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The role of twist and crimp on the vibration behaviour of flax fibre composites

F. Duc, P.E. Bourban *, J.-A.E. Månson

Laboratoire de Technologie des Composites et Polymères (LTC), Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 12, CH-1015 Lausanne, Switzerland

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ABSTRACT

The damping properties of unidirectional, 0/90 and twill 2/2 flax fibre (FF) reinforced epoxy composites containing 40 vol% of fibres have been measured by vibration beam testing (VBT). The influence 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 quantified. Carbon and glass fibre reinforced epoxy composites were considered as comparison. Unidirectional FF instead of glass fibres led to a damping increase of 133%. Under the VBT conditions, the inter and intra-yarn frictions mechanisms were dominant leading to energy dissipation. The damping properties increased with the twist and crimp amount, leading to a damping increase of 79% when a twill 2/2 fabric was considered instead of a $[0/90]_n$ laminate. Fibre/matrix friction improved the damping properties by 23% with a limited fibre/matrix adhesion. Finally damping maps for several material systems were established.

1. Introduction

There is a constant evolution in the field of composite. 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 field such as automotive, aeronautics and sports. Vibrations are undesirable for structures, owing to the need for structural stability, position control, durability, performance and noise reduction. Composite materials have been used more and more for advanced sport equipments not only for their high specific mechanical properties but also for their damping capacity, which reduces notably, through energy dissipation, noise and vibration and enhances the durability of the structure, particularly against fatigue. Damping contributes also to impact resistance owing to its energy dissipating nature: well damped materials have better resistance to impact. A typical carbon fibre (CF) reinforced plastic composite could have at least five times the stiffness/weight ratio and a hundred times more damping than e.g. the aluminium alloys used extensively in aerospace structural applications [1].

Damping phenomena are somehow different with composites materials than with metals. Indeed the damping properties of composites are functions of the respective properties of the constituent materials and, therefore, of the nature and the proportion of each material present. Using NF in composite applications may improve damping properties. The viscoelastic and hierarchical nature of cellulose fibres, the fibre–matrix interface, the fibres aspect ratio and the interactions between fibres can play a role. First studies on NFC are emerging [2–16]. Wielage et al. [17] studied dynamic mechanical properties of flax (FF), hemp and glass fibres (GF) polypropylene (PP) composites using dynamic mechanical analysis (DMA) (1 Hz from −40 °C to 120 °C). They showed that the storage modulus increases and the loss factor decreases with increasing the fibre content. With 30 wt% of fibres in a PP matrix the loss factor was always higher with FF than GF.

In a previous study the authors compared the damping properties obtained by DMA of unidirectional (UD) and twill 2/2 (TW) FF reinforced thermoset (epoxy (EP)) and thermoplastic (PP and polylactic acid (PLA)) composites containing 40 vol% of fibres with those of CF and GF reinforced EP composites [18]. The composites reinforced with FF showed improved damping through different friction mechanisms intrinsic to the use of FF. FF/PP showed the highest damping at 25 °C and 1 Hz with a loss factor of 0.033.

Another study investigated the influence 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 [19]. For example an increase in damping properties with the

* Corresponding author. Tel.: +41 21 693 58 06; fax: +41 21 693 58 80.
E-mail address: pierre-etienne.bourban@epfl.ch (P.E. Bourban).

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twist and the crimp was observed illustrating the importance of FF friction mechanisms.

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 relationship (1), only valid for $\tan\delta < 0.1$ [20].

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

where Q is the quality factor, ψ is the specific damping capacity, ξ is the loss factor, λ is the logarithmic decrement, δ is the phase angle by which stress leads strain, E'' is the loss modulus, E' is the storage modulus, ζ is the damping ratio (or damping factor), ΔW is the energy loss per cycle, W is the maximum elastic stored energy, φ is the wavelength of elastic wave and α is the attenuation. Such diversity results come from the fact that not only different test methods have been considered, but also the work on damping covers a whole range of materials under different working conditions, where different but often overlapping damping mechanisms may apply [1].

Different phenomena influencing the mechanical and damping properties of NFC have been highlighted in literature. However their quantification has not been yet studied in details. The aim of this study is to determine by vibration beam testing (VBT) the role of the amount of twist in the FF yarns and crimp in the FF fabrics on the damping properties of EP reinforced with different UD and TW FF fabrics. The observed properties will be compared with CF and GF reinforced EP composites and with the results obtained in a previous study [19] by DMA.

2. Experimental details

2.1. Fibres and polymer matrix

2.1.1. Carbon fibres

Unidirectional (UD) and twill 2/2 (TW) woven CF fabrics were purchased from *Swiss-Composite* in Fraubrunnen, Switzerland. The fibre average weight (FAW) of the UD and TW fabrics were 270 g/m^2 and 200 g/m^2 respectively.

2.1.2. Glass fibres

UD and TW woven GF fabrics were purchased from *Swiss-Composite*. The FAW of the UD and TW fabrics were 220 g/m^2 and 280 g/m^2 respectively.

2.1.3. Flax fibres

Several UD and TW FF woven fabrics were used throughout this study, each having differences concerning the twist, the crimp, the refinement, the fibre average weight (FAW) or the sizing. Table 1 lists the used FF fabrics giving their main characteristics as well as the twist angles of the corresponding yarns, determined by scanning electron microscopy (SEM) performed on a Philips XLF-30 under an acceleration voltage of 3 or 5 keV and at a working distance of 10 mm. FP, FD and FT fabrics are made with high quality fibres, having less defaults, called dislocations, along their axis.

Table 1
Main characteristics of the used FF fabrics.

Fabric	Architecture	Twist angle (°)	Sizing EP	FAW (g/m^2)
FP	UD	13	Yes	180
FP	TW	13	Yes	300
FD	UD	13	No	180
FT	UD	0	No	200
P	UD	0	Yes	122
B[1]	UD	13	No	300
H	TW	16	No	200

[1] Non-crimp FF fabric.

Table 2
Realized FF/EP based composites, the abbreviations used in this study, their indicative porosity.

Fabrics	Orientations	Abbreviations	Porosity (%)
FP	UD	FP_UD	3.3
FP	0/90	FP_0_90	1.5
FP	TW	FP_TW	6.4
FD	UD	FD_UD	3.2
FT	UD	FT_UD	1.7
FT	0/90	FT_0_90	6.2
P	UD	P_UD	6.8
P	0/90	P_0_90	4.0
B	UD	B_UD	1.0
B	0/90	B_0_90	2.6
H	TW	H_TW	1.7

In order to reduce moisture and thus formation of defects in the composite parts, the fibres were always dried for 12 h at 60 °C before processing.

2.1.4. Epoxy matrix

The EP resin L-235, purchased from *Swiss-Composite*, was used as a thermoset resin. The hardener was Epoxy-Härter 236 from the same company. Its density was 0.99 g/cm^3. E and elongation at break were 3.5 GPa and 1.4% respectively.

2.2. Composite processing

Resin transfer moulding (RTM) was used to produce the composite plates. A volume fibre fraction of 40% was used throughout.

The final dimensions of the plates were $260 \times 260 \times 2.5$ mm^3. Prior to impregnation, the mould and the resin were preheated to 60 °C in order to reduce the resin viscosity. A vacuum pressure of -0.8 bar and a constant injection pressure of 0.7 bar were applied during impregnation. The plates were then cured in the mould at 40 °C for twelve hours. The final glass transition temperatures were of 77 °C and 68 °C for the neat resin and the composites respectively [18]. Porosity measurements have been done on each composites by optical microscopy analysis. Only indicative porosity could be measured owing to surface damaging during the polishing.

Table 2 summarizes the different processed composites with the abbreviations used in this study. The 0/90 composites have been processed by stacking UD fabrics on a $[0/90]_n$ configuration.

2.3. Damping properties

VBT in free vibration mode was used to characterise the damping behaviour of polymer and composite cantilevered beams. In this study, the free vibration is modeled by a beam built in at one side and free at the other. For simplicity reason, this system was assigned one degree of freedom. That hypothesis allows to use the theory of the elementary oscillator to describe the behaviour of a beam after an initial release without later input of energy through an external force. Under such conditions, the vibratory response of a polymer or composite beam is given by the behaviour of a underdamped oscillator for which the displacement (x) over the time (t) is represented by a damped sine curve (Eq. (2)) included between the two envelopes $\pm Xexp(-\lambda t)$ [21].

$$x = exp(-\lambda t)(Acos\omega_1 t + Bsin\omega_1 t) \quad (2)$$

where A and B are constants, λ is the damping coefficient and ω_1 is the damped angular frequency.