Specific Properties of Novel Two-Dimensional Square Honeycomb Composite Structures

M.R.M.Rejab[1, a], W.A.W.Hassan[1,b] ,J.P.Siregar[1,c] and D.Bachtiar[1,d]
[1]Faculty of Mechanical Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, MALAYSIA.
[a]ruzaimi@ump.edu.my, [b]wananuar@ump.edu.my, [c]januar@ump.edu.my, [d]dandi@ump.edu.my

Keywords: Square Honeycomb, Self-Reinforced Polypropylene (SRPP), Specific Energy Absorption, Specific Strength.

Abstract. Hexagonal honeycomb cores have found extensive applications particularly in the aerospace and naval industries. In view of the recent interest in novel strong and lightweight core architectures, square honeycomb cores were manufactured and tested under uniform lateral compression. A slotting technique has been used to manufacture the square honeycomb cores based on three different materials; glass fibre-reinforced plastic (GFRP), carbon fibre-reinforced plastic (CFRP) and self-reinforced polypropylene (SRPP). As semi-rigid polyvinyl chloride (PVC) foam was placed in each of unit cells to further stiffen the core structure. The core then was bonded to two skins to form a sandwich structure. The compressive responses of the sandwich structures were measured as a function of relative density. In this paper, particular focus is placed on examining the compression strength and energy absorption characteristics of the square honeycombs with and without the additional foam core. Comparisons in terms of specific strength and specific energy absorption have shown that the CFRP core offers excellent properties. The presence of the foam core significantly increases the energy absorption capability of overall structure and the SRPP core could potentially be used as an alternative lightweight core material in recyclable sandwich structures.

Introduction

Hexagonal honeycomb sandwich structures are being widely used in lightweight structural applications where high flexural rigidity is required. They are typically manufactured from aluminium (AL) and Nomex® aramid paper, which represent leading candidates in terms of their weight-specific mechanical properties. Extensive reviews of the mechanical properties of the honeycomb materials can be found in the work of Ashby and Gibson [1]. Honeycomb cores are commonly loaded in the lateral direction as they exhibit excellent mechanical properties when loaded in this way. Hence, the uniform lateral compressive behaviour of honeycombs is of great importance.

Previous studies have suggested that square honeycomb cores having a higher relative density are preferable for use in high severity loading situations, such as blast loading as a result of their superior crushing resistance and in-plane tensile strength [2]. An early attempt to manufacture a square honeycomb core was made using 304 stainless steel (SS) sheets and then brazing the assembly. Coté et. al. [3] compared the properties of SS core with commercial aluminium (AL) hexagonal honeycomb core, with the same relative density and cell aspect ratio. They showed that the SS core offered a higher compression strength and was able to absorb more energy compared to the AL core. Then, Russel et. al. [4] fabricated square honeycomb cores from CFRP by slotting, assembling and adhesively bonding composite laminate sheets with various fibre orientations; [0/90], [±45]. They found that a CFRP core with a relative density of 0.2, with a weave [0/90] for specimen based on 6 x 6 cells gives a higher compressive strength and energy absorption. Recently, Coté et. al. [5] have designed and tested a hierarchical composite square honeycomb core under compression loading. The cell walls of the square honeycomb comprise sandwich plates made from glass fiber/epoxy composite skins and a polymethacrylimide (PMI) foam core. The square honeycomb core introduced in the study shows promise as it has a substantially higher through-thickness compressive strength than an equivalent sandwich panel with a monolithic composite core. Recycling of composites is inherently difficult because of their complex composition (fibres, matrix and fillers), the crosslinked nature of thermoset resins which cannot be remoulded and the combination with other materials (AL honeycombs, hybrid composites, etc)[6]. Some studies show that the majority of CFRP waste (so-called 'black junk') coming from aerospace scrap is landfilled [7]. Environmental and economic awareness led the UK strategy for composites [8] to identify increasing sustainability and recycling as the major goals for the aerospace/composites industry. SRPPs are materials made from 100% thermoplastic with a low density possessing a unique combination of high strain to failure and outstanding energy management properties. These advantages highlight SRPP (Curv^{TM} composite) as an alternative candidate in composite industry.

The current work focuses on manufacturing novel square honeycomb cores. The manufacturing routes for producing these cores are discussed first. The compressive responses when subjected to uniform lateral loading are then investigated. The specific strength and specific energy absorption are explained quantitatively and then compared with other competing cores design.

Square Honeycomb Sandwich Structures

Square honeycomb cores were manufactured from a self-reinforced polypropylene (SRPP), a unidirectional glass fibre-reinforced plastic (GFRP), and a woven carbon fibre-reinforced plastic (CFRP). Laminated sheets of each material were prepared (Table 1) using the hot press technique according to the manufacturer's recommended processing cycle. After curing, the sheet was removed from the mould and visually inspected for any defects, once the hot press had cooled to a temperature below 60°C.

Table 1: Material, geometry and densities of the square honeycomb cores

Label	**GF1**	**GF1F**	**GF2**	**GF2F**	**CF1**	**CF1F**	**CF2**	**CF2F**	**SRPP**
Material	Unidirectional GFRP				Woven CFRP				Woven PP
Fibre direction	$[0/90]_s$		$[0/90/0/90]_s$		[0/90]				[0/90]
Nominal wall thickness, *H* (mm)	1		2		1		2		3
Core relative density, $\bar{\rho}$	0.1	With foam	0.2	With foam	0.1	With foam	0.2	With foam	0.3
Core density, ρ (kg/m^3)	206	237	357	389	216	254	309	342	224

In Fig. 1, the sheets were cut into rectangles of height, *D*=30mm and length, *L*=20mm, giving a consistent cell aspect ratio *D/L* = 1.5 for all the specimens. The cross-slot was introduced using a micro-milling machine to give a clearance of 10μm between the sheet and slot, while providing a sufficiently tight fit to assure stability. The slotted rectangles were assembled into the square honeycomb core configuration and then the core was divided into 2 x 2 cells.

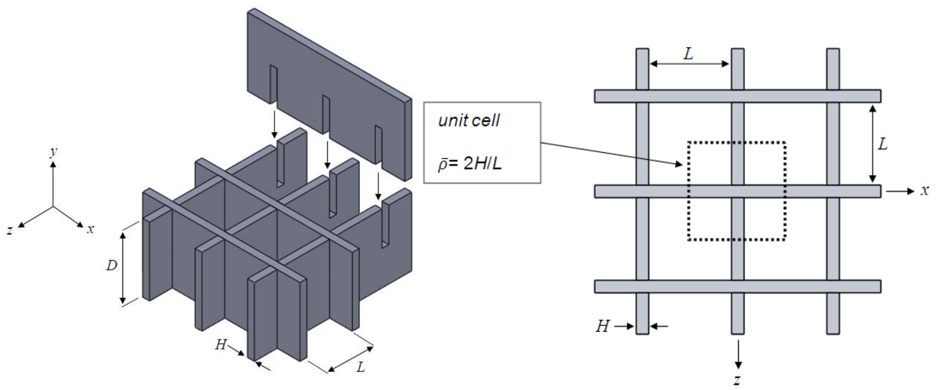

Fig. 1: Schematic of the square honeycomb core structure.

Following this, the core was bonded to the two skins (the skin thickness was equal to H of the core) using a strong epoxy adhesive (Araldite 420 A/B), except for the SRPP core. The sandwich structure was then heated in an oven at a temperature of 120°C for about 1 hour, to cure the adhesive. For the SRPP core, the 3 mm thick SRPP skins were bonded to the top and bottom faces of the core using a thin polypropylene film with a nominal thickness of 60μm (Xiro. 23.601-40 from Collano) and then the entire assembly was pressed at 155°C for 5 minutes to melt the film and give good bonding. The relative density $\bar{\rho}$ of the square honeycomb is defined by

$$\bar{\rho} = \frac{2H}{L} \qquad (1)$$

In addition, to increase the energy absorbing capability of the GFRP and CFRP cores, semi-rigid PVC (H130 from Divinycell) foams with dimensions of 20mm x 20mm x 30mm were placed in each cell (Fig. 2).

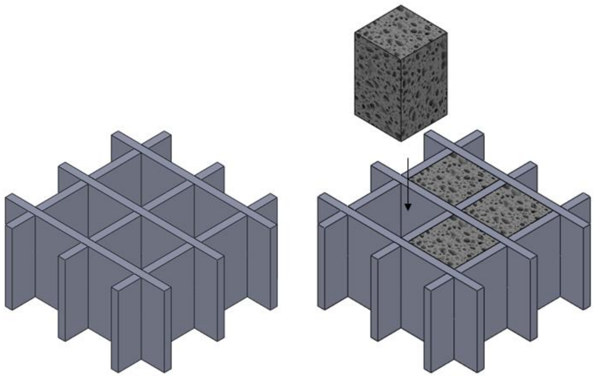

Fig. 2: Two configurations of square honeycomb, with and without foam core.

Experimental Results

Compression tests on the square honeycomb core sandwich structures were conducted using an Instron series 4505 testing machine. All the test specimens were prepared in a rectangular form, with 2 x 2 cells and it was deformed by applying a uniform lateral compression at a static loading rate of 1mm/minute. As the main area of interest was in the deformation behaviour of the panels, an extensometer was used to gather strain data. The test was stopped once the specimen was entirely crushed. The experiments showed that there exists a fundamental difference in the behaviour of the different structures.

Specific Energy and Energy Absorption

The compressive strength and energy absorption of all the square honeycomb cores were divided by weight of the core, to yield a strength-to-weight ratio or specific strength (σ_{sp}) and specific energy absorption (*SEA*) at a strain $\varepsilon = 0.7$ are compared using this intrinsic property.

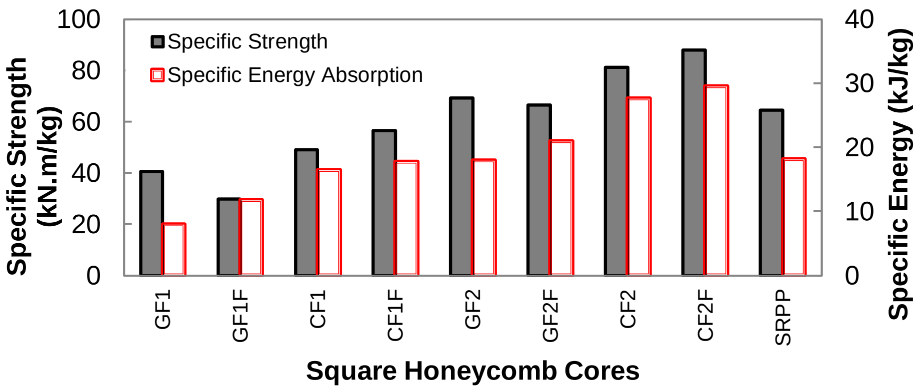

Fig. 3: The specific strength and *SEA* of the square honeycomb sandwich structures.

Fig. 3 shows a comparison between the values of σ_{sp} and *SEA* for the nine different square honeycomb core specimens. The CFRP cores offer very impressive values and have higher values of σ_{sp} and *SEA* than the other core materials. For the GFRP cores, σ_{sp} decreases with the addition of foam but the foam assists to absorb up to 45% more energy compared to the monolithic core. Meanwhile, the SRPP core has comparable σ_{sp} and *SEA* properties to the GFRP, $\bar{\rho}$ =0.2 with foam.

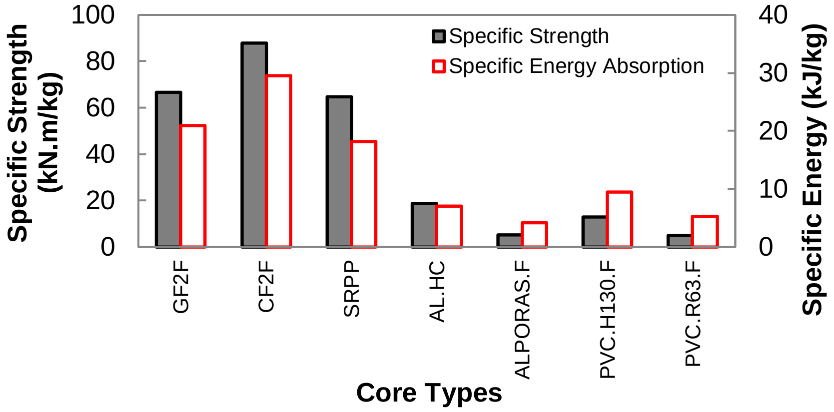

Fig. 4: The specific strength and *SEA* of the competing core types design.

Fig. 4 shows the bar chart for the σ_{sp} and *SEA* with the three best square honeycomb cores compared with the four competing cores: AL.HC (AL hexagonal honeycomb – Hexcel), ALPORAS.F (AL metal foam – Shinko) and polymeric foams (PVC.H130.F – Divinycell and PVC.R63.F – Airex). The square honeycomb cores properties are up to three times better than the competing commercial cores.

Conclusions

The manufacturing route and specific properties of the square honeycomb cores of three different materials subjected to uniform compression were discussed. The following conclusions are made:

a. The square honeycomb cores were made from slotting technique and they have outstanding properties in terms of the σ_{sp} and *SEA* compared with other commercial cores. The CFRP cores are the best type of material for this novel design and fabrication process.
b. The SRPP square honeycomb sandwich structure is a new novel structure where a thin PP film is used to bond the skins and core, and made them 100% recyclable structure. This potential core type design and material is a suitable candidate for aerospace applications in a near future.

Acknowledgement

The authors are grateful to the Ministry of Higher Education for funding this research (FRGS/1/2014/TK01/UMP/02/3).

References

[1] M.F. Ashby, L.J.Gibson, Cellular Solids:Structure and Properties, Cambridge Univ. Press,1997.
[2] T.Wierzbicki, W.Abramowicz, On the crushing mechanics of thin-walled structures, J. Appl. Mech. 50 (1983) 727-734.
[3] F. Coté, V.S. Deshpande, N.A. Fleck, A.G. Evans, The out-of-plane compressive behavior of metallic honeycombs, Mater. Sci. & Engg. A380 (2004), 272–280.
[4] B.P. Russell, V.S. Deshpande, H.N.G.Wadley, Quasistatic deformation and failure modes of composite square honeycombs, J. Mech. Mater.& Struc. 3(7) (2008), 1315–1340.
[5] F. Coté, B.P.Russell, V.S. Deshpande, N.A. Fleck, The through thickness compressive strength of a composite sandwich panel with a hierarchical square, J. Applied Mech. 76 (2009), 61004-1– 61004-8.
[6] S.Pimenta, S.T.Pinho, Recycling carbon fibre reinforced polymers for structural applications: Technology review and market outlook, Waste Management 31 (2011), 378-392.
[7] V.P.McConnell, Launching the carbon fibre recycling industry, Reinforced Plastics 54(2) (2010), 33-37.
[8] BIS, The UK Composites Strategy Report. Department for Business, Innovation & Skills, 2009.