Composite Structures 132 (2015) 148–154

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Evaluation of the damping of hybrid carbon–flax reinforced composites

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ARTICLE INFO

Article history:
Available online 9 May 2015

Keywords:
Flax fibre
Carbon fibre
Hybrid composites
Vibration testing
Damping
Modelling

ABSTRACT

The object of the paper is to investigate the effects of staking sequences and hybridation on the damping properties of flax–carbon twill epoxy composites. Various staking sequences of these hybrid laminates were manufactured by platen press process. Next, dynamic properties were investigated using beam test specimens and an impulse technique. Damping modelling was implemented by using a finite element analysis to evaluate the dissipated energies in each layer of carbon–flax laminates. The obtained results show a good agreement between the experimental damping coefficients and those deduced from modelling. It is also shown that the position of flax layers within the hybrid composites plays a major role on their bending stiffness and damping properties.

1. Introduction

The glass, carbon and Kevlar fibres reinforced polymer composites know a continuously increasing development in all the industrial domains such as marine, aerospace, sports, etc. Today, natural fibres reinforced polymer composites are emerging in the composite applications because they are ecological, their resources are renewable and they are considered neutral toward CO_2 emissions [1]. Thus, due to their good specific properties, natural fibres could constitute, in particular applications, an interesting alternative to glass fibres [2,3]. Consequently, various natural fibres reinforced polymer composites were the subject of several studies [4–14]. In particular, the effect of natural fibres treatment on the mechanical properties of these composites, the degradation of their mechanical properties in a hygrothermal environment and their different damage modes during the failure process were studied [4,9,11,14]. Furthermore, these studies are not sufficient because the development of natural fibres reinforced composite materials in high performance applications requires further information about their dynamic properties such as damping. Indeed, the problem of energy dissipation constitutes an important factor in the mechanical design of structures. Sufficient damping is needed to reduce vibration of structures as well as to avoid fatigue fracture. Moreover, the control of damping phenomena of composite materials passes by the knowledge of the different damping processes, such as the viscoelastic behaviour of the matrix, the damping of the fibre–matrix interphase and the damping due to damage [15]. Currently, the dynamic behaviour of traditional composites was thoroughly studied as reported in several papers [16–23]. The initial works on damping analysis of traditional fibres reinforced composites were specifically developed in [16,17]. Next, several concepts were used to model the damping of these composites [18,19]. In particular, extensive analyses of the damping of glass and Kevlar reinforced composites and laminates with interleaved viscoelastic layers were reported by Berthelot [20,21] and Berthelot and Sefrani using the Ritz method [22,23].

For natural fibre composites, some researchers have already analysed experimentally damping performances [24–27]. For example, Wielage et al. [24] studied the dynamic properties of flax, hemp and glass fibres reinforced polypropylene composites using the Dynamic Mechanical Analysis (DMA). They found that, for the same conditions, the loss factors of flax and hemp composites are significantly higher than the glass ones. Recently, Duc et al. [25] analysed the effect of several parameters on the damping properties of flax fibre reinforced composites such as the impregnation quality, the fibre–matrix adhesion, the twist angle of yarns and crimp in flax fabrics. They particularly observed an increase in the damping properties with fibre twist and crimp showing the important friction mechanisms which are induced. In another work, Le Guen et al. [28] analysed the effect of fibre treatment with polyols on the damping of flax fibre reinforced epoxy composites. They observed a higher damping behaviour of treated flax fibre composites compared with the non-treated ones. This could be attributed to the formation of hydrogen bonds between the polyols and flax micro fibrils within the lamellae as explained in [28]. Duc et al. [26,27] compared the damping properties of carbon, glass and flax fibres composites by considering the DMA and vibration beam

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http://dx.doi.org/10.1016/j.compstruct.2015.05.016

testing. In particular, they showed that flax fibre reinforced composites present a relatively higher damping behaviour with respect to the other composites which could be attributed to the different friction mechanisms intrinsic to flax fibres.

These studies showed that the use of natural fibres as reinforcement of composite materials can significantly improve their damping properties and reduce unwanted vibrations of structural applications. For high performance applications, damping could be, in some cases, insufficient for their safe design. In fact, it should be combined with mechanical performances. It is within this context that the present study of the mechanical and dynamic properties of carbon–flax hybrid composites is proposed. This choice is motivated by the high mechanical performance of carbon fibre as well as the interesting dynamic properties of flax fibre. For this purpose, non-hybrid and hybrid carbon and flax fibre reinforced composites were elaborated to determine, by free vibration testing, the effects of hybridation on the dynamic properties of hybrid composites. Next, we will show how the laminate theory associated to a finite element analysis allows us to describe the damping characteristics of these hybrid composites.

2. Experimental procedure

2.1. Materials

Several non-hybrid and hybrid laminates were prepared by impregnating flax and carbon fibres with SR 1500 epoxy resin and SD 2503 hardener. Carbon twill of 300 g/m^2 and flax twill of 350 g/m^2 were used. The plates of hybrid and non-hybrid laminates were manufactured by platen press process: the different fabrics were first impregnated one by one with the resin and then placed between two steel trays to be cured at 35 °C for 3 h with a pressure of 5 bars.

Six types of twill hybrid laminates with different stacking sequences, shown in Table 1, were elaborated to investigate the effect of hybridation type on the composites damping. The thickness and volume fraction of each plate depend on the considered laminate as indicated in Table 1.

The engineering constants of flax and carbon laminates referred to the material directions $(1, 2, 3)$ or (L, T, T') were measured in static tensile tests on five specimens. The obtained mean values are reported in Table 2.

2.2. Experimental equipment

The dynamic characteristics of the studied composite materials were derived from the analysis of the free flexural vibrations of the test specimens. The equipment is shown in Fig. 1. The test specimens are supported vertically by two fine rubber threads in such a way to have free-free boundary conditions of the beam. An impulse hammer (PCB 086C03 model) is used to induce the excitation of the flexural vibrations of the composite beam.

Table 2
Engineering constants of the non-hybrid twill carbon and flax reinforced composite materials.

Laminates	E_L (GPa)	E_T (GPa)	G_{LT} (GPa)	ν_{LT}
Carbon fibre reinforced epoxy laminate	54.10	54.10	3.60	0.33
Flax fibre reinforced epoxy laminate	11.50	11.50	2.01	0.31

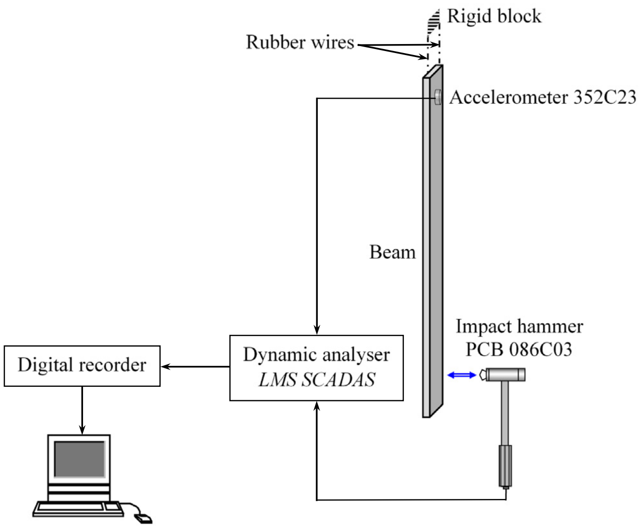

Fig. 1. Experimental equipment.

The specimen response was then detected by an accelerometer (PCB 352C23 model) which measures the acceleration of the transverse vibrations. Next, the excitation and the response signals were digitalized by a dynamic analyser LMS SCADAS Mobile. This analyser associated with a PC computer performs the acquisition of signals, controls the acquisition conditions and the analysis of the acquired signals. The system allows the simultaneous acquisition of four signals with a maximum sampling frequency of 102.4 kHz with a resolution of 24 bits for each channel. Impulse excitations of flexural vibrations were implemented at different points of the beam, and the response was detected at the accelerometer as shown in Fig. 1. These experimental analyses were performed on five specimens with different lengths 230, 250 and 270 mm in order to obtain a variation of the peak frequencies values. The experimental shapes of the natural modes were also estimated by the LMS PolyMAX method [29]. This method is globally divided in two steps: first, a stabilization algorithm is used to determine the natural frequencies as well as their corresponding damping, and second, a least squares frequency domain (LSFD) method is used to calculate the mode shapes. The obtained experimental modes were visualised in order to verify that they correspond to bending modes of beams with two free ends.

Table 1
Designation of the non-hybrid and hybrid laminate composites.

Laminates	Ply number ratio (carbon/flax)	Stacking sequence C: Carbon F: Flax	Plate thickness (mm) (Carbon/Flax)	Volume fraction ratio (%) (Carbon/Flax)
Carbon	8/0	C C C C C C C C	2.6/0	52/0
$[C_3/F]_S$	6/2	C C C **F F** C C C	1.4/1.1	40/12
$[C_2/F_2]_S$	4/4	C C **F F F F** C C	0.6/1	25/22
$[C/F_3]_S$	2/6	C **F F F F F F** C	0.4/2.5	15/35
Flax	0/8	**F F F F F F F F**	0/3.8	0/39
$[F_3/C]_S$	2/6	**F F F** C C **F F F**	0.4/2.7	14/35
$[F_2/C_2]_S$	4/4	**F F** C C C C **F F**	0.8/2.1	24/22
$[F/C_3]_S$	6/2	**F** C C C C C C **F**	1.3/1.1	41/12