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ENERGY-ABSORBING HONEYCOMB STRUCTURES BASED ON CARBON FIBER REINFORCED PLASTICS

Alia R. Aziz[1], Shanmugam Kumar[1], Pradeep George[1] and Wesley James Cantwell[1]
[1]Khalifa University of Science and Technology (KUST),
127788 Abu Dhabi, United Arab Emirates.
alia.aziz@kustar.ac.ae, kshanmugam@masdar.ac.ae, pradeep.george@kustar.ac.ae and wesley.cantwell@kustar.ac.ae

1. ABSTRACT

As a result of their impressive mechanical properties and low density, sandwich structures are being widely used in a large range of engineering applications [1-3]. Recently, there has been a drive to develop new core designs that offer enhanced properties under extreme loading conditions. The present paper investigates the energy-absorbing properties and compression characteristics of a CFRP honeycomb core produced using vacuum assisted RTM. The lightweight cores were produced using a steel mold into which a series of hexagonal blocks were inserted. Initially, a unidirectional carbon fiber cloth was inserted into the gaps between the hexagonal blocks and the mold was wrapped in a vacuum bag and infused with a room-temperature curing epoxy resin. Following the twenty-four hour cure cycle, the steel blocks were removed from the mold to leave a repeating composite honeycomb structure. The compression and energy-absorbing properties of the cores were then determined through a series of quasi-static compression tests. Cores with their fibers oriented a several angles were also manufactured in order to understand the influence of stacking sequence on the compressive behavior.

2. EXPERIMENTAL

In this study, a CFRP honeycomb core is manufactured and tested. This type of structure has been selected since it offers the opportunity to combine the excellent energy-absorbing characteristics of composite materials with a continuous core architecture that is well-established in the design of energy-absorbing engineering components, namely a honeycomb structure.

The CFRP honeycomb cores study in this investigation were manufactured from a unidirectional (UD) carbon fiber cloth (Unitex UT-300/500) and a two-part epoxy resin (Prime™ 20LV). The carbon fiber cloth has a thickness of 0.25 mm and an areal density of 290 g/m^2. The cores were produced using the mould shown in Fig. 1(a). Here, 27 mm high steel hexagons (face-to-face distance = 22 mm) were placed in slots that were machined into the base of the steel mould. Following this, 25 mm wide strips of carbon fibre cloth were positioned in the vertical gaps in the hexagonal structure. The mould was then placed on a large glass table and wrapped in a bagging film. A line injection was used to introduce the resin into the mould and a line vent was used to apply a vacuum. After infusion, the resin allowed to cure under 24 hours. The mould was removed from the bagging film, and the hexagonal blocks carefully pushed out to leave the uniform honeycomb structure shown in Fig. 1(b).

Honeycomb cores based on one, two, three and four fabric layers were manufactured in this investigation. Initially, UD cores where the fibres were arranged in the through-thickness 0^o direction were manufactured and tested. Using this technique allowed the fibre weight fraction, w_f, to be varied between approximately 0.15 and 0.51. Honeycomb cores were also produced with their central layers oriented at either +/-45^o or 90^o to give cores with stacking sequences of (0^o, +45^o, -45^o, 0^o) or (0^o, 90$^o{}_2$, 0^o).

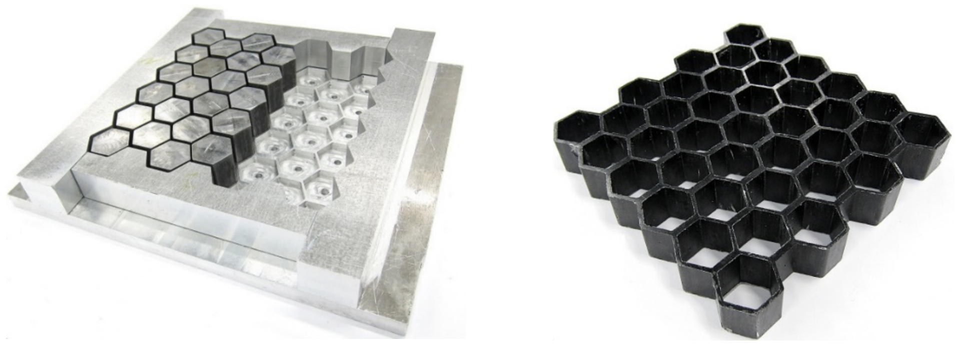
The compression strength and energy-absorbing properties of the CFRP cores were characterized on a servohydraulic universal testing machine. Following testing, force and displacement data were used to determine the compression strength and specific energy absorption (SEA) properties of the composite cores.

3. RESULTS AND DISCUSSION

Following manufacture, a number of samples were scanned in an X-ray computed tomography machine to assess the quality of the manufactured parts and ass the level of voiding. These studies highlighted the uniformity of the cell wall thickness and the very low level of porosity (less than two percent).

Fig. 2 shows force-displacement plots following tests on samples based 1, 2 and 5 hexagons (cells). The weight fraction of fibers in all samples is 0.28. All curves exhibit similar characteristics, with the force increasing to a maximum value dependent on the number of cells in the specimen. The force decreases steadily before increasing as the samples begin to fully crush (i.e. densify) between the plattens. From the figure, it is clear that the densification threshold is similar in all three specimens.

Fig. 3 shows the variation of the compression strength as a function of fiber weight fraction in the core. The figure indicates that the strength of the core increases in a roughly linear manner with w_f. Indeed, the strength increases from approximately 18 MPa to 35 MPa as the fiber weight fraction passes from 0.14 to 0.4. Normalizing these values by the density of the core gives for the specific compression strength that lie between 0.12 and 0.2 MPa.m^3/kg. Available data for the specific compression strengths of crosslinked PVC foams with densities of 200 and 250 kg/m^3 (i.e. comparable to those tested here) are similar, being approximately 0.025 MPa.m^3/kg. Similar data for an aluminum honeycomb with a density of approximately 190 kg/m^3 yields a specific compression strength of 0.097 MPa.m^3/kg. These comparisons highlight the impressive compression properties of the current carbon fiber/epoxy core materials.



(a) ***(b)***

Fig. 1: Photograph of the mould and a carbon fibre/epoxy honeycomb core.

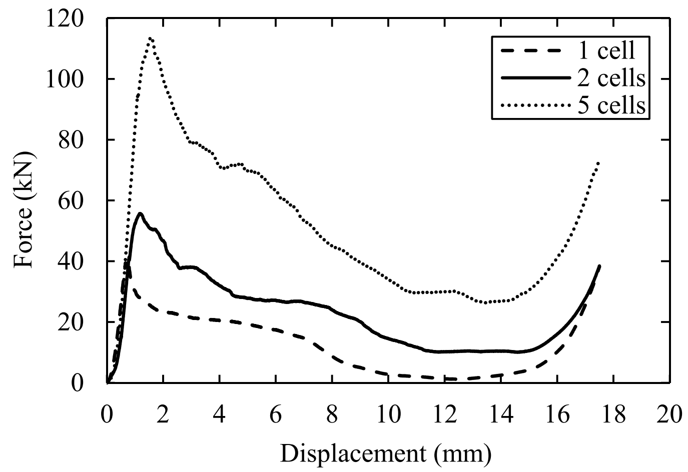


Fig. 2: Force-displacement traces following compression tests on samples containing one, two and five unit cells and a weight fraction of fibers = 0.28.

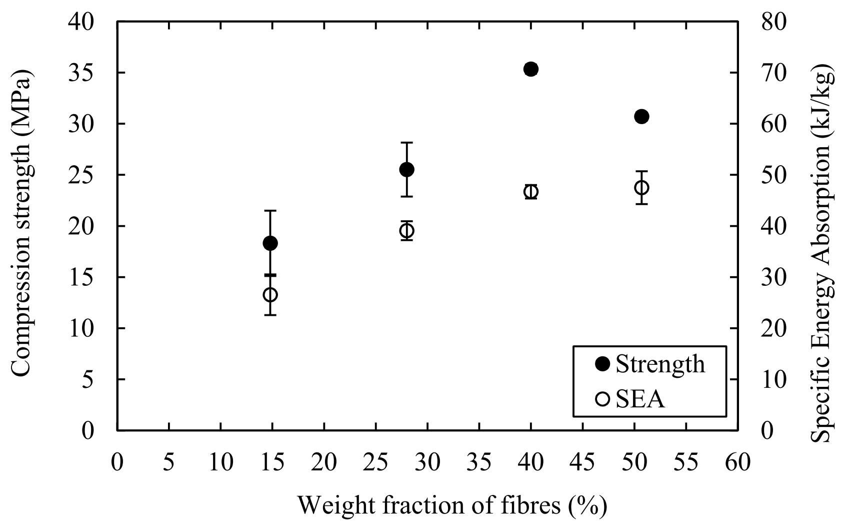


Fig. 3: The variation of compressive strength and specific energy absorption with weight fraction of fibers.

4. CONCLUSIONS

Carbon fiber reinforced epoxy composite honeycomb cores have been produced using a steel mold and the VARTM manufacturing technique. Compression tests on samples based on a unidirectional fiber arrangement have shown that the strength increased with increasing fiber content, reaching a maximum for a core based on $w_f = 0.4$. Further increases in the amount of fibers in the core resulted in a drop in strength, due to increased levels of porosity in the materials. The resulting values of specific compression strength surpassed those of aluminum honeycomb cores by a factor of approximately two. Similarly, the SEA of the composite honeycomb cores increased steadily to 46 kJ/kg, before remaining roughly constant at higher values of w_f.

A number of multidirectional cores based on (0°,90°,90°,0°) and (0°,+45°,-45°,0°) stacking configurations have also been manufactured and tested. Offsetting the fibers served to stabilize the force during the crushing process, although the measured values of SEA were lower than those recorded on the unidirectional samples. Finally, test data from impact tests on sandwich panels based on CFRP cores with CFRP skins will demonstrate the excellent impact resistance of these lightweight structures.

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