Composites Part B 94 (2016) 245–252

Contents lists available at ScienceDirect

Composites Part B

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

On compressive properties of composite sandwich structures with grid reinforced honeycomb core

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ARTICLE INFO

Article history:
Received 11 October 2015
Received in revised form
17 March 2016
Accepted 19 March 2016
Available online 26 March 2016

Keywords:
A. Carbon fibres
B. Mechanical properties
C. Finite element analysis
Grid reinforced honeycomb core

ABSTRACT

In the present study, periodical grids were selected to reinforce soft honeycomb cores of sandwich structures. The grid reinforced honeycomb core can be considered as a combined core with multi-level lattice configuration. In-plane compression tests were carried out to investigate the mechanical properties of carbon fiber sandwich with combined core. Experimental results indicated that the combined core sandwich specimens provided increased stiffness, specific stiffness, energy absorption and critical load, which were higher than the sum of honeycomb core sandwich specimens and grid core sandwich specimens. In addition, a Finite Element Method (FEM) model was proposed to calculate the critical buckling load of the combined core sandwich structures. The effects of core heights, honeycomb-wall thickness and face-sheet thickness on the critical buckling loads of the combined core sandwich structures were examined. The aforementioned experimental and numerical results indicated that the present sandwich structure with grid reinforced honeycomb core could provide improved structural properties for engineering structures.

1. Introduction

Grid and honeycomb cores, which can provide outstanding structural performances [1,2], are frequent candidates for sandwich structures in various fields, for instance, marine vehicles, aerospace vehicles and other light weight structures [3–7]. On one hand, the grid core is used to increase stiffness and strength of sandwich structures under compression and three-point bending condition [7]. It is shown that the grid-core structures were much stiffer and stronger, yet heavier than structures with foam and honeycomb cores [7]. On the other hand, the porous honeycomb core is usually used to reduce structural weight, and to provide other potential benefits, e.g., radar absorbing, thermal conductivity and shock mitigation [8–11].

However, both grid core and honeycomb core have their own disadvantages. On one hand, the grid core sandwich structures cannot provide functionality, for example, energy absorption, thermal conductivity and acoustic damping. On the other hand, the weak and soft honeycomb core is likely to fail under localized loading. Consequently, the structural integrity and mechanical properties of honeycomb core sandwich structures are weakened. Therefore, sandwich structures with single core cannot satisfy all demands in one way or another due to the disadvantages in functions or mechanical properties.

Considering the variety of engineering demands, sandwich structures with mixed or combined core were proposed to overcome the disadvantages [12–15]. X-core sandwich panels consisting of a pin reinforced polymer foam core were manufactured by Rice [12]. Li and Chakka [13] experimentally and analytically studied the low velocity impact properties of a sandwich structure with isogrid stiffened syntactic foam core, and found that the isogrid significantly increased the compression after impact strength of sandwich structures. Yan [14] filled metallic foam into corrugate structure to form combined core sandwich panels. The enhancing effects of filled foam on structural strength and energy absorption were investigated by out-of-plane compression tests and Finite Element Method (FEM) analysis. Recently, the authors proposed a composite sandwich structure with grid reinforced honeycomb

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http://dx.doi.org/10.1016/j.compositesb.2016.03.054
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core and experimentally studied its bending properties [15]. The composite sandwich structure with grid reinforced honeycomb core was inspired by micro structure of tree leaves [15], in which grid acted as the strong and stiff vein of leaves as shown in Fig. 1.

In the present study, in-plane compressive performance of carbon fiber sandwich structure with grid reinforced honeycomb core was examined. Then, the mechanical properties, e.g., critical load, stiffness, energy absorption of three different sandwich structures were tested and compared: (1) the carbon fiber sandwich with aluminum honeycomb core, (2) the carbon fiber sandwich with aluminum-plate orthogrid core, and (3) the carbon fiber sandwich with grid reinforced honeycomb core. Moreover, FEM modeling of the combined core sandwich was conducted to predict the critical buckling loads.

2. Manufacturing of sandwich structures with grid reinforced honeycomb core

2.1. Materials

Cellular aluminum honeycomb with 12 mm thickness, 6.35 mm cell size and 0.06 mm cell-wall thickness was used as one of the core materials. The grid core was made of 6060T5 aluminum flat bars with 12 × 3 mm cross section. Epoxy resin and 200T (3K) 2 × 2 twill-weave carbon fiber fabric with an areal density of 200 g/m^2 were used for face sheets. 2.54-mm-long Kevlar® fibers were evenly distributed to form 8-g/m^2-areal-density short-fiber tissue as interleaf.

2.2. Manufacturing process of specimens

Three types of cores i.e. honeycomb core, grid core and the combined core, were manufactured as follows. The honeycomb cores were 83 mm in height and 46 mm in width. The grid cores were assembled by interlocked two 83-mm-length transverse bars and two 46-mm-length longitudinal bars [15]. For grid reinforced honeycomb cores, as Fig. 2 shown, a grid core was firstly assembled, and then honeycomb blocks were cut and filled into the blank of grid to form the combined core [15].

Then, the carbon fiber fabrics were impregnated by epoxy resin to form the face sheets. Both upper and bottom face sheets of sandwich specimens were made of five layers of 0° carbon fiber fabrics. The Kevlar-fiber tissues were impregnated by the epoxy resin as well to prepare the interleaf. Finally, the face sheets, Kevlar-fiber tissues and core were assembled, as shown in Fig. 1, while the Kevlar-fiber tissues were inserted at interfaces between face sheets, grid and honeycomb blocks to increase the bonding strength [16–18]. The assembled sandwich structures were cured under a compression pressure of 0.6 MPa. The curing temperature was set at 110 °C for 0.5 h for the first curing period and then at 140 °C for 0.5 h for the secondary curing period.

Thickness of cured carbon fiber face sheets was 1.15 mm, and total thickness of cured specimens was 14.3 mm. The height and width of the specimens were 83 mm and 46 mm, respectively. In addition, the average weights of the honeycomb core sandwich specimens, grid core sandwich specimens and combined core sandwich specimens were 14.8 g, 34.3 g and 38.0 g, respectively. Five specimens were manufactured for each type of sandwich structure.

3. In-plane compression test

3.1. Experimental set-up

In-plane compression tests were carried out to investigate the mechanical properties of sandwich structures. Geometry and dimensions of the compression specimens are shown in Fig. 2.

Quasi-static in-plane compression tests were conducted on an Instron 8501 machine, with a displacement loading rate of 10 mm/min. The tests were terminated when the specimens lost load bearing capacity or the displacement load reached 40 mm. Five specimens were tested for each type of sandwich structure.

3.2. Load-displacement curve

Typical load–displacement curves of the three types of sandwich specimens are illustrated in Fig. 3. The load–displacement curves, which obtained the closest peak load to the corresponding average peak load of each group, were selected.

As shown in Fig. 3, the plain honeycomb core sandwich specimen presented a linear load–displacement response until the applied load reached about 7 kN. Then the applied load on honeycomb core sandwich slightly fluctuated and reach a peak load of about 10 kN, when the compression displacement was over 20 mm. After the prolonged fluctuation of compressive load, which absorbed a large amount of energy, the honeycomb core sandwich failed.

For plain grid core sandwich specimen, a higher peak load of about 11 kN was achieved during the linear stage with a higher stiffness than the honeycomb core sandwich. However, the applied load on grid core sandwich sharply dropped after the peak-load point. It is suggested that the grid core sandwich structures suffered fatal damage under compression loading.

Finally, the typical sandwich specimen with combined core exhibited the largest slope at the linear stage of the load–displacement curve, which indicated the highest stiffness among the three types of sandwich structures. Moreover, the peak load of the combined core sandwich specimen was over 22 kN, which was higher than the sum of peak loads of the honeycomb core sandwich specimen and grid core sandwich specimen. Then, the applied load on the combined core sandwich generally declined to a low level at about 3 kN until ultimate failure.

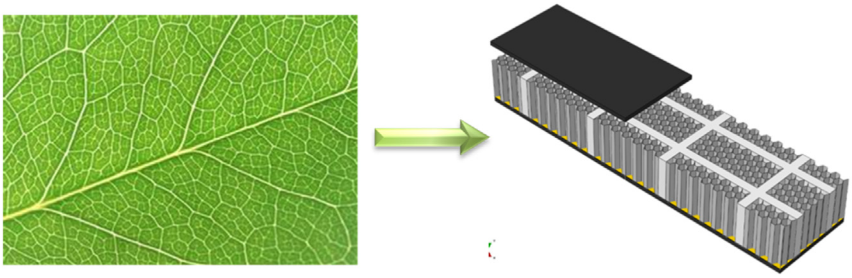

Fig. 1. Schematic of sandwich structure with grid reinforced honeycomb core.