Composites Science and Technology 159 (2018) 87–102

Contents lists available at ScienceDirect

Composites Science and Technology

journal homepage: http://www.elsevier.com/locate/compscitech

Investigation on manufacturing and mechanical behavior of all-composite sandwich structure with Y-shaped cores

Jialin Liu [a, b], Jiayi Liu [a, b, *], Jie Mei [a, b], Wei Huang [a, b]

[a] School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
[b] Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration (CISSE), Shanghai 200240, PR China

ARTICLE INFO

Article history:
Received 30 October 2017
Received in revised form
25 December 2017
Accepted 13 January 2018

Keywords:
Carbon fibers
Mechanical properties
Finite element analysis (FEA)
Sandwich structures

ABSTRACT

A novel all-composite sandwich structure with Y-shaped cores was designed and fabricated by hot-press molding method in this paper. In order to reveal effects of relative density on mechanical behavior, the out-of-plane compressive tests were carried out on composite sandwich structures with different relative densities, varying from 5.34% to 10.53%. Then the effects of relative density on failure modes, mechanical properties, stress-strain curves and energy absorption capacity were studied and analyzed. The results showed that the relative density had visible impact on mechanical behavior of sandwich structure. The stress-strain curves possessed the characteristic of two peaks, and the peak stresses increased as the relative density increased. The numerical simulation based on progressive damage model was developed to reveal the damage evolution process and predict the mechanical properties. Analytical predictions were also presented to predict the compressive strength and stiffness of Y-shaped core, which were compared with numerical results and experimental results. It was observed that the analytical predictions and numerical results were in good agreement with the experimental results.

1. Introduction

The steel sandwich structures with Y-shaped cores were a suitable choice for crash mitigation and under-water shock protection [1]. But poor corrosion and fatigue resistance limited the application of steel products. In recent years, carbon fiber reinforced resin matrix composite sandwich structures have been used in aerospace and ship building [2–5]. The composites would not rust like steel and the maintenance cost was less than steel. Furthermore, the characters of high strength to weight ratio and high stiffness to weight ratio made composite sandwich structures have received much more attention [6]. As the manufacturing was gradually mature [7–15], many different structural topologies have been designed and fabricated, including corrugated cores [8–10], honeycombs [11–14] and truss cores [15–22]. Moreover, the mechanical behavior of these sandwich structures was deeply explored. Fan et al. [9] designed and fabricated integrated woven corrugated sandwich composite panels, which enhanced the skin-core debonding resistance. The predictions for mechanical behavior of integrated woven corrugated sandwich composite panels were close to tested data. Xiong et al. [12] researched the out-of-plane compression properties and energy absorption capacity of all-composite sandwich panels made of the new three-dimensional (3D) grid cores that were interlocked. This new pattern cores have higher energy absorbing ability than traditional cores. Xiong et al. [15] investigated the shear and bending properties of composite sandwich panels with pyramidal truss core using theoretical models and experimental observation. The measured failure load matched well with the analytical results. Isaksson et al. [23] fabricated composite sandwich panels with arc-tangent, wavy trapezoidal and hemispherical shaped cores. It was found that the arc-tangent and trapezoidal cores were prone to buckle, whereas the hemispherical core was more stable under out-of-plane compression.

The research about all-composite sandwich structure with Y-shaped cores is limited at present. But steel sandwich structure with Y-shaped cores has been deeply investigated. Pedersen et al. [1] analytically and numerically investigated the compressive response of the Y-shaped sandwich core made of stainless steel. It was implied that this kind of structure was efficient in absorbing energy. Tilbrook et al. [24] studied the dynamic out-of-plane compressive response of stainless steel Y-shaped sandwich cores

* Corresponding author. School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China.
E-mail address: liujiayi@hust.edu.cn (J. Liu).

https://doi.org/10.1016/j.compscitech.2018.01.026
0266-3538/

by finite element predictions and experiments. The results showed that the front and rear face peak stresses remained approximately equal for impact velocities less than 30 m/s and 60 m/s. Rubino et al. [25] fabricated sandwich beam comprising a Y-shaped core by assembling and brazing. Experiments and finite element calculation indicated that the out-of-plane compressive response of the Y-frame was dominated by bending of its constituent members. Additionally, simulations demonstrated that energy absorption capacity of Y-frame beam exceeded that of the metal foam core sandwich beam. Moreover, other behavior [26–28] of steel sandwich structure with Y-shaped cores was also studied, such as the quasi-static three-point bending response and the low velocity impact response. These researches demonstrated that steel sandwich structure with Y-shaped cores was of high mechanical properties. Although several studies have reported the mechanical properties of steel sandwich structure with Y-shaped cores, less is known about the fabrication methods and mechanical behavior of all-composite sandwich structure with Y-shaped cores. Thus, further work is required to fill this gap in knowledge.

In this paper, a novel hot-press molding method was presented to fabricate all-composite sandwich structure with Y-shaped cores. The mechanical behavior and failure mechanism of composite sandwich structure under out-of-plane compression were tested and analyzed. The effects of relative density on failure modes, compressive strength and stiffness, peak stresses and energy absorption capacity were investigated. The three-dimensional finite element model and analytical model were also presented to predict the mechanical properties. Finally, numerical results and analytical predictions were compared with experimental results.

2. Manufacturing process

The geometric parameters and relative density were crucial to understand the mechanical properties of Y-shaped cores. The unit cell of sandwich structure with Y-shaped cores is shown in Fig. 1. The 1-direction is along the vertical direction, and the 2-direction is parallel to the transverse direction. The geometry of the Y-shaped core is characterized by the thickness t of the constituent members, the height h of the leg of the Y-shaped cores, the inclined angle α of the Y-flanges, the web size e and the overall height H. Hence, the relative density (RD is the abbreviation for relative density) of the unit cell is given by

$$\bar{\rho} = \frac{2(H-h)\sin^{-1}\alpha + 2e + t + h}{HL_1}t \qquad (1)$$

where $L_1 = 4e + 2(H-h)\cot\alpha + t$ as shown in Fig. 1.

There are three units in an overall composite sandwich structure as shown in Fig. 2a and Fig. 2b. The geometric parameters were constant as designed except for the thickness t. Hence, relative density differed with each other for their different thickness t of the constituent members. Fig. 2a shows cross-sectional dimensions of Y-shaped cores. According to Deshpande's work [1], the Y-shaped core made of stainless steel with large webs was efficient in energy absorption. In order to assure that the composite Y-shaped core possessed high compressive strength, we fabricated the composite Y-shaped core with small webs. And the design of the Y-flange inclination $\alpha = \pi/4$ and $h/H = 0.67$ was beneficial to enhance the compressive strength of the Y-shaped core. The parameters were kept constant as $h = 18$ mm, $H = 27$ mm, $e = 2$ mm and $\alpha = \pi/4$, from which the relative density of Y-shaped cores with different layers can be obtained as listed in Table 1. The relative densities of specimens made of 8 layers, 12 layers and 16 layers of unidirectional carbon/epoxy prepreg were 5.34%, 7.95% and 10.53%, respectively. The length L_2 of top and bottom face sheet is equal to 90 mm.

All-composite sandwich structures with Y-shaped cores discussed in this paper were manufactured using unidirectional carbon/epoxy prepreg by hot-press molding method. The mechanical properties of unidirectional prepreg were listed in Table 2. The manufacturing process is shown in Fig. 3. The composite sandwich structures with Y-shaped cores were made of 8 layers, 12 layers and 16 layers of unidirectional carbon/epoxy prepreg, respectively. The top and bottom face sheet and Y-shaped core were configured with the same stacking sequence. The stacking sequences of sandwich structures with the four different relative densities were $[0°/90°/0°/90°]_s$, $[0°/90°/0°/90°/0°/90°]_s$ and $[0°/90°/0°/90°/0°/90°/0°/90°]_s$, respectively. In order to depict the manufacturing process in

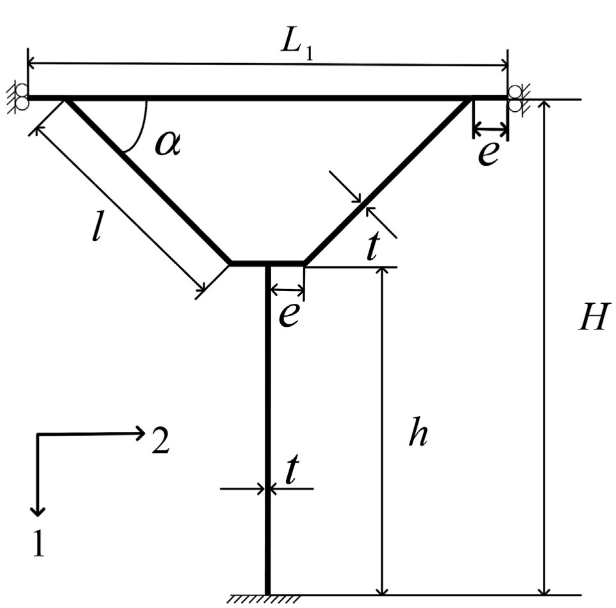

Fig. 1. Sketch of the unit cell of composite sandwich structure with Y-shaped cores.

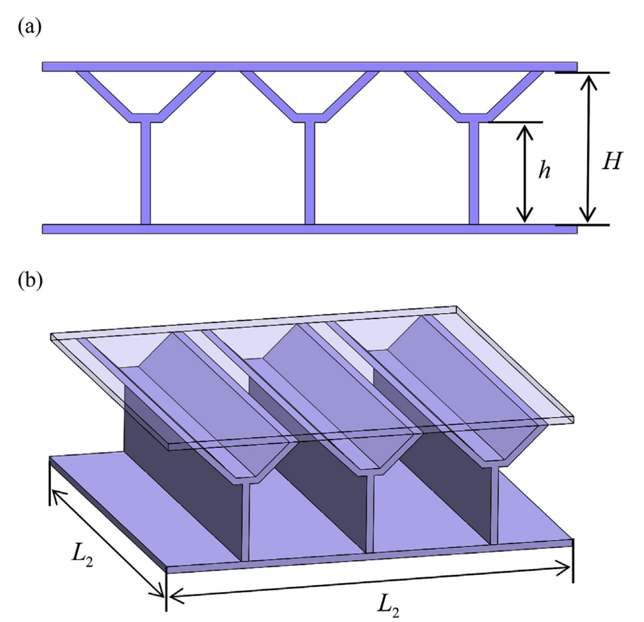

Fig. 2. Schematics of composite sandwich structure with Y-shaped cores: (a) cross-section; (b) 3D geometric model.