DAMPING PERFORMANCE OF FLAX FIBRE COMPOSITES

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Abstract
Dynamic mechanical analysis (DMA) and vibration beam testing (VBT) have been used to assess the damping properties of unidirectional, laminated and woven flax fibre (FF)/epoxy composites. The importance of the impregnation quality, the fibre/matrix adhesion, the quality of the fibres, the twist of the FF yarns and the crimp in the FF fabrics on these properties was investigated. Carbon and glass fibre reinforced epoxy composites were considered as comparison. Unidirectional FF instead of glass fibres led to a damping increase of about 133 %. While the intra fibre friction mechanisms were dominant for damping properties at small deformation (DMA), intra and inter-yarn frictions had more importance at larger deformation (VBT). The damping properties increased with the twist and crimp amount so as with a limited fibre/matrix adhesion. Damping maps revealed that the best compromise between damping and stiffness was obtained with high quality FF.

1. Introduction

There is a constant evolution in the field of composite materials. Composites with higher performance are continuously developed for novel applications. Today, natural fibre composites (NFC) are emerging in the composite world for ecological reason but also to improve some properties of the composite such as damping. Indeed vibration and damping issues have become increasingly important over the last decades in a wide range of applications such as automotive, aeronautics and sports.

Natural fibres (NF) used for composite applications are generally made up of bundles of elementary fibres, each fibre being composed of cell walls in which rigid cellulose microfibrills are embedded in a soft lignin and hemicellulose matrix. These cell walls consist of several layers differing in composition, in the ratio between cellulose and lignin/hemicellulose, and in the orientation of the cellulose microfibrils. Owing to the limited length of the fibre bundles, the spinning of these fibre bundles is necessary to produced continuous yarns, with different twist angles, than can be subsequently formed into textile composites [1].

Using NF in composite applications may improve damping properties owing to the viscoelastic and hierarchical nature of cellulose fibres, the fibre-matrix interface, the fibres aspect ratio and the interactions between fibres. Wielage et al. [2] studied dynamic mechanical properties of FF, hemp and glass fibers (GF) polypropylene (PP) composites using dynamic mechanical analysis (DMA). They showed that the storage modulus increases and the loss factor decreases with increasing the fiber content. With 30 wt% of fibers in a PP matrix the loss factor was always higher with FF than GF.

In a previous study the authors showed that the use of FF as reinforcement in a polymer matrix offers composites with similar specific mechanical properties than those based on GF, while significantly improving the damping properties [3]. They suggested that this enhancement was given on the one hand by the hierarchical structure of elementary FF, such as the intra-cell wall friction between the cellulose microfibrills and the hemicellulose/lignin matrix and the inter-cell wall friction, and on the other hand by the structure of the yarns used to create the fabrics. This latter source of energy dissipation was improved by intra-yarn friction between the elementary fibres in the yarns and by inter-yarn friction.

One problem often encountered when studying vibration is that there are many different definitions and ways of measuring damping. However, at low damping level, all the definitions are linked to each other by the following relationship, only valid for tanδ < 0.1 [4].

$$Q^{-1} = \frac{\psi}{2\pi} = \xi = \frac{\lambda}{\pi} = tan\delta = \delta = \frac{E''}{E'} = 2\zeta = \frac{\Delta W}{2\pi W} = \frac{\varphi\alpha}{\pi} \quad (1)$$

where Q is the quality factor, ψ the specific damping capacity, ξ the loss factor, λ the logarithmic decrement, δ the phase angle by which stress leads strain, E" the loss modulus, E' the storage modulus, ζ the damping ratio (or damping factor), ΔW the energy loss per cycle, W the maximum elastic stored energy, φ the wavelength of elastic wave and α the attenuation [5].

Different phenomena influencing the damping properties of NFC have been highlighted in literature. However their quantification has not been yet studied in details.To achieve such an objective different parameters have to be taken into account, such as the quality of the FF, the refinement process, the quality of impregnation, the quality of the interface, the twist amount in the yarns, the architecture of the fabrics, the crimp level etc. A really complex study at different levels has to be done.

The aim of the present study is to determine the influence of the amount of twist in the FF yarns and crimp in the FF fabrics on the mechanical and damping properties of epoxy (EP) reinforced with different unidirectional (UD) and twill 2/2 (TW) FF fabrics. The properties observed for the FF/EP based composites will finally be compared with those of the currently most widespread composite materials, i.e. GF reinforced EP composites.

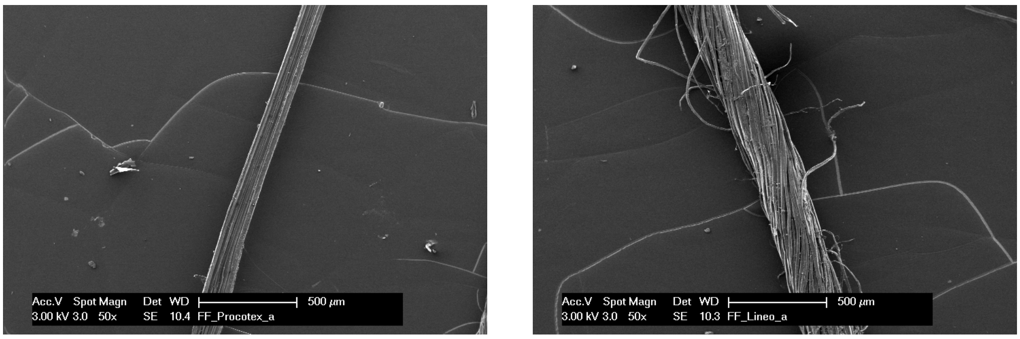
2. Materials and Methods

Unidirectional (UD), 0/90 laminates, twills (TW) made of GF and 6 different flax fibres (FF) reinforcing epoxy (EP) were processed by resin transfer molding (RTM). A volume fibre fraction of 40 % was used throughout. Several FF fabrics were used throughout this study, each having differences concerning the twist, the crimp, the fibres refinement or sizing. Table 1 lists the used FF fabrics and the abbreviations of the composites processed in this study. The twist angle of the FT and P fabrics was of 0° while it was measured by scanning electron microscopy (SEM)

Fabric	Architecture	Abbreviations
GF	UD	GF_EP_UD
	TW	GF_EP_TW
FF_FP	UD	FF_FP_EP_UD
	0/90	FF_FP_EP_0_90
	TW	FF_FP_EP_TW
FF_FD	UD	FF_FD_EP_UD
FF_FT	UD	FF_FT_EP_UD
	0/90	FF_FT_EP_0_90
FF_P	UD	FF_P_EP_UD
	0/90	FF_P_EP_0_90
FF_B	UD	FF_B_EP_UD
	0/90	FF_B_EP_0_90
FF_H	cTW	FF_H_EP_TW

Table 1: Used FF fabrics and abbreviations of the processed composites.

to be around 13° for the others. The FP and P fabrics were the only one containing epoxy sized yarns. Typical obtained SEM images of the yarns used in the P and FD fabrics are represented in figure 1(a) and (b) respectively. FP, FD and FT fabrics are made with high quality fibres, having less defaults, called dislocations, along their axis.



(a) (b)

Figure 1: SEM images of different FF yarns used in the (a) UD P and (b) UD FD fabrics.

The mechanical properties of the composites were determined by tensile tests at 1 mm min^{-1} using a screw driven tensile test machine from UTS Testsysteme GmbH following the ASTM D3039 standard.

The damping properties of the composites were determined by dynamic mechanical analysis (DMA) in the single cantilever mode and vibration beam testing (VBT) in free vibration mode. Temperature sweep tests (TS) were made using DMA to evaluate the damping behaviour of the composites at a specific frequency. Each composite was heated from -40 °C to 120 °C at 2 °C min^{-1} at a constant deformation of 0.01 % at 1 Hz. For VBT measurements, a beam of fixed geometry is clamped to a fixed support. The free extremity of the beam is pulled backward by a nylon rope attached to a mass.

A Dirac impulsion is applied to the system by cutting the rope and a laser velocity-transducer set measured the displacement evolution of the end tip of the beam.

3. Results and discussion

3.1. Dynamic mechanical analysis

Figure 2 compares the loss factor obtained by DMA at 1 Hz and 25 °C for GF and FF/EP based composites in function of the specific Young's modulus (E_s). A marked increase in damping when using FF instead of GF was observed.

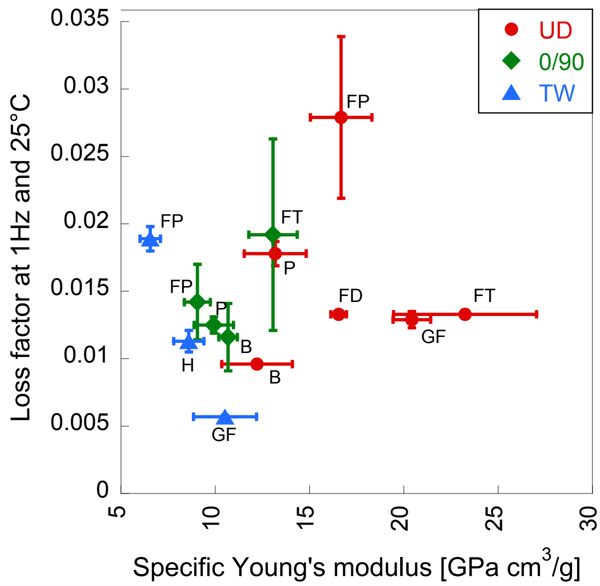


Figure 2: Loss factor determined by DMA in function of E_s for the UD, 0/90 and TW EP based composites.

When the fibre/matrix adhesion is improved through an EP sizing, the matrix/fibre stress transfer is better, activating the friction mechanisms given by the yarns and the elementary fibres. This explains the highest loss factor obtained with FF_FP_EP_UD.

The use of twisted yarns instead of non twisted yarns was supposed to increase the damping properties. It was confirmed with FF_FP_EP_UD which contains dense and not impregnated twisted yarns, allowing friction between the elementary fibres, called intra-yarn friction. With more open twisted yarns, such as FF_B_EP_UD, the EP resin filled better the spaces between the elementary fibres, preventing the intra-yarn friction. The obtained loss factor at 1 Hz and 25 °C with FF_FP_EP_UD is 191 % higher than the one obtained with FF_B_EP_UD.

When considering FF_FP_EP_UD, FF_FP_EP_0/90 and FF_FP_EP_TW, the effect of the architecture on the damping properties is clearly visible . The loss factor decreased of about 50 % with FF_FP_EP_0/90 in comparison to FF_FP_EP_UD. In the 0/90 architecture, the influence of the damping properties of the FF is reduced. In TW composites, the crimp effect acts on the damping properties increasing the friction between the yarns, called inter-yarn friction.

In general, composites made with FT and FP fabrics, where the fibre quality is recognized to be better, showed the best damping properties.

3.2. Vibration beam testing

VBT was used to study the damping behaviour of GF and FF/EP composite beams at broader scale than with a DMA. A larger sample geometry and higher deformations were thus considered which will have an influence on the relative importance of the different friction mechanisms.

Figure 3 compares the loss factor obtained by VBT for GF and FF/EP based composites in function of the specific Young's modulus (E_s).

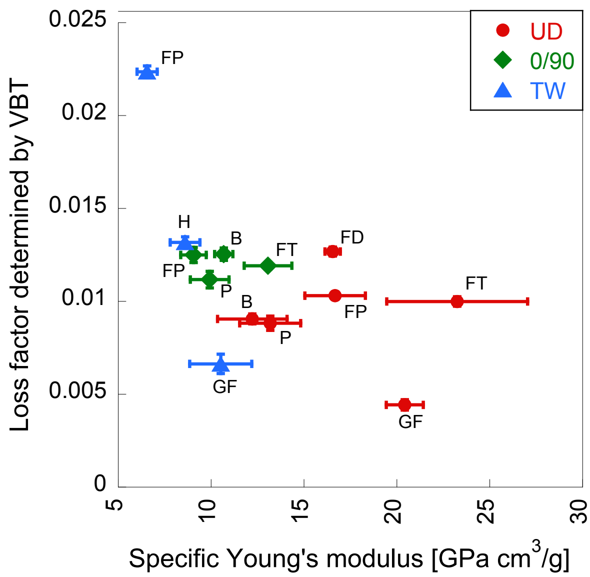


Figure 3: Loss factor determined by VBT in function of E_s for the UD, 0/90 and TW EP based composites.

A marked increase in damping when using FF instead of GF was again measured as illustrated on figure 3. FF_FP_EP_UD showed a loss factor increase of 133 % in comparison with GF_EP_UD. This difference is even much larger when considering the TW composites. The different friction mechanisms inherent to the use of FF have thus an impact on the damping properties. When comparing the FF_P_EP_UD and FF_FT_EP_UD results obtained on the VBT and on the DMA we see that sized FF_P_EP_UD showed lower loss factor than FF_FT_EP_UD under the larger deformations of the VBT, but higher loss factor at small deformations. The EP sizing on the P fabric increased the loss factor in comparison to the FT through better activation of the intra-fibre frictions when tested under the small deformations by DMA. Indeed energy dissipation through intra and inter-yarn frictions is promoted at large deformations. This phenomena are more important when there is no sizing, leading to poor bonding between fibre and matrix. This was also revealed through a loss factor increase of 23 % between the sized FF_FP_EP_UD and the unsized FF_FD_EP_UD.

The use of twisted yarns instead of non twisted yarns also increased the loss factor through intra-yarn friction as shown for UD and 0/90 configurations.

All the 0/90 composites had higher loss factor than their corresponding UD composites. Since the concentration and the nature of the FF were not varying between the corresponding UD and 0/90 composites, this difference was linked to a decrease of the stiffness when considering 0/90 stacking.

The comparison between FF_FP_EP_0/90 and FF_FP_EP_TW showed a significant increase by 79 % of loss factor for FF_FP_EP_TW inducing that the use of TW fabric has a strong influence on the dissipation of energy through inter-yarn friction.

When comparing figure 2 and figure 3, similar trends were observed. However lower loss factors were obtain with VBT measurements. This is linked to the frequency of vibration at which the loss factor was studied. With DMA, a frequency of 1 Hz was considered which is much lower than the frequency of vibration observed during VBT measurements. Friction mechanisms have more time to occur during DMA tests increasing the dissipation of energy and thus the damping properties. Different damping mechanisms occur at low or large deformations. At 0.01 % of deformation and 25 °C (DMA) inter and intra-cell wall friction mechanisms are effective when sized fibres are used while at larger deformation (VBT) inter and intra-yarn friction mechanisms dominate but are reduced with sized fibres. However for both studies, composites made with fibres with the best quality, FT and FP, allowed to obtain the best compromise between the mechanical and damping properties.

4. Conclusion

Damping properties of several flax fibre composites were determined by two different test methods. Different friction mechanisms were revealed to act on the damping properties of flax based composites. The influence of these mechanisms evolve in function of several parameters such as the fibre matrix adhesion, the twist of the flax yarns and the testing conditions.

Similar trends were observed in damping properties of various composites under different solicitations. For example both tests showed an increase of damping properties with the twist angle and crimp through enhanced intra-yarn and inter-yarn friction phenomena. Indeed the use of twill fabric improved the loss factor by 80 % when compared to 0/90 laminate. Furthermore while the intra fibre friction mechanisms were certainly dominant for damping at small deformation (DMA), intra and inter-yarn frictions had more importance at larger deformation as revealed by vibration beam testing (VBT) measurements in free vibration mode.

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