Effect of stacking sequence on the mechanical and damping properties of flax-glass fibre hybrid composites

Khouloud Cheour, Mustapha Assarar, Daniel Scida, Rezak Ayad, Xiao-Lu Gong

To cite this version:

Khouloud Cheour, Mustapha Assarar, Daniel Scida, Rezak Ayad, Xiao-Lu Gong. Effect of stacking sequence on the mechanical and damping properties of flax-glass fibre hybrid composites. 2nde conférence Euromaghrébine des BioComposites, Nov 2018, Hammamet/Sfax, Tunisia. hal-02631062

HAL Id: hal-02631062
https://hal-utt.archives-ouvertes.fr/hal-02631062

Submitted on 8 Feb 2022

EFFECT OF STACKING SEQUENCES ON THE MECHANICAL AND DAMPING PROPERTIES OF FLAX-GLASS FIBRE HYBRID

Khouloud CHEOUR*, Mustapha ASSARAR[1], Daniel SCIDA[1], Rezak AYAD[1], Xiao-Lu GONG[2]
[1] Université de Reims Champagne-Ardenne, Laboratoire d'Ingénierie et Sciences des Matériaux, EA 4695, Reims, 51100, France
[2] Université de Technologie de Troyes, Institut Charles Delaunay, Laboratoire des Systèmes Mécaniques et d'Ingénierie Simultanée, UMR CNRS 6281, Troyes, France
** Corresponding author.*

Abstract

Nowadays, natural fibres are used as reinforcement of composite materials thanks to their low density, their biodegradability and their interesting damping properties. The aim of this study is to show the interest of the mechanical and dynamical properties of glass-flax hybrid composites. So, various staking sequences of glass-flax hybrid composites were manufactured and tested. The damping coefficients were identified by fitting the experimental responses of free-free bending vibrations. The obtained results show that the staking sequences and the position of flax fibre layers in the hybrid composites changed the properties, so a classification of different stacking sequences was established. In fact, the hybrid $[G_2/F_2]_S$, made of two glass external layers placed on both sides of four flax layers, is very interesting. It showed better specific bending modulus and loss factor than glass composites with proportions of 31 and 39% respectively.

Keywords
Damping ; flax fibre ; glass fibre; hybrid composite ; mechanical properties.

1. Introduction

Synthetic fibres reinforced composites are used nowadays in various fields, since they offer many advantages. But their use raises environmental problems at the end of life cycle. The aim of this work is to investigate the effect of adding flax fibre reinforcement to the glass fibre composites. Several works showed the interesting specific mechanical and dynamical properties, several properties of the natural fibre reinforcement [1-4]. But they have an hydrophilic behavior. So to reduce the significant lost of mechanical properties, several studies proposed the hybridization as a solution of both problems [5-8]. The aim of this work is to show the intrest of glass-flax hybridization, since it can provide good mechanical and dynamical properties, mass gain and also environmental advantages.

2. Experimental procedure

2.1 Materials

In this study, non-hybrid and hybrid composite materials with glass/flax fibres reinforcement and epoxy matrix were elaborated. All materials were manufactured by press platen process in the IFTS of Charleville-Mézières. The layers of dry fabrics were impregnated one by one with an epoxy resin SR1500 associated with hardener SD2503 (Sicomin Company). Once impregnated, fabrics were put on heat seal press under 6 bars pressure and 40°C temperature for three hours and a half. The non-hybrid plates were cut to obtain specimens of different lengths (240, 260 and 280 mm) and orientations (0°, 90° and 45°) and hybrid plates in only one orientation 0°. The width of both non-hybrid and hybrid specimens was 26 mm for all orientations and lengths.

2.2 Experimental protocol

The aim of the present work is to characterize dynamic properties of the studied materials using a free flexural vibrations analysis. The same equipment and method were used in a previous work of the authors [9]. The specimen is supported vertically by a rubber in order to have a free-free configuration. It is excited using an impulse hammer (PCB 086C03) in different points and the flexural vibrations are detected by an accelerometer (PCB 352C23) pasted in the specimen using wax. Both signals of excitation and response are digitalized by LMS SCADAS dynamic analyser. The frequency response enables us to identify the natural frequencies and loss factors from LMS PolyMAX method. More details can be found in [10]. The results for each length, orientation and material showed in this work are the average of the five specimens.

3. Finite element analysis

To identify dynamic properties of the studied materials, specimens were modelled by finite element method. The element used in this work is shown in Figure 1.

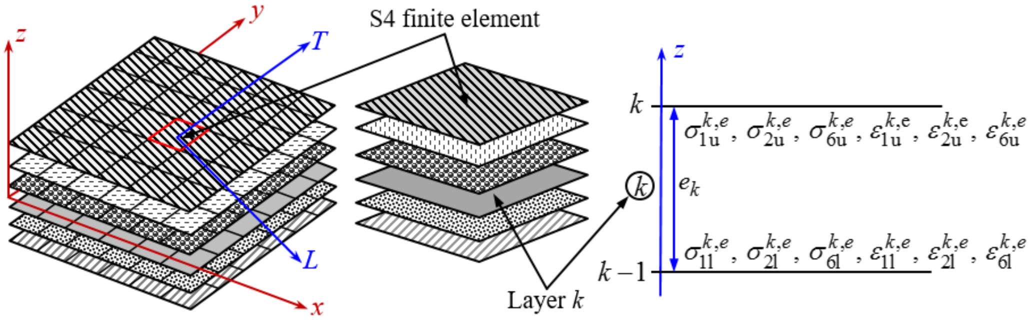

Figure 1. Multilayred finite element S4.

It is a four-node multilayered shell finite element, named S4, of the Abaqus software. This element is based on the first-order laminate theory. Transverse shear stresses could be neglected since thicknesses of specimens are widely lower than their lengths. Once natural frequencies are calculated by finite element analysis, corresponding values of stress and strain on the lower (l) and the upper (u) faces of each layer *k* of the element *e* (Figure 1),

$$\sigma_{\mathrm{il}}^{k,e},\ \sigma_{\mathrm{iu}}^{k,e},\varepsilon_{\mathrm{il}}^{k,e},\ \varepsilon_{\mathrm{iu}}^{k,e},\quad (i=1,2,6) \tag{1}$$

The energy $U^{k,e}$ of the layer *k* in the element *e* can be expressed as follow:

$$U^{k,e}=U_{11}^{k,e}+U_{22}^{k,e}+U_{66}^{k,e} \tag{2}$$

With $$U_{ii}^{k,e}=\frac{1}{2}\iiint_k \sigma_i^{k,e}\,\varepsilon_i^{k,e}\,\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z=\frac{S_e}{2}\int_k \sigma_i^{k,e}\,\varepsilon_i^{k,e}\,\mathrm{d}z,\quad (i=1,2,6) \tag{3}$$

S_e is the surface of the finite element *e*.

The evaluation of the loss factor deduced from the finite element analysis can be done with an energetic approach [11]. The total energy stored in the structure can be expressed as follow:

$$U=U_{11}+U_{22}+U_{66} \tag{4}$$

With: $$U_{ii}=\sum_{\text{elements},e}\ \sum_{\text{layers},k} U_{ii}^{k,e},\quad (i=1,2,6) \tag{5}$$

Then, the dissipated energy with the damping phenomena in the layer *k* of the element *e* can be expressed as a function of loss factors as follow:

$$\Delta U_k^e=\eta_{11k}^e U_{11k}^e+\eta_{22k}^e U_{22k}^e+\eta_{66k}^e U_{66k}^e \tag{6}$$

Loss factors are evaluated in the axis (L,T) of the material in each layer: η_{11k}^e and η_{22k}^e are loss factors in *L* and *T* direction respectively, and η_{66k}^e is the loss factor in the plan (L,T).

The dissipated energy in the finite element *e* can be expressed by:

$$\Delta U^e=\sum_{k=1}^{n}\Delta U_k^e, \tag{7}$$

The total energy dissipation ΔU in the whole structure is then:

$$\Delta U = \sum_{\text{éléments}} \Delta U^e \tag{8}$$

Finally, loss factor estimated by finite element analysis can be deduced from:

$$\eta = \frac{\Delta U}{U} \tag{9}$$

The previously cited formulations, are used to estimate the bending moduli and the loss factors of all the composites of the study.

4. Results and discussion

4.1 Elastic coefficient evaluation

Elastic coefficient (E_L, E_T and G_{LT}) of non-hybrid composites are deduced from free vibration tests of the specimens with different fibre orientations 0°, 45° and 90°. It's worthy to note that natural frequencies of the specimens with 0° and 90° fibre orientation depend on the longitudinal modulus E_L and transverse modulus E_T respectively. Thus, based on the natural frequencies obtained by experimental modal analysis, all moduli can be determined. Thereby for specimens with fibre oriented to 0°, the identification of the longitudinal modulus E_L is done using an iterative method. A variation of modulus value in each iteration is done, until equality between natural frequencies obtained by experimental method and finite element analysis. This method is also used for 90° fibre orientation so transverse modulus E_T can be identified. Then, shear modulus G_{LT} is determined in the same way using results of the specimens with 45° fibre orientation and taking into account variations of both moduli E_L and E_T as a function of frequency.

Regarding hybrid composites, the same procedure was used introducing for each layer the properties deduced for non-hybrid materials. The obtained results were then compared to experimental results.

Table 1. bending modili of flax-glass hybrid composites

composite	Flax	[F_3/G]	[F_2/G_2]	[F/G_3]	Glass	[G_3/F]	[G_2/F_2]	[G/F_3]
E_{fx} (GPa)	21,38	22,08	22,75	25,11	43,21	42,64	41,63	33,19

As explained in a previous work of the authors [9], it is possible to identify elastic moduli using natural frequencies. Table 1 resume the obtained values of the bending modulus of all hybrid and non-hybrid composites. The obtained results prove that introducing two internal flax layers to a glass fibre reinforced composite doesn't considerably affect the bending modulus of the stratified [G_2/F_2]$_S$ since the difference is only about 3%.

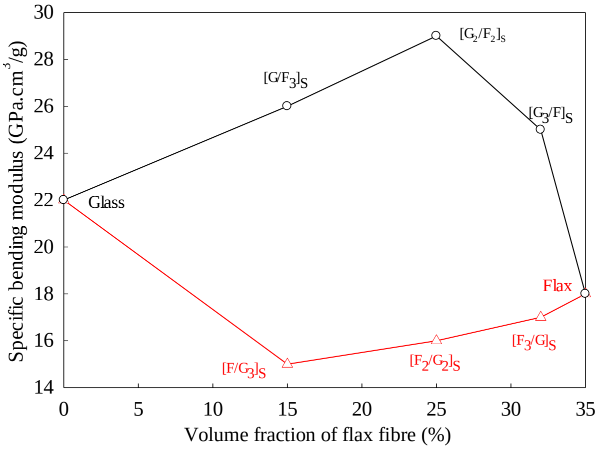

Figure 2. Evaluation of specific modulus as a function of the volume fraction of flax fibre of hybrid materials.

Natural fibre reinforced composites have a lightweight compared to glass fibre composites. That's why a comparison between specific modules (E/ρ) is done in this work. Figure 2 shows the evolution of the specific bending moduli as a function of a volume fraction of flax fibre in the hybrid composite. Unlike the tensile modulus that doesn't depend on the position of the layers in the hybrid [12], the obtained results show that the stiffness of the composites depends on the stacking sequence. Regarding for example a composite with a flax fibre volume fraction about 25%, the specific modulus of the hybrid $[G_2/F_2]_S$ increases by 32% and 61% compared to non-hybrid glass fibre and flax fibre reinforced composites respectively. On the other hand, the hybrid composite $[F_2/G_2]_S$ has a lower specific modulus (27% and 11% lower than non-hybrid glass fibre and flax fibre materials). This result is explained by the fact that glass layers that have a better bending modulus are placed further of the medium plan (glass fibre composites *E*=43 GPa and flax fibre composite *E*=21 GPa).

4.2 Loss factor evaluation

Figure 3 compares the experimental results and those obtained by finite element method for the studied composites. Both methods show the same results, proving that the finite element method allows us to identify the loss factor of the hybrid materials. Figure 3 shows also that the variation of loss factor as a function of the frequency has two different behaviours. This difference is associated to the evolution of the distribution of the dissipated energies on the glass and flax layers as shown in Figure 4. Concerning the $[G_3/F]_S$ laminate where the external layers are glass layers, the loss factor slightly increases with the frequency. In fact, the stored energy in the laminates is essentially dissipated by the glass layers (Figure 4.a), that's why the evolution of the loss factor as a function of the frequency is directed by that of the glass fibre.

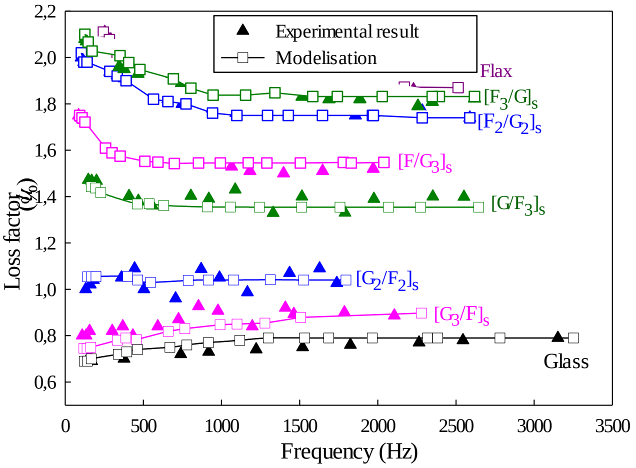

Figure 3. Loss factor as a function of frequency (experimental and modelisation results)

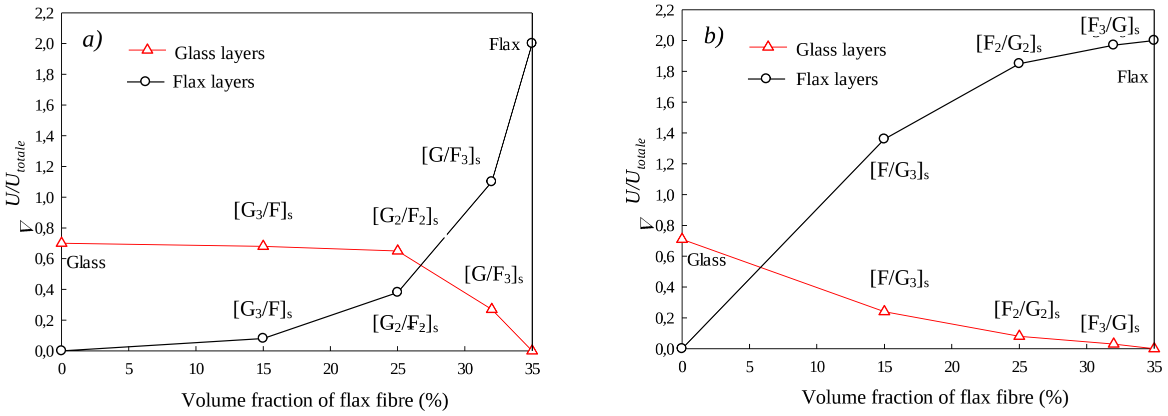

Figure 4. Dissipated energy in flax layers and glass layers for a 500 Hz frequency as a function of volume fraction of flax fibre in hybrid with (a) internal flax layers and (b) external flax layers.

For the hybrid with flax external layers, the effect of the dissipated energy by the flax layers predominates (Figure 4.b). Thus, the observed decrease of the loss factors as a function of frequency of the flax fibre composites leads to a decrease of the loss factors of the hybrid with flax external layers.

In order to compare the loss factors of all studied hybrids, the evolution of these latter is plotted according to flax fibre volume fraction for a 500Hz frequency (Figure 5).

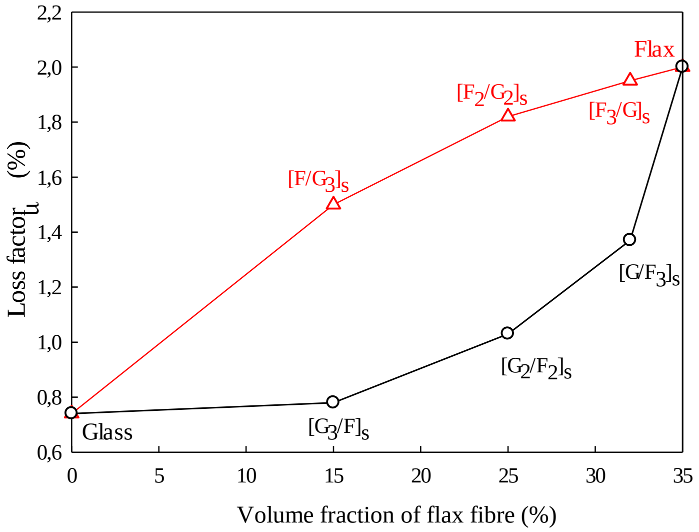

Figure 5. Loss factor as a function of flax fibre volume fraction of hybrid composites for 500Hz frequency

A significant increase of loss factor is observed especially when the external layers are flax layers. For example, the loss factors of the $[G_2/F_2]_S$ and $[F_2/G_2]_S$ laminates are 40% and 146% greater than glass fibre composite, respectively. This growth of damping properties is due to the presence of flax layers which have a better loss factor than glass ones. The loss factor induced by the flax layers in the $[G_2/F_2]_S$ laminate only represents 30% of the global loss factor, whereas it represents 96% in the hybrid $[F_2/G_2]_S$.

This difference between the $[G_n/F_m]_S$ and $[F_m/G_n]_S$ stacking sequences is essentially attributed to the repartition of the stored energies in the different layers. In fact, according to the chosen stacking sequence, between 19% and 88% of the stored energy is dissipated by glass layers in the case of $[G_n/F_m]_S$ hybrids. In the other hand, in the case of $[F_m/G_n]_S$, the energy dissipation is directed by flax layers which represent about 85% and 98% of the global energy.

4.3 Discussion

The choice of a composite material in a structure needs to be proved by a good mechanical performance and damping properties. Tables 2 and 3 show the properties of all hybrid composites of the study.

These results show that replacing flax internal layers by glass layers leads to a lowering of both specific bending moduli and loss factors of the composites (table 2).

Table 2. Mechanical and damping properties of hybrids with flax external layers compared to flax composite

Composite	Flax	$[F_3/G]_S$	$[F_2/G_2]_S$	$[F/G_3]_S$
E_{fx} (GPa)	21,39	+2,95 %	+6,36 %	+17,40 %
E_{fx}/ρ	18,01	-5,56 %	-11,11 %	-16,67 %
η (%)	2,01	-5,01 %	-9,01 %	-25,01 %

Otherwise, the stratified $[G_2/F_2]_S$, made of internel layers of flax, has very interessant mechanical and dynamicals properties. In fact, this material has a specific bending modulus and loss factor which exceed those of the glass fibre composite by about 31% and 39% respectively (table 3).

Table 3. Mechanical and damping properties of hybrids with flax internal layers compared to glass composite

Composite	Glass	$[G_3/F]_s$	$[G_2/F_2]_s$	$[G/F_3]_s$
E_{fx} (GPa)	43,37	-1,68 %	**-4,01 %**	-23,46 %
E_{fx}/ρ	22,01	+18,18 %	**+31,82 %**	+13,64 %
η (%)	0,74	+5,41 %	**+39,19 %**	+85,13 %

5. Conclusion :

Compared to glass fibre and carbon fibre composites, flax fibre showed a very interesting damping properties. Those composites have also a specific bending modulus similar to glass fibre composites one. This flax-glass hybridation has been proposed to have a material with better combined properties. The results of this study proved that hybrid materials have better dynamic properties with, in some cases, better specific moduli. Results also showed that hybridation can provide better properties with an important mass gain.

References

[1] Wambua, P., Ivens, J., Verpoest, I. Natural fibres: can they replace glass in fibre reinforced plastics?; Composites Science and Technology 2003; 63 (9): 1259-1264.

[2] Murali Mohan Rao, K., Mohana Rao, K. Extraction and tensile properties of natural fibers: Vakka, date and bamboo; Composite Structures 2007; 77: 288-295.

[3] Ren, B., Mizue, T., Goda, K. Noda, J. Effects of fluctuation of fibre orientation on tensile properties of flax sliver-reinforced green composites; Composite Structures 2012; 94 (12): 3457-3464.

[4] Genc, G., Hafidi, A.E., Gning, P.B. Comparison of the mechanical properties of flax and glass fiber composite materials. Journal of Vibroengineering 2012; 14 (2): 572-581.

[5] Nunna, S., Chandra, P.R., Shrivastava, S., Jalan, A.K. A review on mechanical behavior of natural fiber based hybrid composites, Journal of Reinforced Plastics and Composites 2012; 31(11) : 759-769.

[6] Jawaid, M., Khalil, H. Cellulosic/synthetic fibre reinforced polymer hybrid composites: a review, Carbohydrate Polymers 2011; 86(1) : 1-18.

[7] Sathishkumar, T.P., Naveen, J., Satheeshkumar, S. Hybrid fiber reinforced polymer composites – a review, Journal of Reinforced Plastics and Composites 2012; 33(5) : 454-471.

[8] Swolfs, Y., Gorbatikh, L., Verpoest, I. Fibre hybridisation in polymer composites: A review, Composites Part A : Applied science and manufacturing 2014; 67 : 181-200.

[9] Cheour K., Assarar M., Scida D., Ayad R., Gong X.L. Effect of water ageing on mechanical and damping properties flax-fibre reinforced composite materials. Composite Structures 2016, 152: 259–266.

[10] Peeters, B., Van Der Auweraer, H., Guillaume, P. The PolyMAX frequency domain method: a new standard for modal parameter estimation; Shock and Vibration 2004; 11: 395-409.

[11] Assarar, M., El Mahi, A., Berthelot, J.M.. Damping Analysis of Sandwich Composite Materials. Journal of Composite Materials, 2009, 43 (13), p. 1461-1485

[12] Zhang, Y., Li, Y., Ma, H., Yu, Y. Tensile and interfacial properties of unidirectional flax/glass fiber reinforced hybrid composites, Composites Science and Technology 2013; 88 : 172-177.