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Optimized Flexural Strength of Aluminium Honeycomb Sandwiches Using Fuzzy Logic Method for Load Bearing Application

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Abstract: This paper discussed experimental results of flexural behaviour of aluminium honeycomb sandwich panels. The flexural behaviour of the panels is studied using fuzzy logic method and focused on permanent after-impact deflections. The response of aluminium honeycomb sandwich panels to three-point bending impact load was examined with three angles of impact. All specimens were subjected to impact angles of 90°, 60° and 45° at constant impact velocity. Three different cell sizes were used for this study in order to observe permanent after-impact maximum deflections. The results showed that the parameter of cell core sized in a good agreement with deflection increase factor, implying the potential in load-bearing application.

Keywords*: Aluminium honeycomb, deflection, cell size, fuzzy logic, blunt impact*

1 Introduction

The honeycomb sandwich panels are widely used in many engineering fields due to their strength in low density, high stiffness however easy to manufacture into complex shape, and high energy absorption capacity (Gibson and Ashby, 1988). The excellence in strength to weight ratio and good bending rigidity has attracted the attention of many construction designers. The typical sandwich panel consists of a lightweight core covered by two thin walls. The separation of the thin walls by the core increases the moment of inertia of the panel with little increase in weight, producing an efficient structure for resisting bending and buckling loads. The choice of high-quality core material in the optimal design of sandwich panels is an important parameter (Howard, 1969).

The crushing strength of sandwich panel have been studied in theory, experimentation and simulation. Wierzbicki (1983) established a method and derive a formula based on the width of the cell, thickness and yield strength to determine crushing strength of metal honeycomb subjected to out-plane loads. Under static out-plane loading, Zhang and Ashby (1992) performed experimental work to analysed the collapse behaviour for both shear and simple compressions. They found out that the strength in compressive and shear were generally independent of the height however highly sensitive to the density of honeycomb. Khan, et. al., (2012) investigated crushing of aluminium honeycomb experimentally for in-plane and out-of-plane loading. By utilizing Digital Image Correlation, they found that the local plastic strain in the core was mainly in the shear band regime. For quasi static and dynamic out-plane loading, Wu and Jiang (1997) performed tests on six types of aluminium alloy honeycomb cellular structures. Response of honeycomb damage was reported differently due to static and dynamic load. It was recommended that to use small in cell size and core height for the best use of honeycomb in energy absorber structure.

For the flexural behavior, Frostig and Baruch (1990) analytically investigate sandwich beams subjected to concentration and distributed loading by using superposition method of two types of beam behaviour. Their proposed method explained concerning the nonlinear response of the transverse and shear stresses between the skin face and the core. This nonlinear behaviour in flexural also investigate by Gdoutos, et.al (2001), by using unidirectional carbon/epoxy facings and a polyvinyl chloride closed-cell foam core the load-deflection behaviour was observed. Some of their finding showed the nonlinear part is attributed to the combined additive effect of material and geometric nonlinearities. Jilin, et.al., (2008) performed three point bending test in static and low-velocity impact for closed-cell aluminium foam. Their paper showed the failure modes and crash processes of beams under impact loading are similar to those under quasi-static loading, but the force-displacement history is very different. The low velocity bending impact also investigated by Umut and Kemal (2016) for sandwich beams with expanded polystyrene (EPS) foam core reinforced by aluminum face-sheets using adhesive bonding technique. They observed the effect of foam

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core density, face-sheet thicknesses and foam core thicknesses to the energy absorbing capability and also for the maximum deflections.

In bend configuration, the experimental results of flexural behaviour for different impact angles are not widely discussed. This study is conducted to enrich the current experimental results of flexural behaviour of aluminium sandwich panels. Three cell sizes of aluminium sandwich panels are impacted with three angles of impact in three point bending configuration. Particular interest is on permanent after-impact maximum deflections that reflect the flexural strength of honeycomb panel. With constant impact velocities, the effect of cell size of the honeycomb panel is investigated. The empirical deflection increase factor is being proposed to explain the increase of deflection strength.

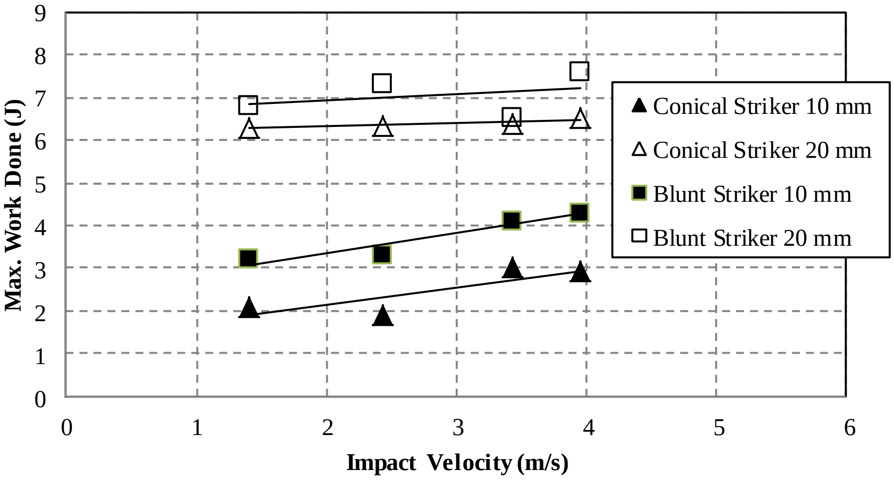
2 Experiment Arrangements

2.1. Aluminium honeycomb panels

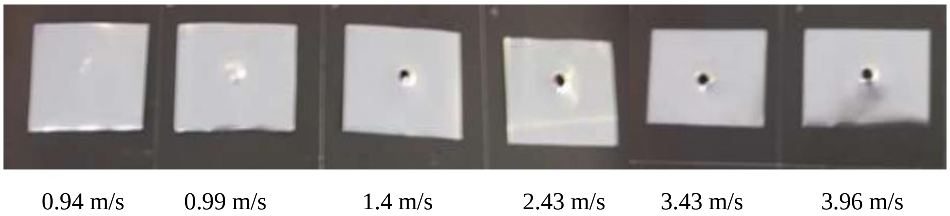
Three hexagonal honeycombs specimens with varying cell size (*D*) of 2 mm, 4 mm, and 6 mm were used in this study. The specification of aluminium honeycombs is shown in Table 1. The wall thickness is 0.4 mm which makes the overall thickness (*c*) to 18 mm for all specimen types. In our previous work, the mechanical properties of aluminium of 0.4 mm thickness have been tested with results elastic modulus of 69 GPa and 109 MPa tensile strength. The performance of maximum work done impacted using blunt and conical striker is presented in Fig. 1a (Siregar, 2015).

For out-plane loads the honeycomb specimen dimension is 90 mm x 45 mm x 18 mm while for impact loads the overall dimensions is 210 mm x 45 mm x 18 mm as in bending configuration. The photographs of each specimen are shown in Fig. 1b.

Fig. 1 Aluminium plat 0.4 mm subjected to impact loading of blunt striker



(a) Impact velocity versus maximum work done using the blunt striker diameter of 10 mm.



(b) Thinned deformed shapes for specimen thickness of 10 mm blunt striker under different impact velocities.

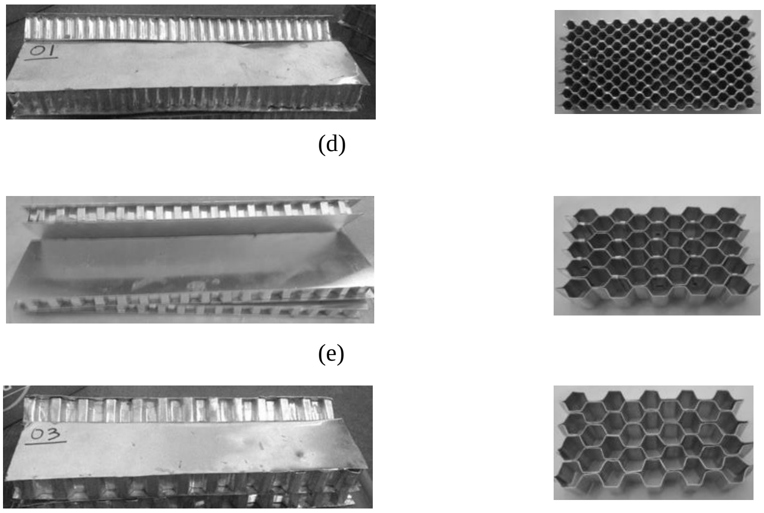
Table 1 Specification of aluminium honeycombs

Specimen Type	Cell size, D (mm)	Core thickness t (mm)	Thickness to cell size ratio t/D (mm)
H2	2	17.2	8.6
H4	4	17.2	4.3
H6	6	17.2	2.87

2.2. Experiment setup

Static and impact test of aluminium honeycomb are performed to examine the response of three different cell sizes. For impact tests, Hopkinson apparatus is used with three-point bend configuration. The input bar has 20 mm in diameter and a length of 3000 mm. Indenter 20 mm half sphere shaped is screwed at one end of the input bar. The input bar is placed touching the surface of specimen while the striker bar impacted the input bar. In other word, the striker is not directly impacting the specimen. The Hopkinson bar arrangement and the specimen setup are presented in Fig. 3. The arrangement can be modified, in-plane configuration and three-point bend configuration. For bend configuration, three angles of impact are set, that are 90°, 60° and 45°, which can be configured by adjusting the jig as shown in Fig. 5. Impact velocity is maintained the same for each experiment in order to observed average deflection of aluminium honeycomb sandwich. Overall, the experiment was conducted according to fuzzy logic method.

Fig. 2 Aluminium honeycomb with three different cell sizes

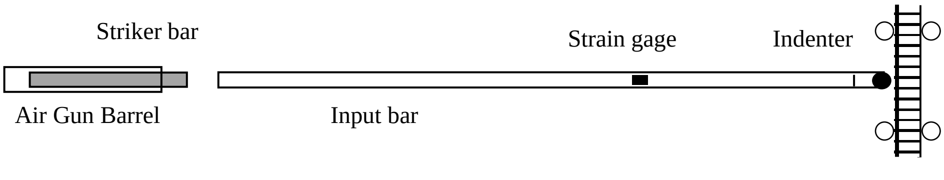


(d)

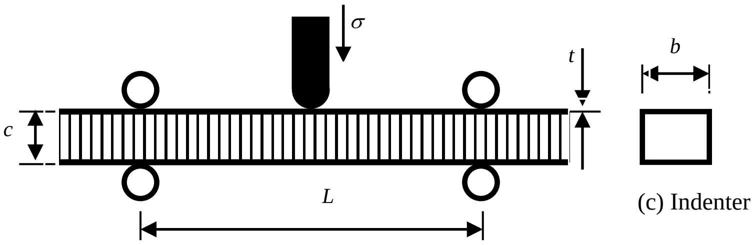
(e)

(f)

Fig. 3 Arrangement of experimental apparatus



(a) Hopkinson bar arrangement



(c) Indenter

(b) Honeycomb specimen setup

L = 100 mm b = 50 mm

c = 25 mm t = 0.7 mm

Fig. 4 Static in-plane force – displacement results

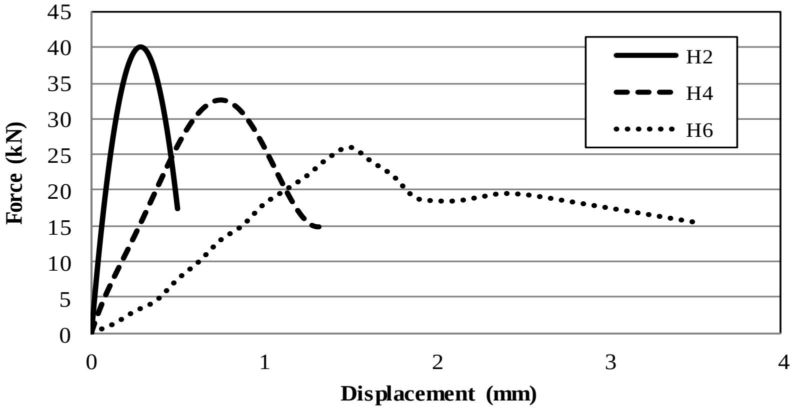
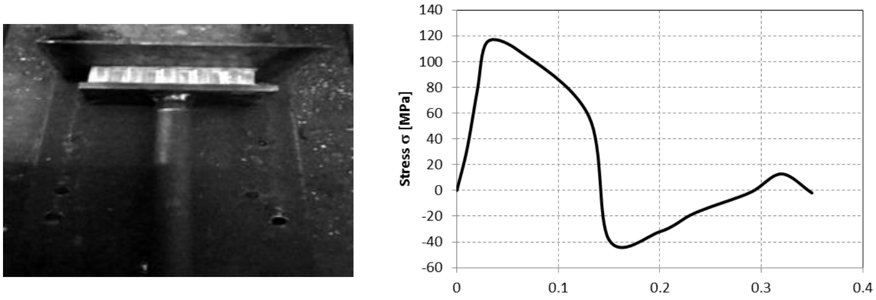


Fig. 5 The incident stress with four impact configurations

(a) angle: 45° (b) angle: 60° (c) angle: 90°



(d) in-plane compression (e) typical incident stress

3 Experimental Result and Discussion

The result of static test of in-plane compressive test is shown in Fig. 4. The cell size of 2 mm showed the highest loads 40 kN, followed by 4 mm (decrease about 18.5%) and 6mm (decrease about 51.3%), of cell size.

In impact test, the impact velocity is maintained the same around 1.3 m/s. The photograph of specimen impacted with 90° load angle is presented in Fig. 5(a) together with incident stress, Fig. 5(b). The incident stress is the applied stress to all specimen tests recorded on the input bar. The result of 90° load angle produces less damage while the result with a 45° impact angle indicates otherwise the worst damage to the sandwich panel. Damage to the sandwich panel is measured by the length of after-impact permanent deflection occurring. This is possible due to there is no hole or tear damage to sandwich panel using the current setup impact configuration. The average deflection for three angles of impact is presented in Fig. 6. It can be seen that the effect of cell size highly influences the deflection of sandwich panel. A less dense honeycomb causes more deflection in the sandwich panel. The increase factor of deflection is attempted to be presented by assuming that the experiment results of the 90° impact angle and cell size of 2 mm as a baseline.

Fig. 6 Average deflection of honeycomb panel subjected to impact loads

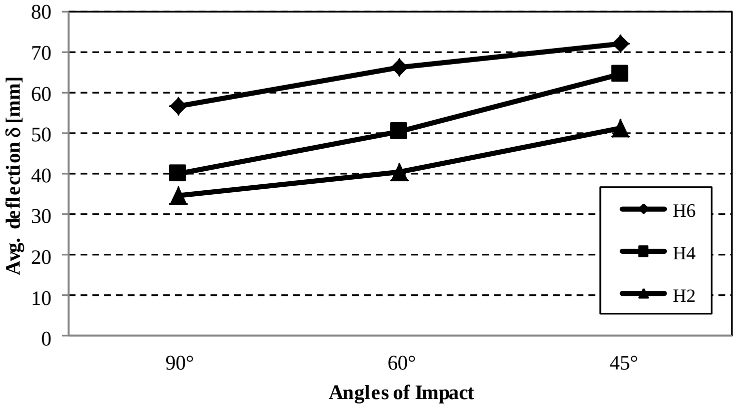
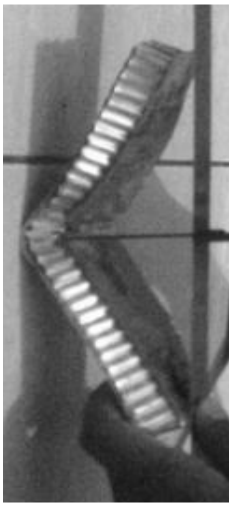


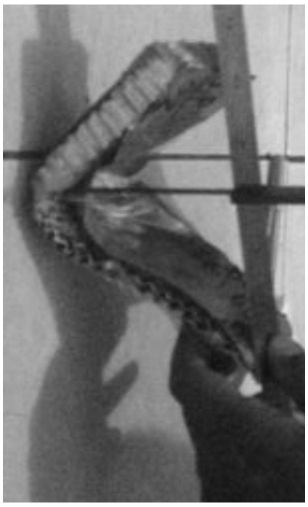
Figure 7 Specimens' deformation in bending configuration

(a) angle: 90°

(c) angle: 60°



(a) angle: 90°



(b) angle: 60°

(c) angle: 45°

4 Conclusion

The flexural behavior of aluminium honeycomb sandwich panels is discussed experimentally with different cell core sizes and impact angles. Permanent after-impact deflections are measured and the result is proposed as correlation of the deflection increase factor to the impact angle. It was found that the parameter of cell core sized shows a good agreement with deflection increase factor. In this case, smaller the cell size the more rigid the sandwich panel. In correlation with angle of impact, with the same impact velocities, the experimental result of 45° impact angle shows the highest permanent after-impact deflection to the sandwich panel.

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