Composite Structures 108 (2014) 234–242

Contents lists available at ScienceDirect

Composite Structures

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

Bending response of carbon fiber composite sandwich beams with three dimensional honeycomb cores

Jian Xiong [a,*], Li Ma [a], Ariel Stocchi [b], Jinshui Yang [a], Linzhi Wu [a], Shidong Pan [a,*]

[a] Center for Composite Materials and Structures, Harbin Institute of Technology, Harbin 150001, China
[b] Research Institute of Material Science and Technology (INTEMA), National University of Mar del Plata (UNMdP), Mar del Plata, Argentina

ARTICLE INFO

Article history:
Available online 24 September 2013

Keywords:
Sandwich beam
Honeycomb
Bending
Mechanical properties
Analytical modeling

ABSTRACT

Bending properties and failure modes of carbon fiber composite egg and pyramidal honeycomb beams were studied and presented in this paper. Three point bending responses of both sandwich beams were tested. Face wrinkling, face crushing, core member crushing and debonding were considered, and theoretical relationships for predicting the failure load associated with each mode were presented under three point bending load. Failure mechanism maps were constructed to predict the failure of composite sandwich beams with pyramidal and egg honeycomb cores subjected to bending. Face wrinkling and core debonding have been investigated under three point bending and the maximum displacement was studied using analytical and experimental methods. The finite element method was employed to determine the ratio (maximum displacement/applied load) of sandwich beam with two different honeycomb cores. Comparisons between two kinds of honeycomb beams were also conducted.

1. Introduction

Sandwich structures effectively provide lightweight stiffness and strength by sandwiching a low-density core between stiff face sheets. The core materials were traditionally manufactured using stochastic metal or polymer foams [1–3], corrugated [4] honeycomb [5,6] and truss materials [7,8]. These combinations of properties are very important in the development of many contemporary vehicles and structures. Usage of fiber-reinforced composites in sandwich structures generally allows an additional weight reduction without jeopardizing the strength and performance of the structure. Thus, sandwich panels made of fiber-reinforced composites are attractive for building ultra-light, high-strength components, specifically for the aerospace industry and flight structures [9]. The behavior of flax and nature fiber composite honeycomb cores were investigated under low velocity impact loading by Petrone et al. [10,11]. Han and Tsai [12] introduced interlocked grid structures with pultruded glass fiber ribs. The interlocking method has been mainly used to manufacture square honeycomb at lower cost compared to hot press [13] and laser cutting methods [14]. Larger-sized, mass-produced sandwich panels have many potential applications in building large-scale structures and ships. In addition, they are energy absorbent [15,16] and attenuate sound transmission [17,18] and heat transfer [19]. Three dimensional honeycomb cores were developed for combining load-bearing structures with multifunctional benefits. The hollow cores with interconnected void spaces can be used to embed electronics and foam to carry out multifunctional applications.

Bending property is very important in the design of lightweight sandwich beams. There is much literature available pertaining to the bending behavior of sandwich beams with various kinds of cores. Liu et al. [20] presented a semi-analytical method for the bending analysis of sandwich panels with square honeycomb cores. He et al. [21] then demonstrated that the stiffness performance of the corrugated core, honeycomb core and X-core sandwich panels with the same structural weight are very close, with that of the honeycomb core sandwich panel a little better than the other sandwich panels. Rathbun et al. [22] have investigated the bending behavior of lightweight metallic sandwich structures with tetrahedral truss cores. Zok et al. [23] reported a protocol for characterizing the bending performance of metal sandwich panels with pyramidal truss cores. Valdevit et al. [24] presented the optimized results regarding sandwich panels with prismatic cores under bending load. Jin et al. [25] conducted bending tests in order to reveal the mechanical property and the failure mechanism of integrated woven corrugated sandwich composites. Liu et al. [26,27] have performed analytical modeling and simulation of the structural performance of sandwich beams with pin-reinforced foam cores and truss cores under bending. Russell et al. [28] manufactured carbon fiber composite square honeycombs that are mainly used as load bearing structures, and the multifunctional benefit is very limited; the bending behavior was then studied using analytical predictions, measurements and finite element

* Corresponding authors. Tel./fax: +86 451 86402376.
E-mail addresses: jx@hit.edu.cn (J. Xiong), sd6419866@sina.com (S. Pan).

0263-8223/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compstruct.2013.09.035

simulations [29]. Li et al. [30] studied the bending behavior of three-dimensional pyramidal truss sandwich beams, and the failure mechanisms were investigated. The interlocked cores reinforced by carbon fibers of the Kagome grid were manufactured and tested by Fan et al. [31]; the bending properties of Kagome and improved carbon fiber reinforced lattice-core sandwich beams were then investigated [32]. In our previous work [33] the out-of-plane and in-plane compressive properties of carbon fiber composite sandwich panels with three-dimensional honeycomb cores were studied. To date, however, there is no research work on the bending behaviors of sandwich beams with three-dimensional honeycomb cores since this innovative core architecture appeared recently for designing lightweight and multifunctional sandwich structures. The fabricated carbon fiber composite three-dimensional honeycomb cores and sandwich panels are shown in Figs. 1 and 2 for egg and pyramidal honeycomb cores, respectively. The properties of the parent material (T700/epoxy composite) are listed in Table 1. In the present paper, the bending properties and failure mechanism of carbon fiber composite sandwich beams with egg or pyramidal honeycomb cores have been researched using analytical predictions, experimental tests and simulations. The details of the analytical predictions for the egg and pyramidal honeycomb beams under three point bending are derived in Section 2. In Section 3, the experiments were conducted to study the bending behavior of the three-dimensional honeycomb beams and compared to analytical results. In Section 4, the finite element models have been built in order to predict the bending behavior of sandwich beams. At last, the conclusions are drawn in Section 5.

2. Experimental

2.1. Fabrication

A method for fabricating carbon fiber composite egg and pyramidal honeycomb cores has been developed in our previous paper [33]. In this work, the plate interlocking method has been used to form the core. First, carbon fiber composite laminates with 0°/90° were made by T700/epoxy prepreg of thickness 0.15 mm (T700/epoxy composite, Beijing Institute of Aeronautical Materials, China), the properties of the unidirectional prepreg used in our experiments are provided in Table 1. Two pieces of honeycomb plates were cut by electronic engraving machine (Harbin Weijifen Organic Glass Products Co., Ltd.), and then these plates are assembled together basing on interlocking method. Each plate interlocked with other plate only from the long caulking groove in order to form egg lattice cores and each plate interlocked with other plates including both long and short caulking grooves to form pyramidal honeycomb cores. The fabricated egg and pyramidal honeycomb sandwich beams are sketched in Fig. 8a and b, respectively. Finally, two face sheets will be bonded on the top and bottom of the honeycomb core to form a sandwich panel.

The relative density of egg honeycombs core can be approximated from

$$\bar{\rho} = \frac{d[(b + a - 2t)(H - h) + 2ah - d]}{a^2 H} \tag{1}$$

where the geometrical parameters, b, H, h, t, d and ω are shown in the schematic figure of the unit cell of the egg and pyramidal honeycomb structure shown in our previous paper. The relative density of pyramidal honeycomb cores is two times of that of egg honeycomb cores. In our samples, all the core relative densities have been calculated basing on analytical parameters of specimens, ranging

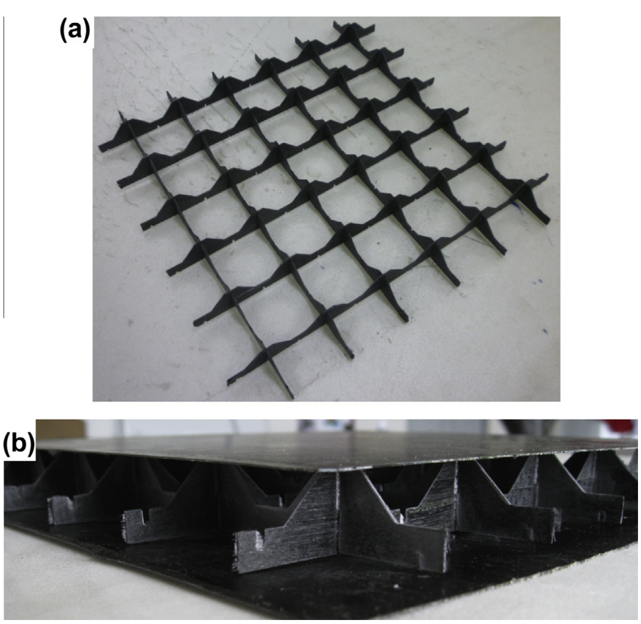

Fig. 1. Photographs of (a) pyramidal honeycomb cores and (b) sandwich panels with $\bar{\rho} = 6.0\%$.

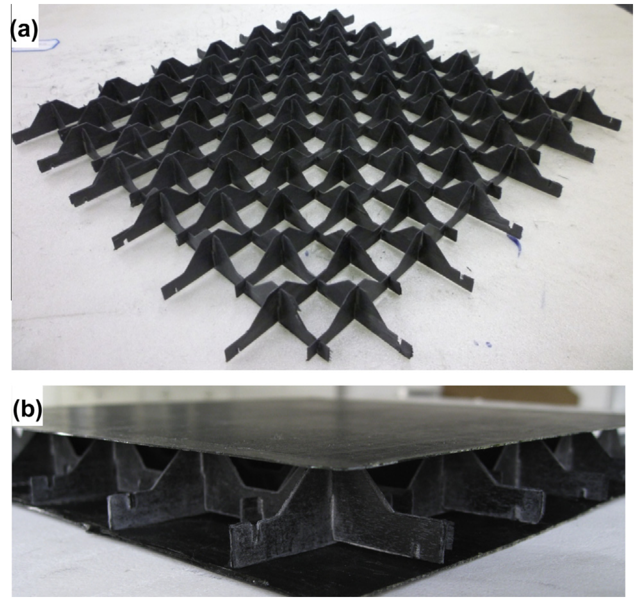

Fig. 2. Photographs of (a) egg honeycomb cores and (b) sandwich panels with $\bar{\rho} = 3.0\%$.

Table 1
Properties of unidirectional lamella (T700/epoxy composites).

Properties	Value
0° Tensile strength (MPa)	1400
0° Tensile modulus (GPa)	123
90° Tensile strength (MPa)	18
90° Tensile modulus (GPa)	8.3
0° Compression strength (MPa)	850
0° Compression modulus (GPa)	100
90° Compression strength (MPa)	96
90° Compression modulus (GPa)	8.4
In-plane shear strength (MPa)	16.0
In-plane shear modulus (GPa)	4.8
Interlayer shear strength (MPa)	60
Poisson's ratio	0.3
Volume fraction of fibers	57% ± 3
Density (kg/m^3)	1550