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Bending Behavior of Sandwich Structure Made of Aluminum Honeycomb Core and Steel Facing

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ABSTRACT
In this work the effect of face sheet thickness on the bending behavior of the aluminum honeycomb core sandwich structure was presented. The sandwich composites were fabricated using aluminum honeycomb core of cell size 10 mm with various steel facing thicknesses i.e. 0.2 mm, 0.64 mm and 0.71 mm. Three-point bend test was conducted to evaluate and analyze different bending properties such as peak load, bending strength, specific bending strength, shear stress, energy absorbed and specific energy absorption. Results show that all bending properties increased with increasing face sheet thickness except the specific properties. The specific bending strength and energy absorption were found to be the highest in the specimen with the thin face sheets. The failure initiation mechanism was found to be the debonding between the core and the face sheet. The thick face sheet showed more catastrophic debonding failure compared with the thin face sheet. The performance of the sandwich can be enhanced by improvement of the bonding between the core and the facings.

Keywords: Sandwich structure, Steel face sheet, Aluminum honeycomb core, Three-point bend test, Bending properties

1. Introduction

Sandwich structure consists of two thin and high strength face sheets separated by a thick lightweight core. It is the distance between two face sheets that gives the high rigidity to this type of structure. The use of lightweight foam or cellular structure as core makes the sandwich structure capable of obtaining high strength to weight ratio [1]. The major applications of the sandwich structure are in the field where the weight saving is crucial such as Aircraft, Marine vehicles, Automobiles, Trains etc. because of the versatility in design. A lot of combination of materials can be made to meet the specific requirements for example an insulating wallboard may be made with thin steel facings with syntactic foam core to obtain protection against the environment as well as low thermal conductivity.

Many researcher have investigated sandwich structures based on the industrial requirements by using different combination of core material and skin materials [2-11]. Skin materials include fiber reinforced composites [6], steel sheet [3] and the core materials are Aluminum foam [3-6], aluminum honeycomb [8-10], plastic foam [11] etc. Most of the researchers concentrated on the impact and blast loading on the sandwich structures. There has been limited study on the effect of face sheet thickness as it is well established that that the thin facing are better in terms of the weight saving. However sometime to secure the higher bending strength or the load carrying capacity there is no other cheap and easy option than increasing face sheet thickness. Yan and Song [5] studied the effect of face sheet thickness on aluminum foam core based sandwich structure and found that the increase in facing thickness causes higher load carrying capacity and bending strength. The study on the effect of facing thickness on cellular sandwich structure is limited in the current literature. In the case of cellular sandwich structures the honeycomb cells in the core has outstanding performance.

Thomas and Tiwari [2] investigated the effect of various parameters on the bending behavior of sandwich composites and found that the honeycomb structure performed well. They have also concluded that the facing thickness has considerable effect on the energy absorption behavior of the sandwich structure.

In this study, Sandwich structures were fabricated with steel facings and aluminum honeycomb core by varying the thickness of the steel facings. The bending properties such as peak load, bending strength, shear strength, energy absorption were investigated for various facing thicknesses. The main objective of this work is to explore the effect of face sheet thickness on bending properties and failure mechanism of the cellular sandwich structure.

2. Materials and methods

Aluminum sheet of 0.5 mm thickness was used for manufacturing the core materials and mild steel sheet was used for facing of the sandwich composite. The thicknesses of steel facing sheets were 0.20 mm, 0.64 mm and 0.71 mm. The epoxy adhesive (Araldite) was used for binding honeycomb core strips and the core with facings.

2.1 Specimen preparation

The plain aluminum sheet was bent by pressing in bending machine (see Fig.1(a)) at a distance of 10 mm interval which was selected edge size of the hexagonal cells. The bent sheet was cut transversely (perpendicular to the direction of corrugation) to a height of 18 mm and a length of 150 mm as shown in Fig.1(b). The stripes

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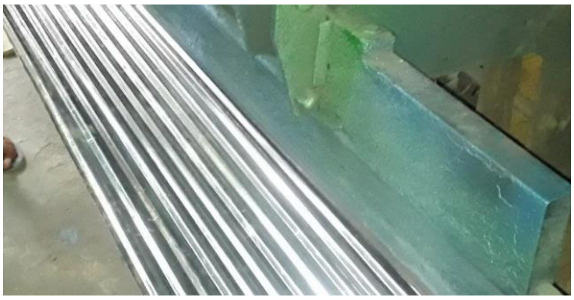
were then joined using adhesive side by side to fabricate the honeycomb core. The mild steel sheet of 0.2 mm, 0.64 mm and 0.71 mm were attached on both side of the core using epoxy adhesive to construct the sandwich structure. The visual inspection confirmed that the adhesive has created sufficient fillet at the core and skin interface which is essential for effective bonding.



(a)

(b)

(c)

Fig.1 (a) Bending Aluminum sheet, (b) preparing core by adhesive and (c) final sandwich structure (Specimen size 150 mm × 35 mm × 18 mm).

2.2 Bending test

Three-point bending test was conducted on a Universal Testing Machine with a 50kN load cell and digital data acquisition system. The cross head speed was approximately 5 mm/min. The bending strength was calculated using the equation from the international standard ASTM D 790-03 [12].

$$\textit{Bending strength} = 3PL/2bd^2 \qquad (1)$$

where, P is the peak load, N; L is the support span length, mm; b is the width of beam tested, mm; and d is the depth of beam tested, mm.

The support length and width of the specimen was 120 mm and 35 mm respectively in this study. The core height was 18 mm and the sandwich height was different for different face sheet thicknesses. The shear stress at the interface between the core and the face sheet was calculated using the formula obtained from international standard ASTM C393/C393M-11 [13].

$$\textit{Core shear stress} = P/((d+c)*b) \qquad (2)$$

where, c is the height of the core. The energy absorption during bending was calculated from the area under the load – displacement curve.

3. Results and discussion

3.1 Bending Properties

The load vs deflection curves for specimens with various face sheet thicknesses are shown in Fig.3. The load increased linearly with cross head displacement until a peak and then the load drops rapidly indicating the failure of the specimen. The plateau region after that indicates the load bearing capacity of bottom face sheet and the core of the specimen after failure. Similar observation has also been seen by other researchers [3, 6]. It can be observed that the load bearing capacity after failure increases with increasing face sheet thickness. The nature of the load-displacement curve discussed above is not applicable for specimen with a face sheet thickness 0.64 mm. In this case the load drop during failure is not present instead a flat region in the curve is seen.

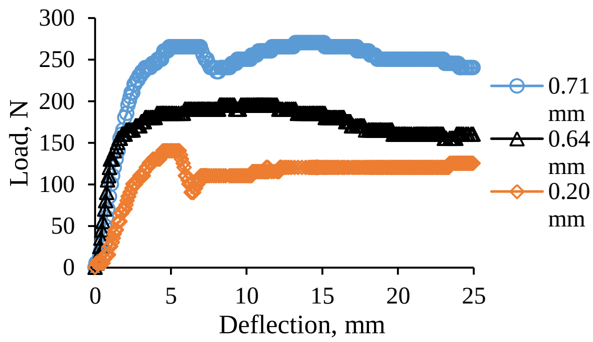


Fig.2 Typical load vs deflection curves for specimens with different face sheet thicknesses.

The peak load and bending strength obtained from the three-point bending test are plotted for various thicknesses with standard deviation in Figs.3 and 4 respectively. Peak load and bending strength increased with increasing face sheet thickness for a constant core height similar to the observation from reference [2, 4, 6]. A small increase in face sheet thickness causes the significant increase in peak load and bending strength because of the increase in the load carrying capacity of the facings. When the face sheet thickness increased from 0.2 mm to 0.64 mm the peak load and bending strength increased by 27.12% and 30% respectively. On the other hand, when the face sheet thickness increased from 0.64 to 0.71 mm the peak load and bending strength increased by 24% and 15.38% respectively. Specific bending strength (Sp. BS) is also plotted in Fig.4 to see the effect of facing thickness. It can be observed that the sp. bending strength is highest for smallest facing thickness and decreased to a minimum for facing thickness 0.64 mm. However when the facing thickness increased to 0.71 the specific bending strength started to increase again because of the high load carrying capacity of the thicker skin.

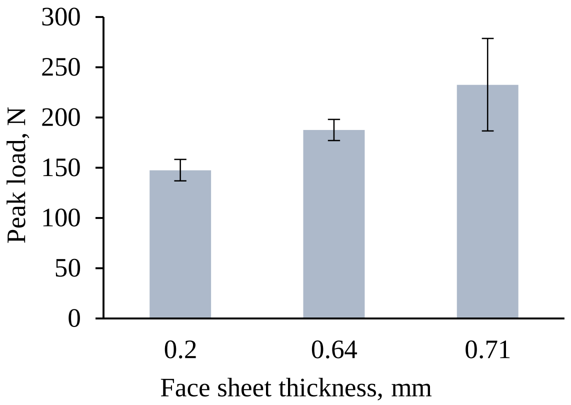


Fig.3 Peak load for different face sheet thicknesses. Error bar indicates standard deviation.

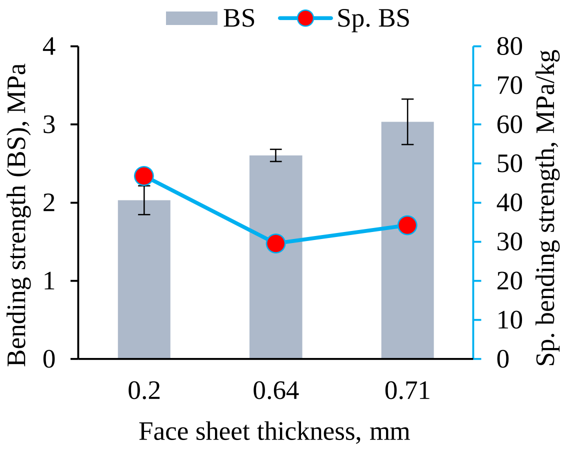


Fig.4 Bending strength and specific bending strength (i. e. Strength per unit mass of the composite) for different facing thicknesses. Error bar indicates standard deviation.

Since the face sheet debonding is the observed failure initiation mechanism which will be discussed in the later section it is important to know the shear stress at the interface between the core and the face sheet. The shear stress is plotted for different face sheet thicknesses in Fig.5 with standard deviation as error bar. It is seen that the shear stress increased with increasing the face sheet thickness by 30.76% and 57.44% when the face sheet thickness was increased by 0.44 mm and 0.51 mm respectively. The shear stress is proportional to the peak load and inversely proportional to the facing thickness as seen from Eq. (2). Since the increase in facing thickness is too small and the increase in peak load is high the shear stress at the interface must also increase.

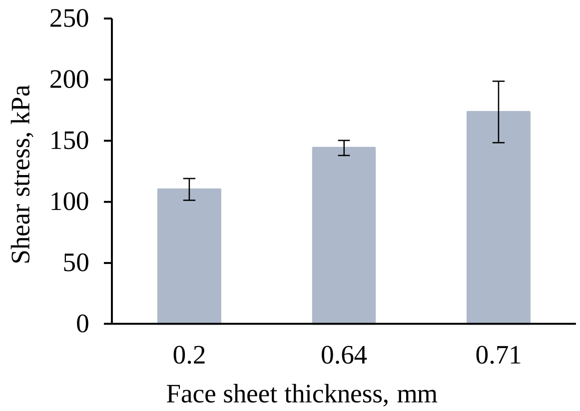


Fig.5 Interfacial shear stress for various face sheet thicknesses. Error bar indicates standard deviation.

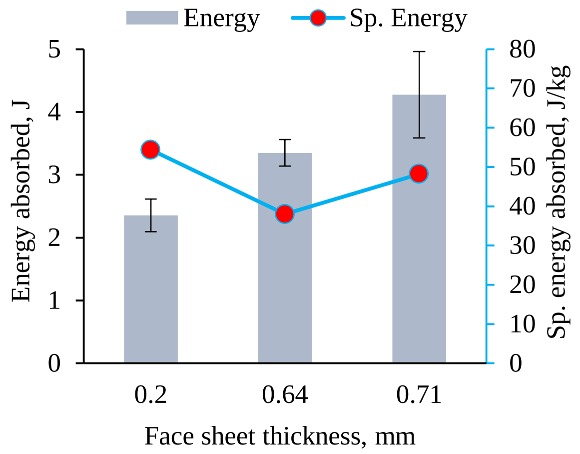


Fig.6 Energy absorbed and specific energy (i.e. Energy per unit mass of the composite) absorbed for various face sheet thicknesses. Error bar indicates standard deviation.

The energy absorbed by the specimen during three-point bending and the specific energy absorption for different facing thicknesses are plotted in Fig.6. The high load carrying capacity of the specimens with thicker facings even after failure (see Fig.2) has resulted in the increase in energy absorption with the increase in facing thickness. Thomas and Tiwari [2] also reported this observation. Similar to the sp. bending strength the sp. energy absorption is found to be the highest for the thin facings because the increase in thickness of the facings has comparatively less contribution to the mass than the load bearing capacity of the sandwich structure.

3.2 Bending failure mechanism

After careful investigation of the failure mechanism during the three-point bending test it has been found that the initial failure of the sandwich is the face sheet debonding i. e. the debonding between the face sheet and the honeycomb core. The debonding initiated when the load is at the peak after the linear elastic line on the load – deflection curve as shown in Fig.7 (a).

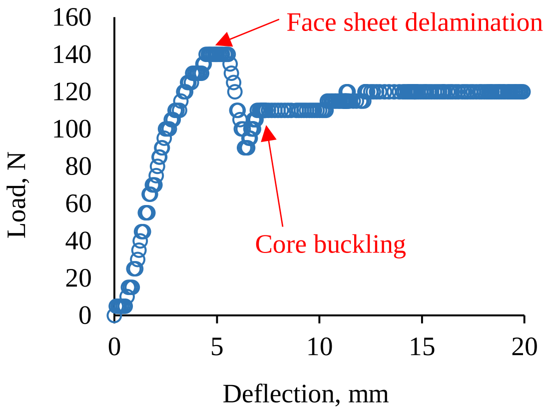


Fig.7 Typical load-deflection curve for specimens with 0.20 mm and 0.71 mm face sheet thicknesses.

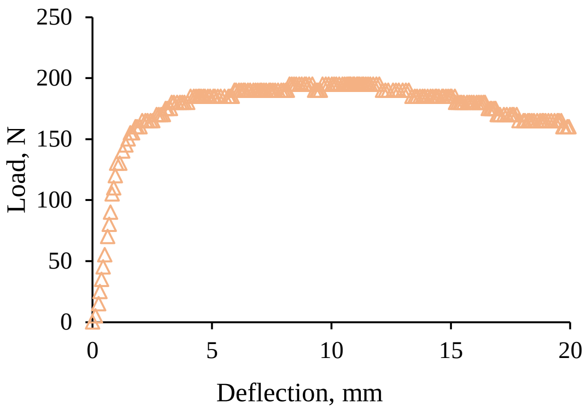


Fig.8 Load – deflection curve for specimens with 0.64 mm face sheet thickness.

But it has been found difficult to locate the debonding initiation for specimen with facing thickness 0.64 mm as the load – deflection curve did not show a clear load drop as shown in Fig.8. Some photographs of the failed specimens are shown in Fig.9 to illustrate various failure type. The debonding of face sheet occurred locally (see Fig.9(a)) or at one side on the top of the specimen (see Fig.9(b)) for thin face sheet (0.20 mm). After debonding the core started to buckle and the load was carried by the lower face sheet and the core which is indicated by the flat line in the load deflection curve in Figs.7 and 8. The examples of the core buckling are shown in Figs.9(b) and (c). Nonetheless the debonding occurred on the both sides on the top of the specimens with face sheet thickness 0.64 mm and 0.71 mm. After unloading it was seen that the top phase sheet was debonded completely. From the above discussion it can be concluded that the bonding between the core and the face sheet play an important role in terms of failure initiation and the performance of the sandwich construction may be further enhanced with the improvement of the face sheet bonding.

(a) Local debonding

(b) Debonding on one side (circle) and core buckling (rectangle)

(c) Debonding on both side (circle) and core buckling (rectangle)

Fig.9 Some photographs of the specimen failure during three-point bending test.

4. Conclusion

Sandwich composites were fabricated using aluminum honeycomb as core and steel as facing for various facing thickness. The effect of steel facing thickness on bending behavior of the sandwich structure was investigated. The findings of this work are summarized below:

- Bending properties such as peak load, bending strength, shear strength and energy absorption were increased with increasing facing thicknesses.
- The specific bending strength and specific energy absorption were found to be highest on the specimens with thin facings.

- The load – deflection curve shows a plateau region indicating the high energy absorption capacity of the fabricated sandwich composites.
- The failure of the sandwich composite initiated with face sheet debonding followed by core buckling.
- The debonding of the face sheet was worsen with the increase in face sheet thickness.

5. Acknowledgement

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