Honeycomb structures manufactured by a new method and its failure analysis

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Abstract. Nowadays, honeycomb sandwich panle is widely used in the field of aircraft and spacecraft, due to its light weight, high strength and good impact resistance. So the stability and buckling behavior of the structure are crucially important. In the present work, two type aluminum honeycomb sandwich panles were manufactured by a new manufacturing method (i.e. a press and folding process). To evaluate the structural failure of the panle, the three-point bending test was carried out, and found that the face sheets and the honeycomb core were splitted open under a local load, but the panle has not been completely failure. In addition, the buckling behavior of the panle was implemented with finite element analysis (FEA).

1. Introduction

In the field of aerospace and spacecraft, structural materials with high strength, high stiffness and lightweight are indispensable [1]. Therefore, honeycomb sandwich panel, as a kind of functional and structural material, is more and more popular. The structure is consisting of a honeycomb core and two face sheets, which is usually manufactured by using metallic foils or composites [2]. This structural material not only have excellent mechanical properties, but also have good impact resistance, sound insulation and sound absorption, heat resistance and so on [3]. Therefore, it is considered as one of the most promising materials.

Because the structure of the honeycomb sandwich panel is relatively complicated, many production processes and large-scale manufacturing equipments are required, resulting in very high cost [4]. Additionally, the buckling mechanism of the structure is very complex, so the structural failure can not be predicted accurately. Therefore, it is limited in wide applications.

In this study, the hexagonal honeycomb cores were designed based on the origami technology [5], and the aluminum honeycomb sandwich structures were manufactured by a new manufacturing method (i.e. a press and folding process). Two type specimens were studied one with the honeycomb core bonded by common adhesive and another with the honeycomb core bonded by aluminum claws. The three-point bending test was carried out to evaluate the structural failure, and found that the face sheets and the honeycomb core were splitted open under a local load, but the panle has not been completely failure. In addition, the finite element analysis (FEM) was implemented with ANSYS 17.0, the results showed that when the honeycomb first buckled, the critical load of the structure was about
0.299 kN. It offers a simple and effective method to manufacture a honeycomb sandwich panel, which has an excellent structural stability.

2. Design and Modeling
Based on the origami technology, the unfolded diagrams of the honeycomb core structure were designed by Auto CAD software. The beam model with the size of 300×60×26.6 mm (core height: 25 mm) was established, and the cell size of the honeycomb core was set to 19 mm. Generally, when it is impacted, the honeycomb core and the two face sheets bear the external force at the same time, so the model includes a honeycomb core and two face sheets, which is for evaluating buckling behavior of honeycomb sandwich panel.

3. Material, Specimens manufacture, and Experimental

3.1 Material
Aluminum foil and aluminum plate with a density of 2.7 g/cm³ were purchased from UACJ Foil Corporation (Tokyo, Japan). The thickness of the foil is 0.1 mm, and the thickness of the plate is 0.8 mm.

3.2 Specimens manufacture
Aluminum was used to fabricate the face sheet and the honeycomb core, according to the size of the model designed by CAD. The production process comprises four steps: ① corrugation forming, ② slit introduction, ③ folding, and ④ face sheets adhesion.
① Corrugation forming: Aluminum sheets were formed into a corrugated shape. Conventional methods including roll forming and press forming (Fig. 1 (a)) were used, which was no special technical issues in this step.
② Slit introduction: The slit lines on the aluminum sheets were cut according to FLD (folding line diagram). Cutting plotters and laser cutters (Fig. 1 (b)) were both considered in this step.
③ Folding: Corrugated sheets were folded in a zigzag manner at the slits positions. Fig. 1 (c) shows a prototype for a relevant folding machine.
④ Face sheets adhesion: The adhesive (PM200, CEMEDINE CO., LTD, Japan) was used to bond the honeycomb core and the face sheets.

Two type specimens were manufactured one with the specimen bonded by using common adhesive and another with the specimen bonded by aluminum claws which was developed by our group [6] (shown as Fig. 2). The wall thickness of the honeycomb core was 0.1 mm, the height of the honeycomb core was 25 mm, and the thickness of the face sheets was 0.8 mm.
3.3 Experiment
The three-point bending tests were performed with a universal testing machine (AG-50kNG, Shimadzu Inc., Kyoto, Japan) based on ASTM C393-00. The head speed was 2 mm/min, and the span of the support bars was 250 mm.

3.4 Simulation
In order to better investigate and visualize the structural stability of the honeycomb sandwich, a commercial finite element analysis (FEA) was carried out by the software ANSYS 17.0. The thicknesses of core and face sheets were set to 0.1 mm and 0.8 mm, respectively. The Young's modulus and Poisson ratio of the aluminum core and face sheets were 71 GPa and 0.33, respectively.

4. Results and Discussion
The three-point bending tests were carried out and an example of collapse honeycomb sandwich specimen was shown as in Fig. 3. Obviously, whatever the type of specimen is, the face sheets have been greatly deformed in the center of the specimens under a certain load. And the face sheets and the honeycomb core were split open, with the collapse of the honeycomb walls. However, as the load continues to work, the honeycomb sandwich has not completely failed, as we reported in the previous research article [5].

For the buckling analysis, a local force $F_0 = 1$ kN was applied above the model, which was based on the previous studies. The analysis results only took the first-order eigenvalue, which was also the eigenvalue of the first buckling for the structure. Fig. 4 shows the result of buckling analysis for the characteristic value of honeycomb sandwich panel. It indicated that the eigenvalue of the honeycomb structure is $F_{act} = 0.299$.
when the first-order buckling occurred. Therefore, when the honeycomb first buckled, the critical load of the structure was calculated as follows.

\[ F_{\text{ulteig}} = F_0 \cdot F_{\text{Factor}} \]  

(1)

So the critical load of the structure was \( F_{\text{ulteig}} = 0.299 \text{ kN} \).

5. Conclusions
In this work, the aluminum honeycomb sandwich structures were manufactured by a new manufacturing method (i.e. a press and folding process). The stability of the structure was verified by three-point bending experiment, and found that the face sheets and the honeycomb core were splited open under a local load of 1 kN, but the whole structure has not been completely failure. In addition, the FEM results showed that the critical load of the structure was about 0.299 kN when the honeycomb first buckled. The manufacture method provides a theoretical and technical basis for popularizing the applications of honeycomb sandwich panels.

6. References
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