting block and free on the other side (Figure 3b). An impact hammer (PCB 086B03, model SN5909) is used to induce the excitation of bending vibrations of the beam near the embedding block.

The response is detected at the other end using an accelerometer (PCB 352C23, model SN109866). The obtained signals are then digitized and processed by a dynamic signal analyzer from 'Siglab' society. This analyzer consists of an acquisition card and processing software, associated with control and signal processing. Signals and associated processing are then saved for post-processing. The modal properties and resonant frequency were thus determined using the bandwidth method shown in Table 3.



(a) (b)

Fig.3. Experimental dynamic analysis in the case of impact excitation.

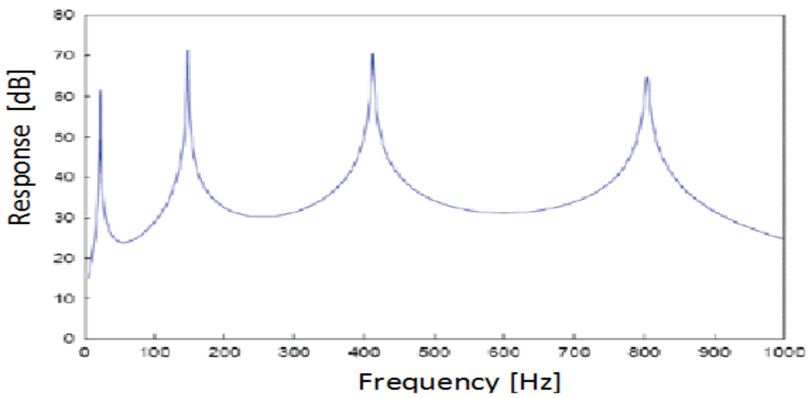


Fig.4. Example of Clamped-Free beam responses in terms of vibration frequency

Table2

α value according to the corresponding vibration mode for a clamped-free specimen [19]

N° mode	α value
1	3.516
2	22.034
3	61.701
4	120.91

The modal properties and resonant frequencies shown in Table 3 bellow, have been recorded using the bandwidth method.

Table 3

Resonant frequency (f) results for several resonant modes according to the distance between the measuring point and clamped support

	Weft direction plate			Warp direction plate		
L (m)	mode 1	mode 2	mode 3	mode 1	mode 2	mode 3
0.150	41,25	278	803	65,6	418,1	1249,3
0.175	36,87	240,6	691,2	54,3	336,2	958,12
0.200	27,5	190	550	31,25	208,5	611,25

The values of Young modulus are presented in Table (4-5) using the inverse method of Berthelot [19] and given by equation (3) as follows:

$$\omega_0 = 2\pi f \quad (1)$$

$$\omega_n = \alpha_n.\omega_0 \quad (2)$$

$$E = \frac{\omega_n.L^4.\rho.S}{I} \quad (3)$$

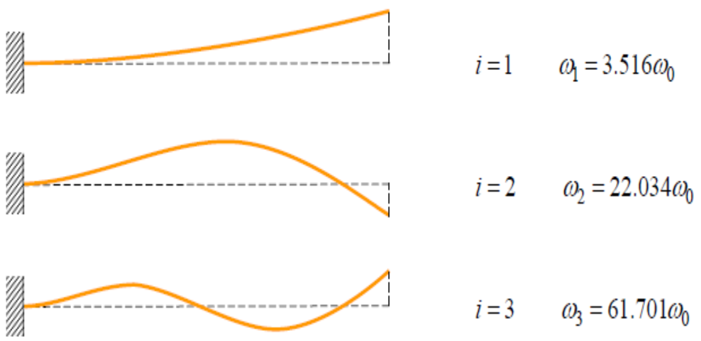


Fig.5. Bending vibrations of a beam clamped at one end and free at the other.

Table 4

Young modulus values for several resonate vibration modes in accordance with the distance between measuring point and clamped support for the case of warp fiber orientation

L (m)	E mode 1 (GPa)	E mode 2 (GPa)	E mode 3 (GPa)	E static test (GPa)
0,15	5,457	5,645	6,427	7,430
0,175	6,927	6,764	7,004	7,430
0,2	3,910	4,437	4,863	7,430

Table 5

Young modulus values for several resonate vibration modes in accordance with the distance between measuring point and clamped support for the case of weft fiber orientation

L (m)	E mode 1 (GPa)	E mode 2 (GPa)	E mode 3 (GPa)	E static test (GPa)
0,15	2,158	2,508	2,660	3,480
0,175	3,194	3,464	3,648	3,480
0,2	3,031	3,684	3,937	3,480

Young modulus values obtained by static and dynamic methods according the fiber orientation for several resonate vibration modes are given in table 4 and 5. The variability of the Young's modulus can be explained by the effects of boundary condition accuracy which affects directly the length of tested specimens where obtaining a perfect clamping proves difficult. It is mainly due to the uncertainty of several parameters such as the dimensions of the specimens (length), the fibers orientation, the application at the impact point, the number of saved points to do the analysis, the systematic or random errors … We have estimated the values by clamped beam responses in terms of vibration frequency. The obtained signals are then digitized and processed by a dynamic signal analyzer. This analyzer consists of an acquisition card and processing software, associated with control and signal processing.

2.3 Acoustic acquisition

During the monotonic tensile tests, the specimens were equipped with an EPA acoustic emission sensor with a bandwidth of 100 kHz to 1MHz. A coupling agent was used between the sensors and the material. The signals were recorded with a sampling frequency of 5MHz. Two preamplifiers with a gain of 40 dB were used. Subsequently, "broken mine" tests were performed to determine the temporal windowing parameters, which were defined as follows: PDT = 50µs, HDT = 100µs and HLT = 200µs. The amplitude acquisition threshold was set at 35 dB. Figure 6 presents the results obtained during acoustic emission monitoring of a monotonic tensile test and shows a different behavior in comparison with conventional composites.

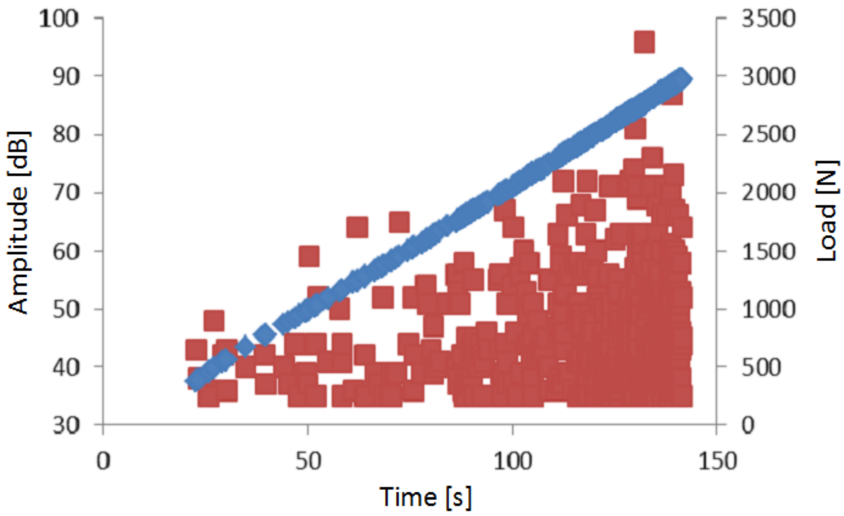


Fig.6. Evolution of the load and amplitude of acoustic events perceived as a function of time

The stress / strain curve indeed has nonlinearities, unlike a glass-epoxy composite that behaves linearly to failure. Firstly, a "bend" reflecting a significant decrease in stiffness is observed for a value close to 0.25% deformation, and for a stress of about 10-25 MPa. Beyond 0.25% deformation, the stress-strain curve evolves almost linearly until failure. First, it should be noted that the first events appear precisely at the level of the "bend". The amplitude of these events is between 35 dB (corresponding to the value defined as the acquisition threshold) and about 60 dB.

3. Results and discussions

3.1 Eco - Composite Properties

The obtained eco-composite jute / green epoxy 56 presents a different mechanical behavior in comparison with conventional composites in unidirectional quasi-static tensile tests. The stress / strain curve, shown in Figure 2, indeed has non-linearities, unlike a glass-epoxy composite that behaves linearly to failure. Firstly, a "bend" reflecting a significant decrease in stiffness is observed for a value close to 0.1% of strain, and for a stress of about 5-20 MPa in the warp direction and 3-15 MPa weft direction. Beyond 0.1% deformation, the stress-strain curve evolves almost linearly until rupture. However, it is possible to detect a slight inflection in the vicinity of 0.30% deformation for both orientations. This result reflects a reversible elastic behavior at the beginning of the test followed by a viscoplastic behavior due to the viscoplastic behavior of the resin and the viscoelastic behavior of the natural jute fibers.

3.2 Mechanical characteristics

The values of the mechanical properties of the composite Eco-composite obtained by four layers laminated for warp and weft jute fiber orientations (table 4 and 5), mainly the Young's modulus, determined from the static test results are presented with a good prediction and are considered relatively reliable for industrial applications related to modeling and mechanical construction. Test results from the modal dynamic analysis are relatively close to those determined previously but they are accompanied by the order of 5% of uncertainties which may affect their reliability especially if these results will be used for high precision applications (aeronautical, mechanical, civil engineering, ...etc) However, the process of implementation may have an influence on the mechanical properties of the composite, because of a certain amount of resin absorbed or lowered in the interstices between the folds of the fabric. On the other hand, the variability of the results observed on the rupture of the specimens is not important. This is mainly due to local variations in the properties of the jute. A variabilist approach seems essential to better understand the rupture of test pieces.

3.3 Acoustics results

To classify the events, the k-means algorithm was used. This algorithm tends to group the acoustic events into classes according to their similarity in the sense of five temporal classifiers: amplitude, rise time, duration, energy, and the number of shots at the peak. The classification results obtained are shown in Figure 7.

The first events appear for amplitudes between 35 dB (corresponding to the value defined as the acquisition threshold) and about 70 dB. During this test, four classes of acoustic events were observed. A comparison of the obtained classes in terms of statistic dispersion according to the used classifier allows to attribute damage mechanisms to this classes. Class A corresponds to matrix cracking and the propagation of these cracks, class B is attributed to the decohesion of fiber / matrix and fiber / matrix bundles, class C corresponds to fiber shedding and delamination, and class D is attributed to fiber breakage.

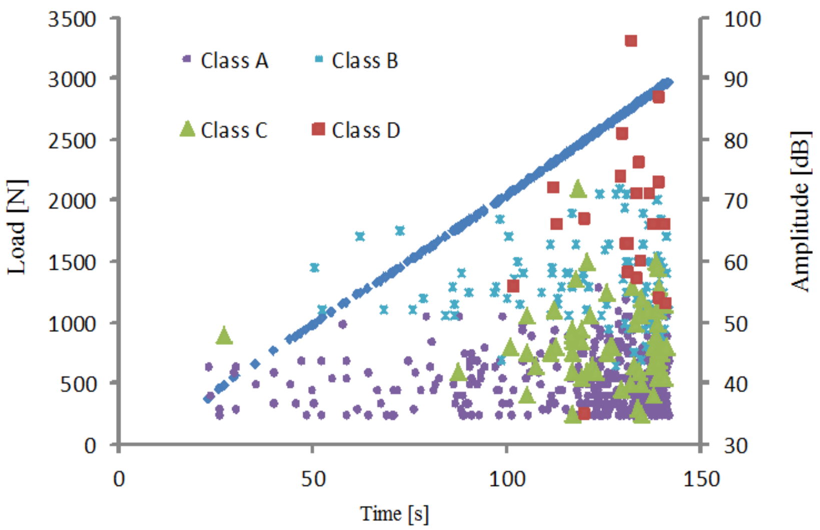


Fig.7. Evolution of the load and the amplitude of acoustic events perceived as a function of time

4. Conclusion

The eco-composite material made with a combination of jute and green epoxy 56 has been obtained by successive laminating according to molded under vacuum method. Samples were tested in static and dynamic analysis using different fiber orientations by acoustic emission monitoring in order to determine the mechanical characteristics. Acoustic emission data were analyzed using the k-mean algorithm, which proved to be particularly effective in processing acoustic emission data without resorting to traditional algorithms, thus taking into account the simultaneous evolution of mechanical and acoustic energies.

The study of the appearance and the propagation of these damage mechanisms made it possible to provide explanations on the non-linearity's of the tensil behavior of this eco-composite

Results showed a different mechanical behavior of the eco-composite from that of conventional composites in quasi-static tensile tests. The values of Young's modulus, determined from the static test are considered relatively reliable for industrial applications. The modal dynamic analysis is relatively close to those determined previously for static results but they are accompanied by the order of uncertainties 5% which may affect their reliability.

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