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DAMAGE CHARACTERIZATION OF FLAX FIBRE COMPOSITE USING LINEAR AND NONLINEAR VIBRATION RESONANT TECHNIQUES

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1. Introduction :

Through the last decade, the use of vibration analysis, as a non-destructive test has become a major issue to identify the mechanical behaviour of composite. Indeed, these experimental methods lead to evaluate both the stiffness of the structure and its damping behaviour, as well as the viscoelasticity behaviour [1]. Generally, mechanical testing applied on composite material induces many damage mechanisms such as matrix micro-cracking, fibre/matrix debonding, delamination and fibre breakage [2]. In this context, Hammami et al [3] have studied the effect of delamination on the linear and nonlinear behaviour of glass fibres composite. They found that the natural frequencies decreases and the loss factor increases with the debonding length. Idriss et al [1] have studied the vibration behaviour of laminate composite, which were subjected to cyclic loading. The results have shown that the rigidity loss causes the decreasing of frequency and the increasing of loss factor. In the present study, linear and nonlinear dynamic tests, applied on flax fibres composite laminates, were carried on to investigate the effect of damage on the vibration behaviour. The damage was created by tensile tests for different strength thresholds, which are function of the ultimate tensile strength UTS.

2. Theoretical background

The Hooke's law gives the stress – strain relation in case of elastic and isotropic material. However, for heterogeneous or damaged material, a new theoretical approach is developed [3]. It is based on classical and non-classical nonlinearity. Thus, the stress–strain relationship is given by:

$$\sigma = \int K(\varepsilon; \dot{\varepsilon}) d\varepsilon \quad (1)$$

Where, $K(\varepsilon, \dot{\varepsilon})$ is the strain amplitude and strain rate dependent modulus given by:

$$K(\varepsilon; \dot{\varepsilon}) = K_0(1 - \beta\varepsilon - \gamma\varepsilon^2 - \alpha(\Delta\varepsilon + \varepsilon \cdot \text{sign}(\dot{\varepsilon}))) \quad (2)$$

Where, $(\beta\varepsilon - \gamma\varepsilon^2)$ refers to the classical nonlinear behaviour. However, the term $\alpha(\Delta\varepsilon + \varepsilon \cdot \text{sign}(\dot{\varepsilon}))$ represents the non-classical nonlinear or hysteretic behaviour. (α) is the hysteresis nonlinear parameter, $(\text{sign}(\dot{\varepsilon}))$ and (ε) are respectively the linear modulus and the strain rate.

$$\begin{aligned} \text{if } \dot{\varepsilon} \leq 0 & \quad \text{sign}(\dot{\varepsilon}) = -1 \\ \text{else} & \quad \text{sign}(\dot{\varepsilon}) = 1 \end{aligned}$$

The hysteresis nonlinear behaviour of the damaged material can be determined by monitoring the resonance amplitude and the resonance frequency.

The hysteretic parameters, (α_f) , is given by:

$$\frac{\Delta f}{f_0} = \frac{f - f_0}{f_0} = \alpha_f \varepsilon \quad (3)$$

Where, f_0 is the frequency at low amplitude excitation and f is the frequency measured at higher amplitude.

3. Materials and experimental procedure

The bio-composite used in this study consists on flax fibre associate to thermoplastic Elium resin. The laminate was made by liquid resin infusion. After processing, the fibre volume fraction was determined and it is about of 40% [2]. In order to evaluate the linear vibration behaviour of the composite beams, free vibration tests were carried out with the experimental device presented in Figure 1. Specimens were tested in a clamped-free configuration, according to the standard ASTM E-756. The beams were excited by an impact hammer close to the clamped extremity. The displacement of the free end was measured by a laser vibrometer. The excitation and response signals were processed by an acquisition card system and analyzed. Then, the data was processed with MATLAB software. However, for the nonlinear vibration behaviour the hammer is replaced by a shaker and the laser vibrometer by an accelerometer.

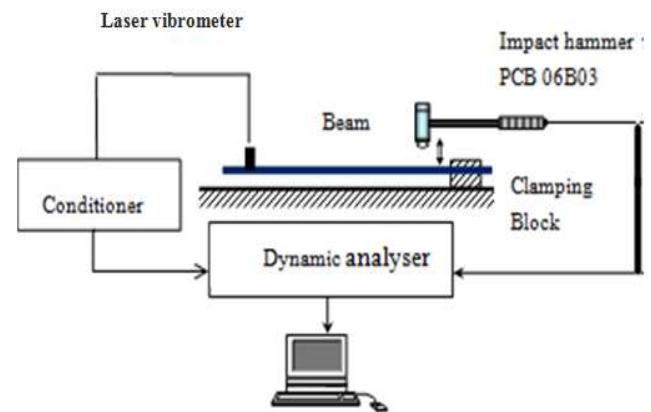


Fig 1. Experimental setup for free vibration analysis.

4. Results and Discussion

4.1. Effect of damage on linear vibration behaviour

In order to study the relationship between damage inside materials and vibration behaviour, two configurations of specimens unidirectional and cross ply composite were subjected to unidirectional tensile tests for different stress ratio. Then, the modal resonance tests were applied. The results are given for unidirectional specimens by presenting the loss factor as function of frequencies for each stress ratio (Figure 2).

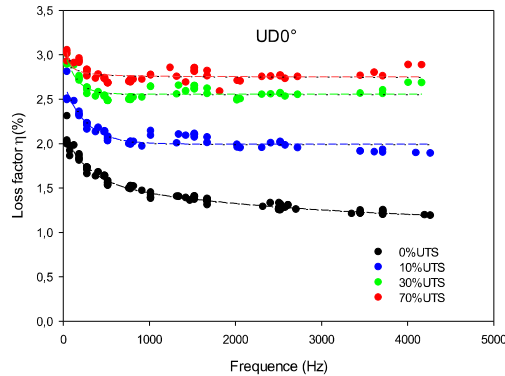


Fig 2. Effect of damage on the linear vibration behaviour.

It appears clearly that increasing the damage induces increasing in the damping properties of the composite. Tensile tests create defects such as micro cracks and fibre/matrix interfaces rupture, which probably generates energy dissipation through the matrix/matrix and matrix/fibre friction. Thus, fibre/fibre friction may also occur inside technical fibres.

4.2. Effect of damage on nonlinear vibration behaviour

In order to characterize the damage using the nonlinear behaviour of the bio-composites, resonance curves were measured with increasing excitation for undamaged and damaged specimens. Results were obtained for the six first bending modes. Figure 3 shows that in first mode, and for a loading at 80% of ultimate tensile strength, the resonance peaks are shifting to lower frequency when increasing the amplitude. The same attitude was remarkable for all modes with different sensibility. It is noticeable that when damage increases, the nonlinearity of composites increases.

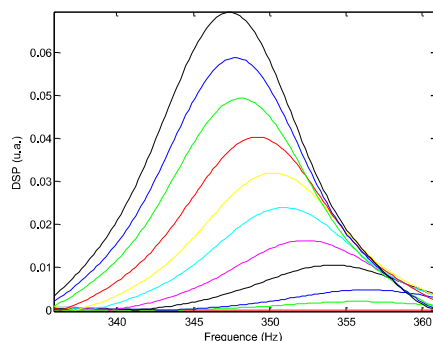


Fig 3. Model1 Resonance curves at 10 different excitation levels.

The results allow evaluating the frequency shifting as function as the strain amplitude for different damage level

(Figure 4). The plots show a linear behaviour. In case of undamaged specimen, there is no significant variation. However, for 80% damaged specimen the slope is very important.

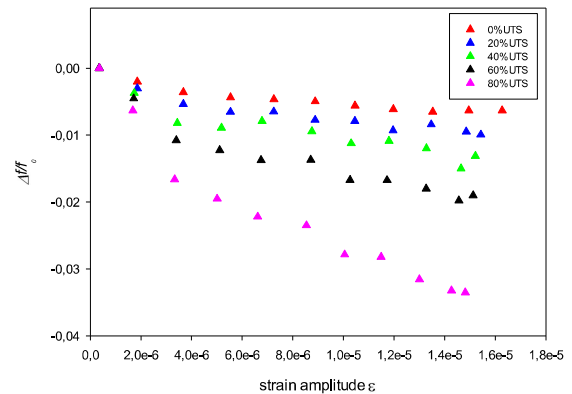


Fig 4. Evolution of the frequency shift vs. strain amplitude in bending model1.

Figure 5 shows the variation of the normalized hysteretic elastic parameter as a function of the damage for the first bending mode. This nonlinear elastic parameter increases with increasing the damage ratio. The results obtained for different modes allow concluding that the low frequency modes are more sensible to damage.

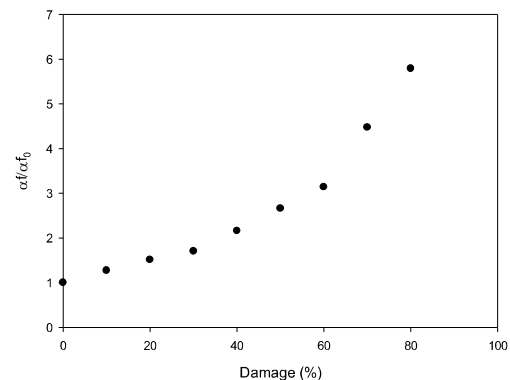


Fig 5. Evolution of the normalized hysteretic vs. damage in bending model1.

Conclusion

This study provides an experimental analysis of the impact of damage in flax fibre composite on the linear and nonlinear vibration behaviour. The results have shown that this technique could be an appropriate non-destructive method to evaluate the health of composite.

References

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