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Manufacturing and testing of a sandwich panel honeycomb core reinforced with natural-fiber fabrics

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ABSTRACT

A novel honeycomb core made of a natural-fiber reinforced composite consisting of a vinylester matrix reinforced with jute fabric is introduced. Six-mm- and 10-mm-cell honeycombs are manufactured using two compression-molding techniques. Best results are obtained for the mold with lateral compression. Experimental tests are conducted to characterize the elastic response of the composite and the core response under flatwise compression. The effective elastic properties of the core are computed via a homogenization analysis and finite element modeling. The results of the homogenization analysis are in very good agreement with estimations done using analytical formulas from the bibliography. The flatwise compression tests show that the core failure mechanisms are yarn pull-out and fiber breaking. The large wall thickness relative to the cell size of the jute–vinylester cores, which inhibits buckling, and the heterogeneities in the composite, which are preferential damage initiation sites, explain the observed behavior. When compared in terms of the specific strengths, the jute/vinylester cores introduced in this work show similar performances to those of their commercially available counterparts. The results from this study suggest that jute-reinforced cores have the potential to be an alternative to standard cores in applications that sustain compressive static loads.

1. Introduction

Sandwich panels are widely used as a means to build high-performance lightweight structures [1,2]. Sandwich panels consist of two thin and stiff face-sheets (or skins) bonded to a thick and light core. The face sheets provide the flexural stiffness and strength to the panel, while the role of the core is to transmit the shear between the face sheets. A strong core can also contribute to the flexural stiffness and to the out-of-plane shear and compressive strength of the panel [1,3]. On the other hand, a core with poor mechanical properties undermines the performance of the panel [3]. Typically, cores are made of foams or balsa [4,5] or they are fabricated using corrugated, truss or honeycomb structures [6,7]. Corrugated cores provide unidirectional support to the skins [8,9], while honeycomb cores provide bidirectional support [1]. The most used materials in honeycomb fabrication are aluminum, polymers and composites like Nomex [10].

Sandwich panels are used not only because of their advantages in terms of weight saving and structural performance, but also as an effective means to reduce costs [11]. Thus, there is always an interest in the development of new materials and designs for low-cost high-performance cores. In particular, the large cell-size of the sandwich structures for civil applications (typically in the range from 500 mm to 1500 mm) allows the fabrication of cores using fiber-reinforced polymers [12]. For example, Ji et al. [12] introduced a glass-fiber reinforced-polymer corrugated-core which is fabricated via the assembly of pultruded and thermoformed shapes [13].

At the same time, there is also an increasing interest to substitute glass and carbon fibers by natural ones [14]. Natural fibers present some advantages when compared to their synthetic counterparts: they are cheaper, they have lower mass per unit area, they are eco-friendly, recyclable and biodegradable by nature, they do not produce skin irritation, and they provide good acoustic-insulating properties [15–17]. In contrast, natural-fiber reinforced composites have substantially inferior mechanical performance and water resistance properties than conventional glass-fiber reinforced composites [18,19]. In any case, natural-fiber reinforced materials have found uses in several novel applications, ranging from furniture and packaging to more complex engineering uses, such as building materials and structural parts for automobiles [20–22].

There are developments towards the use natural fibers for the reinforcement of sandwich-panels cores. In this sense, Rao et al. [23,24] have introduced hollow cores made of polypropylene with chopped sisal fibers as reinforcement. These cores are fabricated

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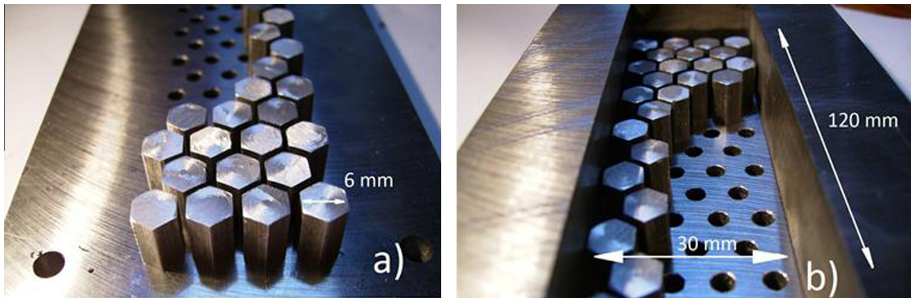

Fig. 1. Mold with fixed inserts: (a) bottom plate and inserts and (b) pre-assembled honeycomb mold.

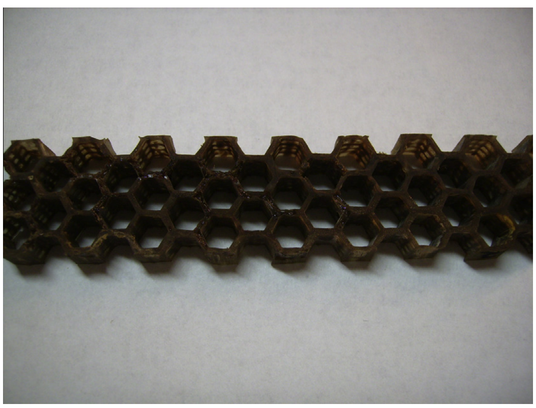

Fig. 2. Honeycomb core manufactured using the mold with the fixed inserts.

using thermoforming and assembling process. Thin continuous rolls of the sisal–polypropylene composite are produced in conical twin screw extruders and then thermoformed into half hexagonal or sinusoidal profiles. Finally, the profiles are attached together by ultrasonic bonding. Rao et al. [23,24] conclude that their panels are suitable in automobile, aerospace, packaging and building/construction industries. Recently, Petrone et al. have studied polymeric honeycombs reinforced with short and continuous flax fibers. They report results about the impact and dynamic behaviors of the panels [25] and about the feasibility to use them in structural and functional applications [26].

It is introduced in this paper a novel honeycomb core made of a natural-fiber reinforced composite. The composite consists of a thermoset-polymer (vinylester) reinforced with jute fabrics. The paper reports the details of two methods for the fabrication of 6-mm and 10-mm cell-size cores, the experimental characterization of the anisotropic elastic behavior of the composite, and the experimental characterization of the core response under flatwise compression. The failure mechanisms of the core in the compression tests are identified and discussed. In addition, there are also reported the effective elastic properties of the 10-mm cell core, which are computed via a computational homogenization method. The specific strengths of the cores are compared to those of commercially available products.

2. Materials and experimental methods

2.1. Honeycomb fabrication

The matrix material was prepared using the general-purpose vinylester resin Derakane Momentum 411-350 (Dow Chemical) provided by Poliresinas San Luis (Argentina). Methyl ethyl ketone peroxide (MEKP) was used as catalyst in a weight ratio of 1:0.05. The reinforcement material was a commercially available woven jute fabric provided by Casthanal Textil CIA (Brazil). The fabric surface density was around 300 g/m^2 and the average yarn diameter of the jute was 0.9 mm. The jute fabrics were washed with distilled water and detergent solution, and then dried to constant weight in a vacuum oven at 80 °C.

The honeycomb cores were manufactured by compression molding at laboratory scale using two molds:

2.1.1. Mold with fixed inserts

The walls and the inserts with the shape of the cells were kept in place by screwing them to the bottom plate from behind, see Fig. 1. The mold dimensions were 120 mm in length (ribbon direction), 30 mm in width and 10 mm in height, and it contained a 5 × 18 array of 6-mm (cell size) hexagonal inserts. The clearance between the inserts, and thus the honeycomb wall thickness, was t = 1.4 mm.

To prepare the fiber-reinforced honeycombs, the jute fabric was placed between the inserts following a zigzag pattern in the ribbon direction. In order to facilitate the placement of the reinforcement and its uniform distribution along the walls, the jute fabric was put in place at the same time the inserts were fixed to the bottom plate. No longitudinal force was applied to the jute fabric while disposing it into the mold. Afterwards, the vinylester was poured into the mold at 20 °C. Then, the ensemble was molded under a 50-MPa pressure in a hydraulic press during 1 h at 80 °C. Finally, the cores were post cured during 2 h at 140 °C in an oven. The wall thickness resulted in $t = 1.43 \pm 0.10$ mm. It is worth to note that as consequence of the manufacturing process, the average fiber-volume contents are different for the longitudinal and diagonal walls. Since the longitudinal walls contain two fabric-layers, its fiber content should double that of the diagonal walls, which have a single fabric layer. This was confirmed by the experimental measurements, which resulted in fiber volume contents of 29% and 14% for the longitudinal and the diagonal walls, respectively. A picture of the honeycomb core is shown in Fig. 2.

Although effective, this fabrication method has a drawback due to the fixed position of the inserts: it is not possible to press the walls in the direction of the thickness during the curing process. This limitation undermines optimum consolidation of the fibers into the cell wall. A second manufacturing method is proposed next to walk around these problems.

2.1.2. Lateral compression mold

The second mold allowed for the lateral compression of the ensemble. It consisted in a series of aluminum "combs" with the shape of the cells, which could displace laterally, see Fig. 3. This mold was used to manufacture samples of size 120 mm × 60 mm × 10 mm with a 12 × 6 cell array. In order to improve ease of manipulation the cell size was changed to 10 mm.