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Aluminium Foam Sandwich Panel with Hybrid FRP Composite Face-Sheets: Flexural Properties

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ABSTRACT

The increasing demand for high-strength light-weight fibre reinforced polymer (FRP) composite materials has driven the researchers to further innovate and introduce hybrid reinforcement materials. The usage of hybrid FRP composite and metal foam in the fabrication of sandwich panel in structural industries is still new and limited research has been reported in this area. In addition, there is limited research data on aluminium foam as a core material in sandwich panel and needs to be further studied. This research is aimed to determine the bending properties of closed-cell aluminium foam sandwich panel with hybrid FRP composite face-sheets. The three-point bending tests were carried out in order to determine mechanical properties of the material, such as Young's modulus and strength. The sandwich panels were prepared using FRP composite face-sheets, which consist of carbon and glass fibres and epoxy matrix, and closed-cell aluminium foam core material. The results show that aluminium foam sandwich panel with hybrid FRP composite face-sheets exhibit higher flexural strength and modulus compared to the neat closed-cell aluminium foam panel. It also has higher flexural strength and flexural modulus, by 338% and 136% respectively, as compared to the aluminium honeycomb sandwich panel.

Keywords: Aluminium foam, aluminium honeycomb, flexural strength, flexural modulus, hybrid FRP composite

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INTRODUCTION

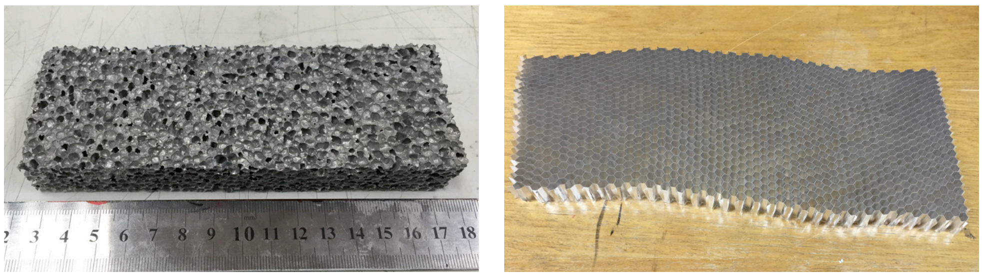
The invention and development of new materials have encouraged many researchers to investigate various types of high strength and lightweight materials that can be used in construction, automotive and aerospace industries. These investigations lead to porous metal, such as aluminium foam, as one of the areas of interest by many researchers because of its excellent stiffness to weight ratio. Aluminium foam is a cellular structure which contains aluminium solid with a large volume fraction of gas-filled pores. It has low density, high ductility, low thermal conductivity and competitive cost (Ismail, Jumahat, Abdullah, Hashim, & Ahmad, 2015).

Sandwich structure composite is a special class of composite materials, which is fabricated by attaching two thin stiff skins to a thick but lightweight core material. These structures are specifically designed to achieve the requirement of least mass to carry optimum load capacity. The sandwich structures have higher specific strength and stiffness compared to the pristine or constituent materials. The materials usually used as core are made up of honeycomb, foam, balsa wood and synthetic foam, and normally, these comprise polymeric and aluminium base (Crupi, Epasto, & Guglielmino, 2012; Sharma, Murthy, & Krishna, 2004). The selection of suitable core materials is crucial to maintaining the effectiveness of sandwich structure. Core materials must be strong enough to resist compressive and crushing loads as well as shear forces imposed on the panel.

Previous studies have been conducted and proved that hybrid reinforcement may contribute to better mechanical performance of the FRP composite structure (Ismail, Jumahat, Ahmad, & Ismail, 2015). Therefore, in this study the hybrid FRP composite will be used as a face sheet and will be combined with closed-cell aluminium foam in order to fabricate sandwich panel. Three-point bending tests will be conducted on the neat aluminium foam panel, hybrid FRP composite-aluminium foam and hybrid FRP composite-aluminium honeycomb sandwich panels in order to investigate the mechanical response of the panels under transverse loading. This research is aimed to determine the bending properties of closed-cell aluminium foam sandwich panel with hybrid FRP composite face-sheets. The mechanical behaviour of the panels concerning the flexural load-deflection curves and the failure deformation are also compared and discussed.

MATERIALS AND METHODS

The research was conducted using two types of core materials: commercial closed-cell aluminium foam and hexagonal aluminium honeycomb. Figure 1 shows the samples of core materials used in the experiment. The aluminium foam quality has an average density of 0.35 g/cm^3 and average pores size of 3.0 mm. Meanwhile, the hexagonal aluminium honeycomb has an average density of 0.07 ± 0.01 g/cm^3 and a 7.49 mm cells' diameter. Both these core materials have a thickness of 20 mm. These core materials were sandwiched with the hybrid FRP composite face-sheets. The hybrid FRP composite face-sheets consisted of carbon fibre reinforced polymer (CFRP) composite and glass fibre reinforced polymer (GFRP) composite. A 3K, 2×2 twill weave carbon and 7781 e-glass prepregs were used to create the hybrid FRP composite. These prepregs material is already impregnated with epoxy resin (27% to 33%) according to the data sheet given by the manufacturer ("Product data sheet - Prepreg 3K, 2x2 Twill Weave Carbon," 2010; "Product data sheet - Prepreg 7781 E-Glass," 2010). The prepregs were cut into 150 mm length and 50 mm width according to the sample of three-point bending test. The carbon and glass prepregs were stacked together and placed in the hot press machine for the curing process. The temperature of the hot press machine was set at 154°C for one hour soaking time. The cured hybrid FRP composite was removed from the hot press machine once the temperature of the material dropped to less than 66°C.



(a) (b)

Figure 1. The core materials: (a) closed-cell aluminium foam; and (b) hexagonal aluminium honeycomb

The closed-cell aluminium foam and aluminium honeycomb were cut into a size of 150 mm length and 50 mm width. These materials were attached together with the hybrid FRP composite face-sheets at the top and the bottom side using Araldite glue. After curing the araldite glue adhered firmly in between the materials and filled up the empty hole space of the foam core, thus enhancing the bonding strength between the core and the face-sheet materials.

Three-point Bending Test

Three-point bending tests were performed to determine the bending properties for each of the structures of the panel. An Instron 3382 100 kN Floor Model Universal Testing machine as shown in Figure 2 was used to conduct the three-point bending test. Three types of different materials structure (neat closed-cell aluminium foams panels, aluminium foam sandwich panels with hybrid FRP composite face-sheets and aluminium honeycomb sandwich panels with hybrid FRP composite face-sheets) were tested according to the ASTM D7250/D7250M.

The specimens of 150 mm length × 50 mm width × 22 mm thickness (20 mm core and 1 mm face-sheets) as shown in Figure 3 were bent under three-point bending configuration. The specimens were mounted on a steel cylinder of 10 mm diameter with a span length of 125 mm. Measurement of the specimens' thickness and width were done at three different points using a digital electronic Vernier calliper before commencing the experiment. The purpose of this measurement is to obtain the average value of width and thickness. These data were then recorded in the software of the machine. The three-point bending tests were conducted at a crosshead displacement rate of 1 mm/min at room temperature and load-displacement curves were recorded during the test.

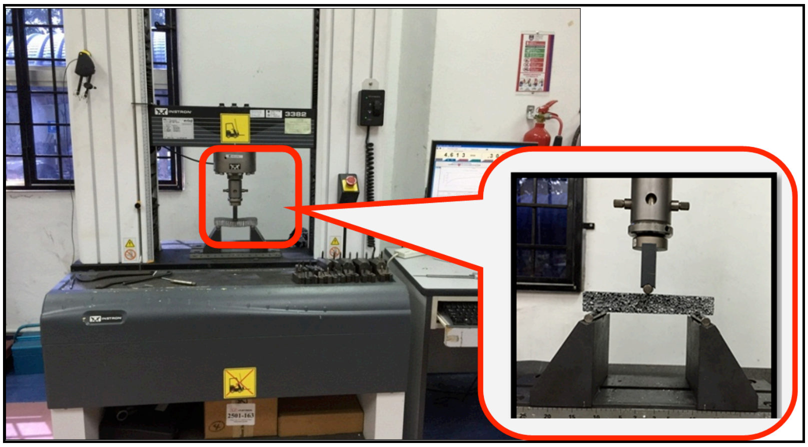


Figure 2. Instron 3382 100 kN floor model universal testing machine with three-point bending test rig

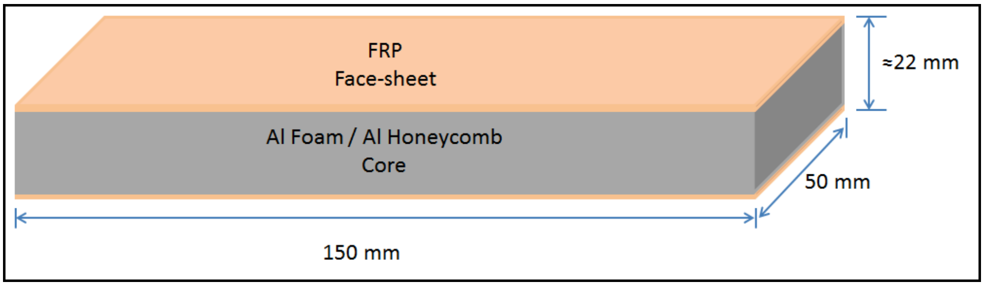


Figure 3. Dimension of specimen for three-point bending test

RESULTS AND DISCUSSION

Figure 4 shows the load-deflection curves of the neat closed-cell aluminium foam and hybrid FRP composite face-sheets sandwich panels subjected to the static three-point bending test. It is clear that that initially, all the panels have linear-elastic behaviour, followed by elasto-plastic phase until a peak value is reached. However, the neat closed-cell aluminium foam panel only has one peak load whereas the aluminium honeycomb and aluminium foam sandwich panels with hybrid FRP composite face-sheets have two peaks load, with the first peak higher than the second peak. The peak load of the neat closed-cell aluminium foam occurs just before it starts to fail at approximately 2 mm deflection. Subsequently, the flexural load decreases towards the x-axis. The loss load after the peak load is physically evident as illustrated in Figure 5 - crack load initiation exists. As the displacement increases, the bending failure is propagated towards the upper phase of aluminium foam panel until the flexural load becomes zero.

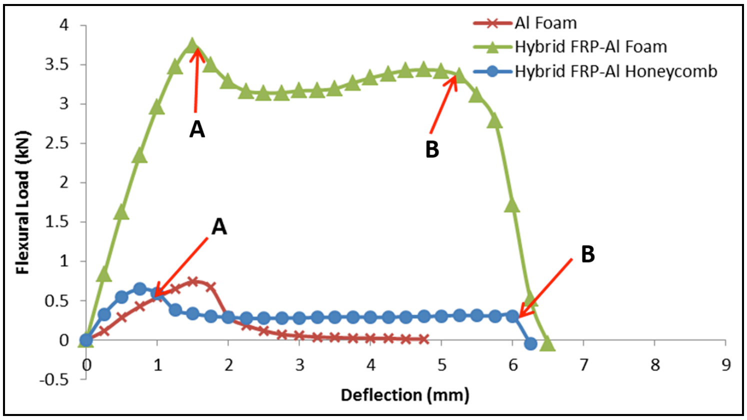
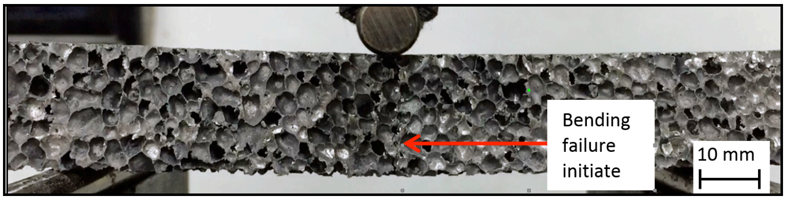
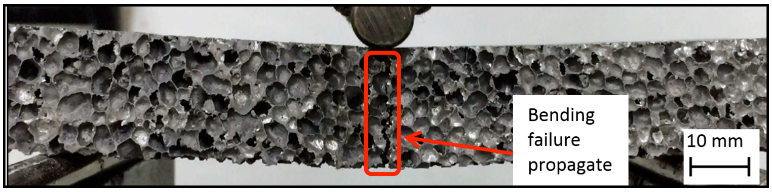


Figure 4. Load-deflection curves of the neat closed-cell aluminium foam and hybrid FRP composite face-sheets sandwich panels



(a)



(b)

Figure 5. Failure deformation of the neat closed-cell aluminium foam panel

For the aluminium honeycomb and aluminium foam sandwich panels with hybrid FRP composite face-sheets, the flexural load-deflection curves experienced two loss load; identified as A and B in Figure 4. Point A in the aluminium honeycomb sandwich panel represents the face-sheets yield. As the displacement increases, the face-sheets yield also increases. The aluminium honeycomb sandwich panel displays a long plateau region owing to the uniformity of the cell size of the aluminium honeycomb. At the end of the plateau region, the panel experiencing debonding between the aluminium honeycomb of the core and the top face-sheets is indicated at point B. The failure deformation of aluminium honeycomb sandwich panel is shown in Figure 6.

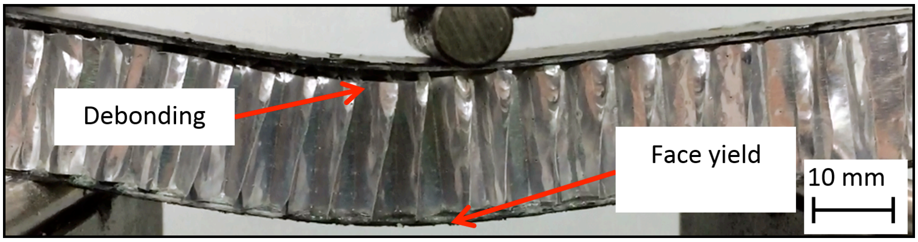
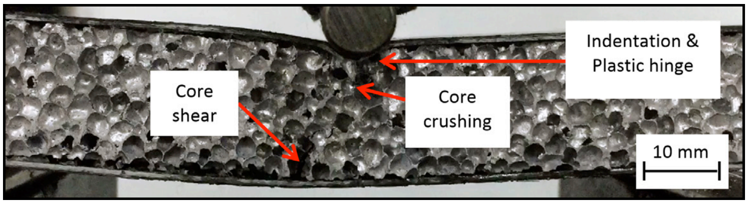
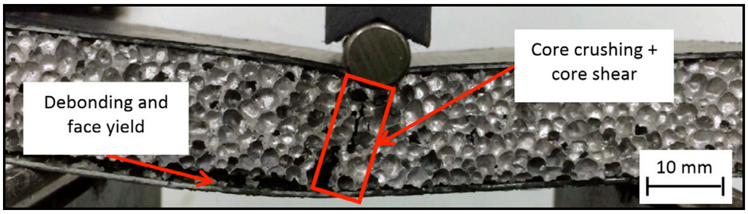


Figure 6. Failure deformation of the aluminium honeycomb sandwich panel with hybrid FRP composite face-sheets

In the aluminium foam sandwich panel, point A represents the failure of top face-sheet such as indentation and plastic hinge, and aluminium foam core failures, such as core crushing and core shear. The increase in displacement leads to an increase in core shear and core crushing as well. The entire core shear then connects with each other. The bottom face sheet is yielded during the load drop at point B. The debonding between core and bottom face-sheets is propagated due to the face sheet yielding. It has been identified that these failures occur when the core is thick enough (Yu, Wang, Li, & Zheng, 2008). The failure deformation of aluminium foam sandwich panel is shown in Figure 7.



(a)



(b)

Figure 7. Failure deformation of the aluminium foam sandwich panel with hybrid FRP composite face-sheets

Figure 8 shows the graph of flexural strength and modulus value of the neat closed-cell aluminium foam panel and both aluminium honeycomb and aluminium foam sandwich panels with hybrid FRP composite face-sheets. The graph shows that the aluminium foam sandwich panel exhibits the highest flexural strength value of 23.7 MPa, followed by the aluminium honeycomb sandwich panel and the neat closed-cell aluminium foam panel, with flexural strength value of 5.8 MPa and 5.4 MPa, respectively. The use of hybrid FRP composite face-sheets in the aluminium foam sandwich panel revealed a significant improvement in flexural strength of 309% compared to the neat closed-cell aluminium foam panel. However, the capability of the hybrid FRP composite face-sheets is limited when it is used in the aluminium honeycomb sandwich panel due to huge mismatch of stiffness; high stiffness of the hybrid FRP composite and low stiffness of the aluminium honeycomb (Shi, Sun, Hu, & Chen, 2014). The flexural strength of aluminium foam core sandwich panel is 338% higher than that of the aluminium honeycomb sandwich panel. This is because the aluminium foam is built from solid aluminium with gas-filled pores, while aluminium honeycomb structure is a combination of corrugated aluminium sheets with an adhesive material. As a result, the aluminium foam has good material properties, is stronger and stiffer than the aluminium honeycomb. In addition, the aluminium foam has a closed-cell wall structure with larger bonding surface compared to the aluminium honeycomb.

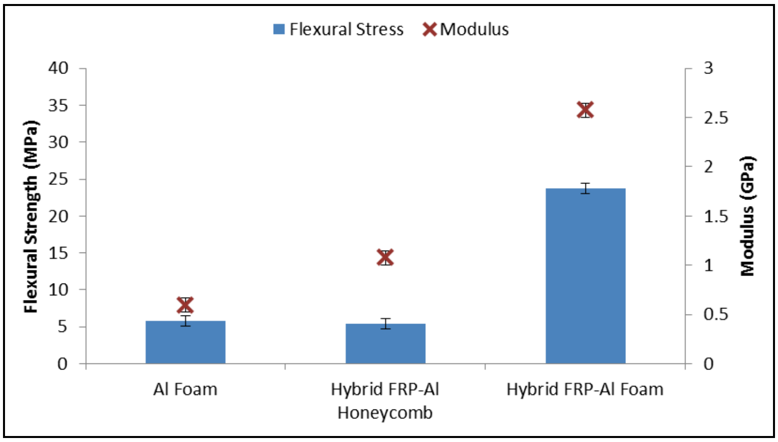


Figure 8. Flexural strength and modulus value of sandwich panels

The flexural modulus of the aluminium foam sandwich panel is the highest with 2.6 GPa, followed by the aluminium honeycomb sandwich panel with 1.1 GPa. On the other hand, the neat closed-cell aluminium foam panel exhibits the lowest flexural modulus of 0.6 GPa. The flexural modulus of the aluminium foam sandwich panel is 136% higher than the aluminium honeycomb sandwich panel and 333% higher than the neat closed-cell aluminium foam panel. This proves that the replacement of core material with aluminium foam enhanced the properties of the conventional (aluminium honeycomb core) sandwich panel. In addition, the presence of aluminium foam in sandwich panel improved the properties of the neat closed-cell aluminium foam panel. The aluminium honeycomb sandwich panel exhibits a higher flexural modulus of 83% than the neat closed-cell aluminium foam panel. Thus, from this study, it can be ascertained that the presence of hybrid FRP composite face-sheets on the aluminium honeycomb sandwich panel increases the stiffness of the whole structure of the sandwich panel.

CONCLUSION

A new sandwich panel consisted of closed-cell aluminium foam sandwich panel with hybrid FRP composite face-sheets was successfully developed in this research. The three-point bending tests were carried out to determine the flexural strength and flexural modulus (bending properties) of the aluminium foam sandwich panel with hybrid FRP composite face-sheets. The use of hybrid FRP composite face-sheets in the aluminium foam sandwich panel revealed a significant improvement in flexural strength and flexural modulus by 309% and 333%, respectively, compared to the neat closed-cell aluminium foam panel. The aluminium foam sandwich panel also exhibited higher flexural strength and flexural modulus by 338% and 136%, respectively, compared to the aluminium honeycomb sandwich panel by using the same face-sheets. The combination of the hybrid FRP composite face-sheets and aluminium foam core produced a superior sandwich panel by demonstrating high bending properties compared to the pristine material as well as the conventional sandwich panel. It can be concluded that the new developed closed-cell aluminium foam sandwich panel with hybrid FRP composite face-sheets is a promising advanced material and has high potential to be deployed in modern mechanical structures.

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