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Fabrication and mechanical testing of glass fiber entangled sandwich beams: A comparison with honeycomb and foam sandwich beams

Amir Shahdin [a], Laurent Mezeix [b], Christophe Bouvet [c], Joseph Morlier [a,*], Yves Gourinat [a]

[a] Université de Toulouse, ISAE/DMSM, Campus Supaero, 10 av. Edouard Belin BP54032, 31055 Toulouse, France
[b] Université de Toulouse, INPT-ENSIACET/CIRIMAT, 118 Route de Narbonne, 31077 Toulouse, France
[c] Université de Toulouse, UPS/LGMT, Bat 3PN 118 Route de Narbonne, 31062 Toulouse, France

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ABSTRACT

The aim of this paper is the fabrication and mechanical testing of entangled sandwich beam specimens and the comparison of their results with standard sandwich specimens with honeycomb and foam as core materials. The entangled sandwich specimens have glass fiber cores and glass woven fabric as skin materials. The tested glass fiber entangled sandwich beams possess low compressive and shear modulus as compared to honeycomb and foam sandwich beams of the same specifications. Although the entangled sandwich beams are heavier than the honeycomb and foam sandwich beams, the vibration tests show that the entangled sandwich beams possess higher damping ratios and low vibratory levels as compared to honeycomb and foam sandwich beams, making them suitable for vibro-acoustic applications where structural strength is of secondary importance, e.g., internal paneling of a helicopter.

1. Introduction

Sandwich structures are commonly used in aerospace and automobile structures, since they offer great energy absorption potential and increase the flexural inertia without significant weight penalties. The purpose of the core is to maintain the distance between the laminates and to sustain shear deformations. By varying the core, the thickness and the material of the face sheet of the sandwich structures, it is possible to obtain various properties and desired performance [1–4]. Examples of widely used laminate materials are glass reinforced plastic (GRP) and carbon fiber. There are many wide varieties of core materials currently in use. Among them, honeycomb, foam, balsa and corrugated cores are the most widely used. Usually honeycomb cores are made of aluminum or of composite materials: Nomex, glass thermoplastic or glass-phenolic. The other most commonly used core materials are expanded foams, which are often thermoset to achieve reasonably high thermal tolerance, though thermoplastic foams and aluminum foam are also used. For the bonding of laminate and core materials, normally two types of adhesive bonding are commonly employed in sandwich construction, i.e., co-curing and secondary bonding.

Characterization of sandwich materials has been carried out in detail in scientific literature. The determination of the sandwich material behavior under crushing loads and the measurements of the ductile fracture limits is normally done with the help of compression tests [5,6]. Typically, cores are the weakest part of sandwich structures and they fail due to shear. Understanding the shear strength properties of sandwich core plays an important role in the design of sandwich structures subjected to flexural loading [7,8]. Therefore, three-point bending tests are often performed to find the flexural and shear rigidities of sandwich beams [9–11]. The vibration characteristics of sandwich materials have drawn much attention recently. The dynamic parameters of a structure, i.e., natural frequency, damping and mode shapes, are determined with the help of vibration testing which provides the basis for rapid and inexpensive dynamic characterization of composite structures [12]. Ewins [13] gave a detailed overview of the vibration based methods. A wide amount of literature is present related to vibration testing of composite sandwich beams [14–20]. The equations that explain the dynamic behavior of sandwich beams are also described extensively in the literature and notably in [21,22].

The importance of material damping in the design process has increased in recent years as the control of noise and vibration in high precision, high performance structures and machines has become more of a concern. In polymeric composites, the fiber contributes to the stiffness and the damping is enhanced owing to the internal friction within the constituents and interfacial slip at the fiber/matrix interfaces. At the same time, polymer composites researchers have focused more attention on damping as a design variable and the experimental characterization of damping in composites and their constituents [23,24]. A comprehensive review on the status of research on damping in fiber-reinforced composite materials and structures has been presented by Chandra et al. [25]. Their paper presents damping studies involving macro-mechanical, micro-mechanical and viscoelastic approaches;

* Corresponding author. Tel.: +33 5 61 33 81 31; fax: +33 5 61 33 83 30.
E-mail address: joseph.morlier@isae.fr (J. Morlier).

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models for inter-phase damping, damping and damage in composites. In recent years, several investigators have considered a number of innovative ideas in order to improve the mechanical performance of sandwich structures. But the majority of these works present in scientific literature for example [26–29], are related with the improvement of the mechanical properties (in particular the longitudinal Young's modulus and the transverse shear modulus) and the impact toughness (energy absorption characteristics) of sandwich structures. However works related to the enhancement of damping in sandwich structures are relatively few in number as compared to enhancements in mechanical properties and impact toughness. A way of increasing damping in sandwich materials is by putting a viscoelastic layer as core between the two laminates [30,31]. Yim et al. [32] studied the damping behavior of a 0° laminated sandwich composite cantilever beam inserted with a viscoelastic layer. Gacem et al. [33] improved damping in thin multilayer sandwich plates having five layers composed of elastomer and steel. Afterwards they submitted the structure to shear vibrations under a compression preload. With the advancement of technology in electro-rheological (ER) materials, their applicability to sandwich structures has been increased significantly due to their merits such as variable stiffness and damping properties [34]. The vibration analysis of a sandwich plate with a constrained layer and electro-rheological (ER) fluid as core has been investigated by Yeh and Chen [35]. Jueng and Aref [36] also investigated the feasibility of a combined composite damping material system. In this new configuration, they used two different types of composite materials. One is a polymer honeycomb material and the other is a solid viscoelastic material. The honeycomb material is helpful to enhance the stiffness of the entire structure, and the solid viscoelastic will provide more energy dissipation properties in the multilayer panel systems when subjected to in-plane shear loading. These advanced polymer matrix composite (PMC) systems are also addressed for seismic retrofitting of steel frames [37]. Damping layer in sandwich structures can be made of any suitable material which provides the vibration damping function. Damping can be promoted in sandwich structures by using rubber-type cores made of butyl rubber or natural rubber, plastics such as polyvinyl chloride (PVC), adhesives of various polymer materials including epoxy-based materials, silicones, polyurethane, etc. [38,39]. A 3MTM VHBTM structural glazing tape is also used as damping layer in sandwich structures [40].

These advancements have led to the need for developing materials possessing better damping characteristics. Entangled sandwich materials can be used as potential dampers and sound absorbers in specific applications like the inner paneling of a helicopter, where structural strength is not the primary requirement. Entangled materials are made from natural materials (wool, cotton, etc.) as well as artificial ones (carbon, steel, glass, etc.) and are quickly becoming of widespread use as sound absorbers [41]. Bonded metal entangled materials offer advantages for use as heat exchanger [42] or insulation [43]. These materials possess low relative density, high porosity and are cost-effective. Recently, a novel type of sandwich has been developed with bonded metallic fibers as core material [44–48]. This material presents attractive combination of properties like high specific stiffness, good damping capacity and energy absorption. Entangled materials with carbon fibers have also been studied as core material [49]. Entangled materials with cross-linked carbon fibers present many advantages as core materials, i.e., open porosity, multifunctional material or the possibility to weave electric or control cables on core material. Mezeix et al. [50] studied the mechanical behavior of entangled materials in compression. Mechanical testing has also been carried out on specimens made of wood fibers [51], glass fibers [52] and various matted fibers [53]. There are also some works in the literature related to 3D modeling of wood based fibrous networks based on X-ray tomography and image analysis [54]. Unfortunately, only a few works can be found in the scientific literature devoted to the mechanical testing of entangled sandwich materials, and no scientific literature can be found related to the vibration testing of entangled sandwich materials or even simple entangled materials.

The type of sandwich structures considered in this article consist of two thin but relatively stiff sheets bonded to each side of a 10 mm thick light-weight core in a symmetrical configuration with the help of co-curing process. The proposed entangled sandwich specimens are currently in the phase of research and are not a finished article as yet. Therefore the mechanical behavior of these sandwich materials are compared for now with standard sandwich beams with honeycomb and foam cores only. Once further expertise is developed in fabricating entangled sandwich specimens, their mechanical behavior especially damping capability shall be compared with innovative sandwich specimens such as multi-layered sandwiches with viscoelastic cores, 3D fabric sandwich structures including glass fibers in the thickness directions, thermoplastic cored sandwiches, etc. Furthermore, compression and three-point bending tests are carried out to determine the compressive and shear modulus. Vibration testing is used to diagnose the quality of the fabrication process and also to verify the potential damping capabilities of the entangled sandwich specimens.

2. Experiments

2.1. Materials and specimens

Three types of sandwich beam specimens are fabricated and tested in this article with entangled glass fibers, honeycomb and foam as core materials. The skins for all the sandwich beams used are made of glass woven fabric 20823 supplied by Brochier. The sandwich beam specimens are fabricated using an autoclave and an aluminum mold. The skin and the core are cured simultaneously in order to have an excellent bond. The physical properties of the skin are given in Table 1. The glass woven fabric is impregnated with the help of epoxy resin. The epoxy resin SR 8100 and injection hardener SD 8824 are provided by Sicomin. The upper and lower skins consist of two 0.5 mm thickness plies containing 50% of resin by volume. The combined weight of the upper and lower skins is approximately 19 g for each of the three types of sandwich specimens.

The entangled sandwich beam cores consist of glass fibers that are made of a yarn of standard glass filaments. The properties of the glass fibers are presented in Table 2. The fibers are provided by the company PPG Fiber Glass Europe. The same epoxy resin is used as in case of the skins for the cross-linking of glass fibers. All the test specimens presented in the article are carefully weighed using a Mettler balance.

The honeycomb and foam cores can be selected from a wide range of metallic and non-metallic honeycomb cores and a variety of non-metallic foams. The honeycomb sandwich beams in this article are made of Nomex-aramid honeycomb core (HRH 10) supplied by Hexcel composites [55]. The honeycomb core has a nominal cell size of 6.5 mm and a core thickness of 10 mm. In case of the foam sandwich beams, the foam core has a thickness of 10 mm and is provided by Rohacell (51 A). Mechanical properties

Table 1
Properties of glass woven fabric.

Elastic modulus in the longitudinal direction (E_x)	23,000 MPa
Elastic modulus in the transverse direction (E_y)	23,000 MPa
Shear modulus (G)	2900 MPa
Poisson ratio	0.098