Composites Part B 87 (2016) 233–244

Contents lists available at ScienceDirect

Composites Part B

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

The initial plastic failure of fully clamped geometrical asymmetric metal foam core sandwich beams

Jianxun Zhang, Qinghua Qin*, Xiaohuan Han, Weilong Ai

State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace, Xi'an Jiaotong University, Xi'an 710049, China

ARTICLE INFO

Article history:
Received 2 March 2015
Received in revised form
4 September 2015
Accepted 12 October 2015
Available online 6 November 2015

Keywords:
Geometrically asymmetrical sandwich beam
A. Foams
B. Mechanical properties
D. Mechanical testing

ABSTRACT

The initial plastic failure of fully clamped geometrical asymmetric metal foam core sandwich beams is analytically and experimentally investigated. Initial failure modes of the clamped asymmetric sandwich beams are observed, i.e. face yield, core shear and indentation. The analytical formulae for the initial failure loads are developed and used to construct the initial failure mechanism maps for the fully clamped geometrical asymmetric sandwich beams. It is shown that the initial failure modes of the sandwich beams depend on geometry and material properties of the sandwich beams. The predicted failure mechanisms of fully clamped asymmetrical sandwich beams are consistent with the experimental results and obviously different from those of simply supported ones. Finally, the minimum weight designs are presented by using the analytical formulae.

1. Introduction

A sandwich structure is a kind of important lightweight structure, and is widely used in a number of critical engineering, such as aircraft, spacecrafts, vehicle, etc. Two kinds of sandwich structures may be identified in terms of the top and bottom face sheets in material characteristics and geometrical properties [1–3], i.e. the symmetric sandwich structures made of two identical face sheets in material and geometry, and the asymmetric sandwich structures with the face sheets of different thickness and materials, and/or any combination of these.

In the past decades, investigations were devoted to exploring the failure mechanisms and structural response of symmetric sandwich structures under bending. Gibson and Ashby [4], Ashby et al. [5], Bart-Smith et al. [6], McCormack et al. [7], Chen et al. [8], Crupi and Montanini [9] and Yu et al. [10] carried out experiments to examine the quasi-static behaviors of the simply supported symmetric sandwich beams under three/four-point bending, respectively. The failure modes were observed, i.e. face yield, core shear, indentation, face wrinkling, combined core shear and indentation, and combined indentation and face yield. Wang et al. [11] experimentally and analytically studied the bending behavior of sandwich panels with GFRP face sheets and a foam-web core loaded in four-point bending, and good agreement was obtained between the analytical and experimental results. Recently, Fan et al. [12,13] and Xiong et al. [14] experimentally investigated the bending performations and deformation mechanisms of the woven textile sandwich panels, carbon fiber reinforced lattice-core sandwich panels and carbon fiber composite egg and pyramidal honeycomb sandwich beams under three-point bending, respectively. Chemami et al. [15] studied the static and fatigue failure modes of two different composite sandwiches made of fiberglass and epoxy resin for skins and PVC foam for the core in three-point bending. Kabir et al. [16] found that the lower strength face sheet is associated with lower failure loads for the aluminum sandwich panels with thin foam cores under three-point bending load and the decrease is not proportional to the yield strength due to the additional failure mode of face yielding.

Most of the aforementioned work focused on the bending behaviors of symmetric sandwich structures under three/four-point bending. Zhang et al. [17] investigated the failure mechanisms of geometrically asymmetric metal foam core sandwich beams under three-point bending. They gave the initial failure modes, obtained the initial failure loads of the geometrically asymmetric sandwich beams, and constructed the failure mechanism maps of asymmetric ones.

Few investigations on the bending behaviors of the fully clamped symmetric and asymmetric sandwich structures were

---

* Corresponding author. Tel./fax: +86 29 82664382.
E-mail address: qhqin@mail.xjtu.edu.cn (Q. Qin).

http://dx.doi.org/10.1016/j.compositesb.2015.10.027
1359-8368/

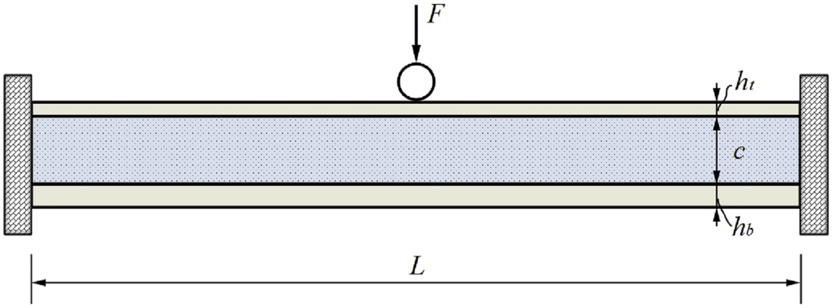

Fig. 1. A sketch for fully clamped geometrical asymmetric sandwich beam.

reported. However, in the engineering practice, sandwich structures are often clamped to a stiff and strong support framework. Compared with three/four-point bending boundary condition, the fully clamped boundary is close to connection type in the engineering practice. Tagarielli and Fleck [18] and Tagarielli et al. [19] studied the competing collapse mechanisms and obtained the failure mechanism maps of the fully clamped and simply supported symmetric sandwich beams with metal foam core and PVC foam core. Jing et al. [20] investigated the deformation and failure modes of clamped symmetric sandwich beams with open-cell aluminum foam cores under quasi-static and dynamic impact loading. Compared with dynamic experiments, sandwich beams subjected to quasi-static tests show more deformation and failure modes. Tan et al. [21] observed failure modes of clamped symmetric sandwich beams with aluminum alloy open-cell foam core subjected to

Table 1
Dimensions of the clamped bending specimens for the case of $\alpha = 1$.

Specimens	b (mm)	h_t (mm)	h_b (mm)	c (mm)	L (mm)
5-1	40.0	0.5	0.5	6.2	320
5-2	40.0	0.5	0.5	6.3	320
5-3	40.0	0.5	0.5	6.3	320
5-4	39.8	0.5	0.5	14.0	240
5-5	39.7	0.5	0.5	14.2	240
5-6	39.6	0.5	0.5	14.3	240
5-7	39.8	1.0	1.0	29.5	240
5-8	39.8	1.0	1.0	29.5	240
5-9	39.6	2.0	2.0	15.5	240
5-10	39.8	2.0	2.0	15.5	240
5-11	39.9	2.0	2.0	29.5	240
5-12	39.8	2.0	2.0	29.6	240
5-13	39.7	4.0	4.0	23.5	240
5-14	40.1	4.0	4.0	23.5	240
5-15	40.0	4.0	4.0	23.7	240

Table 2
Dimensions of the clamped bending specimens for the case of $\alpha = 2$.

Specimens	b (mm)	h_t (mm)	h_b (mm)	c (mm)	L (mm)
6-1	39.5	1.0	0.5	2.8	360
6-2	39.7	1.0	0.5	2.8	360
6-3	39.8	1.0	0.5	3.0	295
6-4	39.6	1.0	0.5	3.3	295
6-5	39.9	1.0	0.5	3.4	295
6-6	39.8	1.0	0.5	4.0	320
6-7	39.8	1.0	0.5	4.0	320
6-8	39.5	1.0	0.5	4.0	290
6-9	39.1	1.0	0.5	4.0	290
6-10	39.7	1.0	0.5	7.0	350
6-11	39.7	1.0	0.5	15.2	240
6-12	39.7	1.0	0.5	15.3	240
6-13	39.8	1.0	0.5	16.0	240
6-14	39.7	1.0	0.5	24.5	240
6-15	39.7	2.0	1.0	10.4	240
6-16	39.6	2.0	1.0	10.5	240
6-17	39.6	2.0	1.0	10.5	240
6-18	39.7	2.0	1.0	37.7	240
6-19	39.5	2.0	1.0	43.9	240
6-20	39.8	2.0	1.0	43.8	240
6-21	39.8	2.0	1.0	44.0	240
6-22	39.6	3.0	1.5	11.6	240
6-23	39.3	3.0	1.5	11.7	240
6-24	39.6	3.0	1.5	14.8	240
6-25	39.7	3.0	1.5	15.0	240
6-26	39.6	3.0	1.5	15.2	240
6-27	39.7	4.0	2.0	11.0	240
6-28	39.5	4.0	2.0	11.0	240
6-29	39.8	4.0	2.0	11.1	240
6-30	39.7	4.0	2.0	17.0	240
6-31	39.8	4.0	2.0	29.7	240
6-32	40.0	4.0	2.0	29.7	240

Table 3
Dimensions of the clamped bending specimens for the case of $\alpha = 1/2$.

Specimens	b (mm)	h_t (mm)	h_b (mm)	c (mm)	L (mm)
7-1	39.8	0.5	1.0	2.9	360
7-2	39.6	0.5	1.0	3.1	295
7-3	39.6	0.5	1.0	3.5	295
7-4	39.7	0.5	1.0	4.0	290
7-5	39.4	0.5	1.0	4.0	320
7-6	40.0	0.5	1.0	4.0	320
7-7	39.8	0.5	1.0	7.0	350
7-8	39.8	0.5	1.0	15.3	240
7-9	39.8	0.5	1.0	15.5	240
7-10	39.1	0.5	1.0	15.5	240
7-11	39.8	0.5	1.0	16.0	240
7-12	39.8	0.5	1.0	16.0	240
7-13	39.6	0.5	1.0	24.5	240
7-14	39.5	0.5	1.0	24.7	240
7-15	39.5	0.5	1.0	24.7	240
7-16	40.0	0.5	1.0	24.7	240
7-17	39.8	1.0	2.0	10.5	240
7-18	39.8	1.0	2.0	10.5	240
7-19	39.1	1.0	2.0	43.9	240
7-20	39.7	1.0	2.0	43.9	240
7-21	39.5	1.0	2.0	44.0	240
7-22	39.8	1.0	2.0	44.0	240
7-23	39.7	1.5	3.0	11.7	240
7-24	39.4	1.5	3.0	11.9	240
7-25	39.7	1.5	3.0	14.9	240
7-26	39.7	1.5	3.0	15.0	240
7-27	39.7	2.0	4.0	11.0	240
7-28	39.6	2.0	4.0	11.2	240
7-29	39.7	2.0	4.0	16.0	240
7-30	39.6	2.0	4.0	17.0	240
7-31	39.8	2.0	4.0	17.0	240
7-32	40.0	2.0	4.0	17.1	240
7-33	40.0	2.0	4.0	29.5	240
7-34	39.8	2.0	4.0	29.8	240