Composite Structures 113 (2014) 362–368

Contents lists available at ScienceDirect

Composite Structures

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

Modal characterisation of recyclable foam sandwich panels

G. Petrone [a,*], V. D'Alessandro [a], F. Franco [a], B. Mace [b], S. De Rosa [a]

[a] Department of Industrial Engineering – Aerospace Division, Universitá degli Studi di Napoli "Federico II", Via Claudio 21, 80125 Napoli, Italy
[b] Department of Mechanical Engineering, University of Auckland, Private Bag, 92019 Auckland, New Zealand

ARTICLE INFO

Article history:
Available online 28 March 2014

Keywords:
Sandwich panels
Recyclable
Modal analysis
Damping

ABSTRACT

The reduction of the mass of a structure is an important issue in the engineering field since it leads to reduced emissions and operating costs. On the other hand, weight saving often leads to an increase of vibration and noise transmission. For this reason, in the last years, the dynamic design of lightweight structures has received more emphasis, particularly in engineering applications where dynamic loads can produce high amplitudes of vibration. At the same time, the research has been also focussed on the use of "green materials" with the intention to satisfy both weight and comfort requirements. This paper presents the results of an experimental campaign performed on two ecologically friendly sandwich panels. All the investigated panels present a recyclable core, while the face sheets are made of natural or plastic fibres combined with recyclable resin. In order to evaluate the vibrational characteristics, the mode shapes, the natural frequencies and the damping ratio of the sandwich panels are identified experimentally through modal tests, adopting the roving hammer technique. The structural loss factor is also measured using the reverberation time method. Experimental results, in terms of modal parameters, are compared with numerical ones, obtained through a finite element model.

1. Introduction

Sandwich panels are of particular interest and widely used in engineering applications because of their several advantages such as: high strength to weight ratio, excellent thermal insulation and good performance as water and vapour barriers. A sandwich panel consists of layered composite structure, obtained by bonding two thin but strong and stiff face sheets to a relatively thick low-density core. The face sheets are generally designed to provide bending and in-plane shear stiffness while the role of the core is to carry the shear loads that is transmitted through their thickness. Several core types are available, such as honeycombs, foams and cellular metals [1]. The type of core to be used should be carefully selected depending on their application requirements. In fact, among the load bearing capability, the selection of the core should consider the enhancement of the performance in terms of fire retardant, thermal conduction and sound transmission/absorption. Honeycomb cores have the greatest shear strength and stiffness-to-weight ratios but require special care to ensure adequate bonding of the face sheets to the core since honeycombs are hollow. The hexagonal honeycomb is the basic and most common cellular honeycomb configuration and it is available in many metallic and non-metallic materials. Instead, the foam cores have very low thermal conductivity, making them a prime choice for thermal insulation; very low dielectric loss, allowing transmission of microwaves without attenuation or scattering; good absorption capability, suiting them as materials for noise abatement. Furthermore, they are cheaper than the honeycomb cores and allow an easy manufacturing of sandwich panels [1,2]. While the main requirement of the core is to be thick and light, the face sheets should have sufficient stiffness to withstand the tensile, compressive and shear stresses produced in their plane by applied loads. Face sheets are usually made of Fibre Reinforced Plastic (FRP), which offers numerous advantages over conventional materials: low weight; low cost; possibility to be modified by using different variety or types of fillers and fibres to suit the strength and modulus requirements of a particular application. The most common reinforcing fibres are inorganic materials such as glass, carbon and aramid, which offer good mechanical properties [3,4]. These materials have traditionally been selected for high performance, mass reduction, safety, and ease of manufacturing for all applications including transportation, civil, as well as military. However, with the recently increased regulatory and ecological accent on recycling, composite materials must now be examined for their potential as recyclable and reusable materials. The recyclability of all materials, components, and systems, in fact, has gained an increased international emphasis, and this leads to the attention on the use of natural

* Corresponding author. Tel.: +39 3348006958.
E-mail address: giuseppe.petrone@unina.it (G. Petrone).

http://dx.doi.org/10.1016/j.compstruct.2014.03.026
0263-8223/

fibres as alternative to the synthetic ones [5,6]. Natural fibres, such as kenaf, hemp, flax and sisal, have attracted renewed interest especially as a glass fibre substitute in the automotive industry and packaging applications. They are low cost, low density, acceptable specific strength properties, ease of separation and biodegradability. All the natural fibres are lignin-cellulosic and their properties vary with location, origin and age of the plant [7].

Natural Fibre Composites (NFCs) have already found widely used in different applications: sport, musical instrumentation, infrastructure, marine and automotive. However their use is not a new idea since as long ago as 1941, Henry Ford developed a prototype composite car made from hemp fibres [8]. Nowadays, the automotive field is still the predominant one in NFC applications: manufacturers such as BMW and Mercedes-Benz are beginning to incorporate hemp into car components. For instance the Mercedes S-class [9] uses 43 kg of natural fibre (hemp fibres) reinforced thermoplastics (polypropylene) in door cards, seat bases, pillar inners, head liner, rear cargo shelf and trunk components and other internal applications (Fig. 1); the 2005 Ford Mondeo uses polypropylene reinforced with kenaf in its door linings [10].

Although sandwich structures have significant advantages, they present some less favourable properties. In fact, the weight saving advantages produced by the sandwich effect leads to the presence of vibrations and thus of noise, providing undesirable effects: mechanical failure of the structures and discomfort of the passengers. Experimental dynamic characterisation of sandwich plates made of traditional composite materials have been evaluated extensively [11–21], whereas only few works regarding the analysis of sandwich panels made of bio-based materials can be found [22–24].

Knowledge of the passive damping of sandwich structures is fundamental in order to reduce the vibrations. Even if the usage of bio-based materials is receiving increased attention in several engineering applications, few studies have been performed on the damping properties of natural fibre sandwich composites [23,25].

Part of the work explained below has been presented at ICCST/9 conference [26]. In this paper, two sandwich panels are investigated experimentally. Both of them use a recyclable foam core, but one has face sheets made of natural fibre, while the other one has face sheets with glass fibre. The modal parameters, natural frequencies, mode shapes and modal damping, are carried out from experimental tests. A finite element model is built and validated by comparing the numerical and experimental results. Finally, further estimation of the structural loss factor is performed by using the reverberation time measurements.

2. Materials and manufacturing

Two different kinds of sandwich panels were manufactured and investigated. In order to study the possibility of replacing glass fibres with flax ones, the two panels were manufactured by using the same core material and different face sheets material. The used core is a recyclable, pre-preg compatible foam core (DIAB® Divinycell F90), offering excellent FST (Fire, Smoke and Toxicity) properties, good mechanical and processing characteristics. The material properties of the core are listed in Table 1.

The first type of face sheets is made of five plies of Plytron, with a lay-up 0/90/0/90/0. Plytron is a commercially available pre-preg material consisting of 35% volume fraction of unidirectional glass fibres in a polypropylene (PP) matrix. The synthetic glass fibres typically exhibit high strength and stiffness and although it is not a Natural Fibres Composite (NFC), the use of a PP matrix still allows for mechanical recycling of the entire sandwich panel. The other type of face sheets is made of five plies of flax/PE, with a lay-up 0/90/0/90/0. Flax is a natural fibre that has become recently available in commercial grades for use in NFCs. Flax fibres were consolidated with polyethylene (PE) sheets to manufacture a face sheet laminate. The material properties of both the face sheets, indicating with the subscript 1 the longitudinal direction and the subscript 2 the transversal one, are listed in Table 2.

All the sandwich panels, herein discussed, were manufactured at CACM (Centre for Advanced Composite Material) of the University of Auckland, using a vacuum bag technique. The vacuum bagging is a clamping method that uses atmospheric pressure to hold the adhesive or resin-coated components of a lamination in place until the adhesive cures [27]. This technique involves first the positioning of the sandwich panel lay-up onto a tool, hence the placing and sealing of a flexible bag over the lay-up. All the air is evacuated from under the bag by using a vacuum pump. The removal of the air forces the bag down onto the lay-up thanks to the atmospheric pressure (1 bar). At the end, the assembly, constituted by the tool, the sandwich panel layers and the vacuum bag, is placed inside an oven (Fig. 2). No adhesive layers were used to bond face sheets and cores, in order to reduce the number of parameters affecting the damping of the panels. The bonding was obtained during curing, where the resin flows out from the uncured face sheets and creates the bonding between the face sheets and the core.

3. Experimental investigation

3.1. Test specimen

Experimental tests, on two different sandwich panels, are performed. The sandwich panels consist in a three-layer composite comprising a recyclable, pre-preg compatible foam core and two face sheets made of flax-PE for the panel A, glass-PP for the panel B. The two panels, shown in Fig. 3, have the same in-plane dimensions (400 mm × 200 mm) but different thickness of the core. In particular the core thickness of the panel A is 26 mm, whereas the core thickness of the panel B is 20 mm. Panel dimensions are listed in Table 3.

(a) (b)

Fig. 1. Example of natural fibre composite parts for interior applications of a Mercedes vehicle [36].