COMPRESSIVE CHARACTERISTICS OF NOVEL CONTOUR CORE

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Abstract

An experimental investigation is presented into the compression response and subsequent failure modes in novel all-composite core parts based on a glass fiber reinforced plastic (GFRP) and a carbon fiber reinforced plastic (CFRP). The contour-cores were fabricated using a compression moulding technique. The deformation in contour parts is investigated as a function of the number of unit cells. The specific energy absorption of the contoured structures has also been determined for the GFRP and CFRP contour core parts.

1. Introduction

Sandwich panels are continuously being improved by developing new structural geometries with minimum weight for the automobile, aeroplane, marine and construction industries. Sandwich panels with fibre reinforced plastic skins and a cellular core, have been shown to offer superior stiffness, strength and energy absorption properties compared to their monolithic counterparts. In recent years, various core designs offering significant improvements in static, dynamic and energy abortion properties have been proposed [1,2]. However, there is an increasing demand for lightweight structures with an improved crash resistance [3]. Efforts have been made to replace foam cores [4,5] with honeycomb cores [6,7], origami-cores [8,9] in sandwich structures.

The failure mechanisms observed in composites can vary greatly from thin to thick laminates. This can be understood from the fact that failure in thick composites often involves more complex fracture modes than in plain composite laminates. From a statistical point of view, the possibility of the composite containing larger defects increases with increased thicknesses. Thicker composites contain more layers, leading to a greater possibility of fibre misalignment [10].The mechanical properties of corrugated sandwich panels based on three different materials have been investigated in order to evaluate their overall potential [11]. A potential new class of energy-absorbing aluminium egg box structure was introduced to understand the collapse behaviour of the panel. Experiments suggested that egg-box structures deform by either the rotation of a stationary plastic hinge or by a travelling plastic knuckle, depending on the in-plane kinematic constraints imposed on the egg-box [13]**.**

In this paper, a novel contour core structure based on carbon and glass fibre composite materials is presented. The main focus is to investigate the influence of the number of unit cells on the overall deformation and collapse behaviour of contoured core structures. The static fracture modes will be investigated in the different sizes of contoured core. Finally, the energy-absorbing capabilities of the carbon and glass fibre contour cores are investigated and compared.

2. Experimental Procedure

2.1. Geometry and Material fabrication process

The geometry of the core for the sandwich panel investigated here is defined by a repeating arrangement of contoured unit cells. An aluminium mould was used to produce the shaped structure, with nominal cell height of 12.5 mm and unit cell length of 20 mm, as shown in Figure 1. The mould was manufactured by using a numerically-controlled milling machine. Prepreg carbon/epoxy, and glass/epoxy sheets were used to fabricate the composite cores. The specimens were manufactured by feeding sheets of prepreg into a press. Two aluminium moulds mounted on a pressing machine to press the composite sheet between the upper and lower dye of the mould to achieve the press load geometry. Woven fibre prepregs were draped between the lower and upper moulds. The composites were cured temperatures of 130°C, and 145°C, and at a maximum pressure of 6 bar for 90 minutes. The specimen thickness was found to be almost uniform across the core.

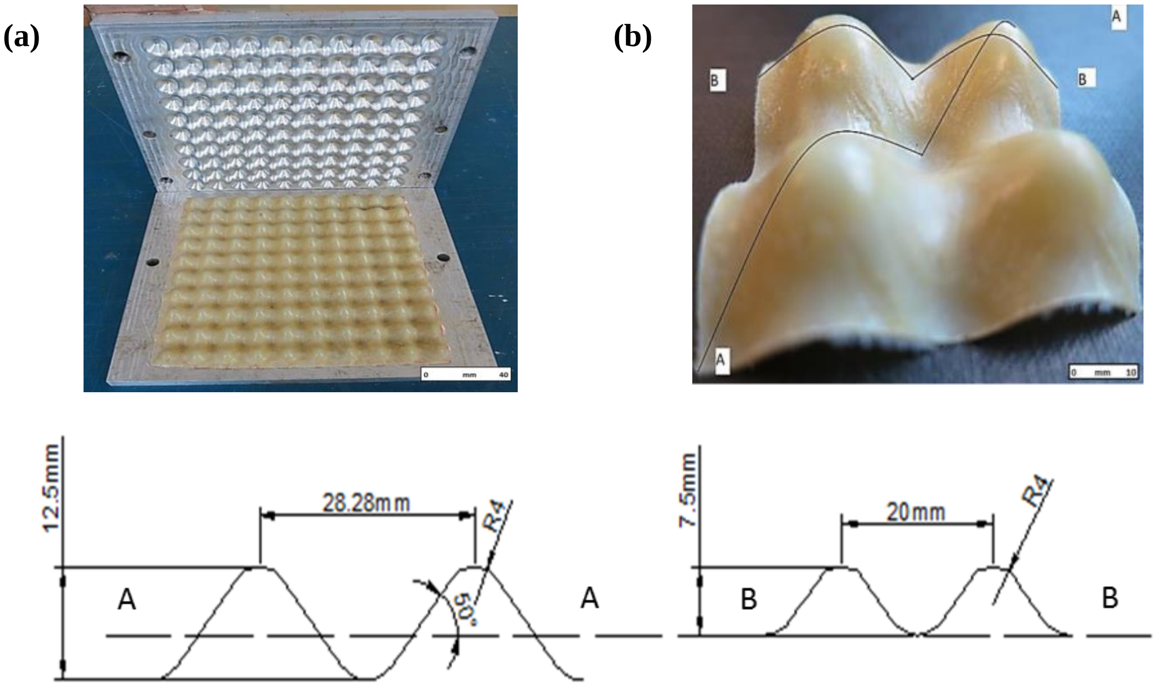


Figure 1. (a) The mould (b) Geometry and dimensions of the core.

2.2. Compressive tests

This study investigated the influence of core size, on the load-bearing capability and the energy-absorbing characteristics of the composite cores. Here, three different sizes of core structure were considered. Initially, compression tests were carried out at a crosshead displacement rate of 1 mm/min using a universal testing machine (INSTRON 4505). The load-displacement traces were recorded until the specimens had been fully crushed. The traces were represented in terms of nominal stress (load divided by initial projected area) versus nominal strain (displacement divided by the original specimen height). All tests were performed three times.

3. Results and discussion

Compression testing on the core structures highlighted significant differences and their respective responses are therefore summarised separately below.

3.1. Compressive response of the GFRP egg box core

Figure 2(a) shows representative collapse curves for the GFRP contour core structure for, the core (unbounded) and sandwich structures (bonded) samples. Generally, the GFRP samples exhibited a more brittle type of behaviour, involving extensive crushing and matrix cracking with fiber fracture. The response of the bonded GFRP sample differs significantly from that of the unbonded samples. Initially, both traces respond in a linear elastic manner before the peak stress is reached. The bounded contour core relatively showed a higher peak stress than unbounded core. This was caused by the skin preventing the core from sliding horizontally during compression. The stress then progressively decreased as fiber began to fracture. In the unbonded core, after an initial rise in stress up to 1.5 MPa, the collapse response was roughly constant until final densification.

3.2. Compressive response of CFRP egg box core

Typical stress-strain traces following compression tests on the CFRP core structures are presented in Figure 2(b), In first stage, the crushing response is linear up to the peak stress. The response then becomes nonlinear and the measured stress begins to decrease progressively as the specimen flattens between the plattens, with cracks and fibre fracture occurring within the structure. Densification starts at a nominal strain of between 0.8 to 0.9. However, for the sandwich structure, the peak stress was slightly higher than the plain core. The stiffness of the sandwich sample is much greater than that associated with the plain samples, an affect that is due to the constraint applied by the skins.

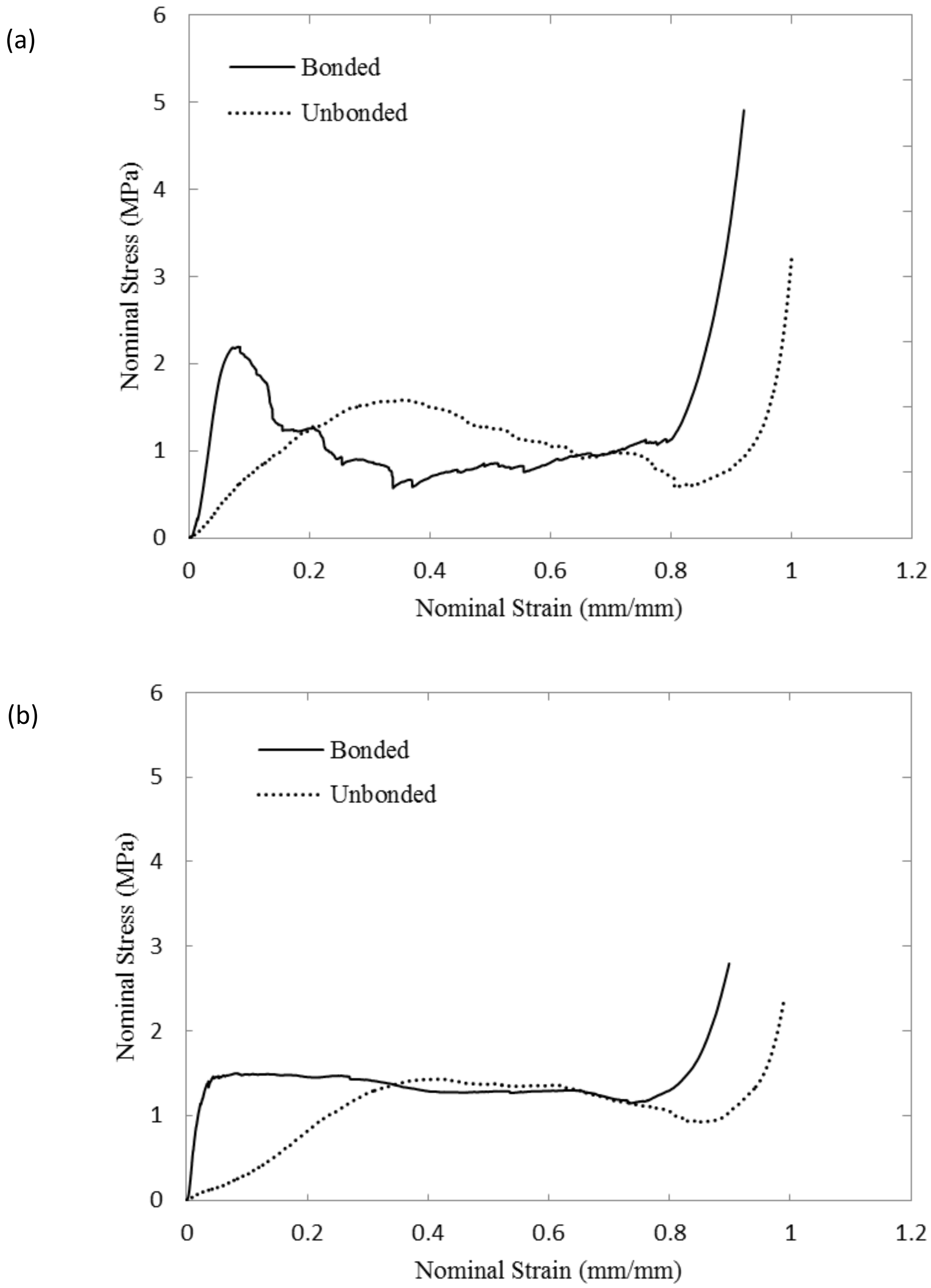


Figure 2. Collapse response of bonded and unbonded (a) GFRP and (b) CFRP cores.

3.3. The effect of varying the number of unit cells

It would be expected that the performance of multiple unit cells should accurately reflect that of a single cell system. In order to investigate this, tests were undertaken on samples based on (1x1), (2x2) and (3x3) cells. During compression of a (1x1) unit cell, the collapse process is initiated by sliding of the bottom edges of the unit cell on the platten. This is due to the fact that the unit cell is cut and separated from a contoured sheet, and is free to stretch on bottom platen. The unit cell was flattened with fibre fracture, as shown in Figure 3a. During compression of the (2x2) and (3x3) cells, fiber fracture was observed, This is also confirmed from the experimental observations that in GFRP structures, the matrix was cracked with fibre splitting on dome region and in the area between the unit cells. Similar damage was observed in the CFRP core. This damage behaviour is due to the restraining effect and thus increased structural rigidity due to the presence of the neighbouring cells connected to each other in the (2x2) or (3x3) cells. The effect of varying the number of unit cells on the compression strength of the CFRP and GFRP core is shown in Figure 4(a) and (b).These results indicate the influence of the connected neighbourhood cells on collapse properties. An examination of the figure indicates that the specific strength increases rapidly with increasing number of unit cells, with the specific strength of the (3x3) core being roughly three times that of the (1x1) core parts.

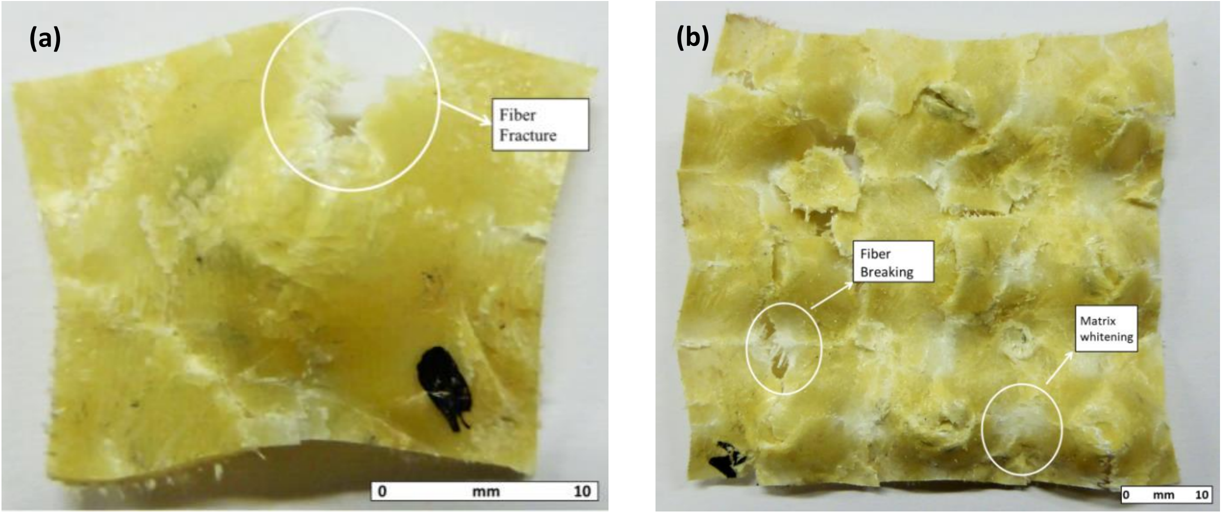
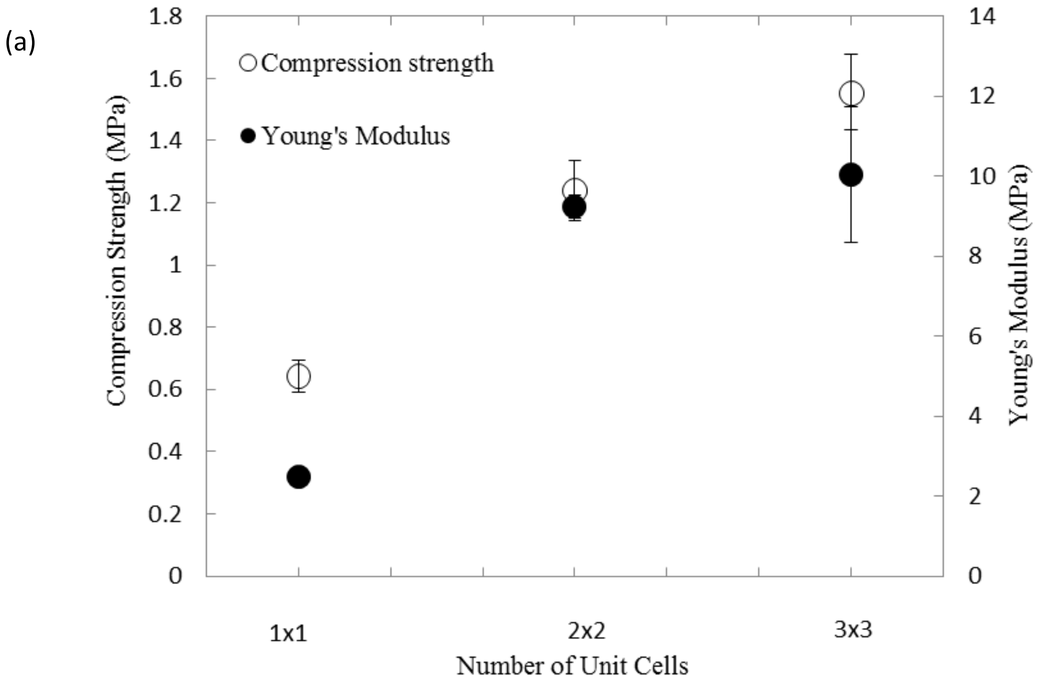


Figure 3.Photograph of damage in GFRP samples based on (a) (1x1) and (b) (3x3) unit cells.



(b)

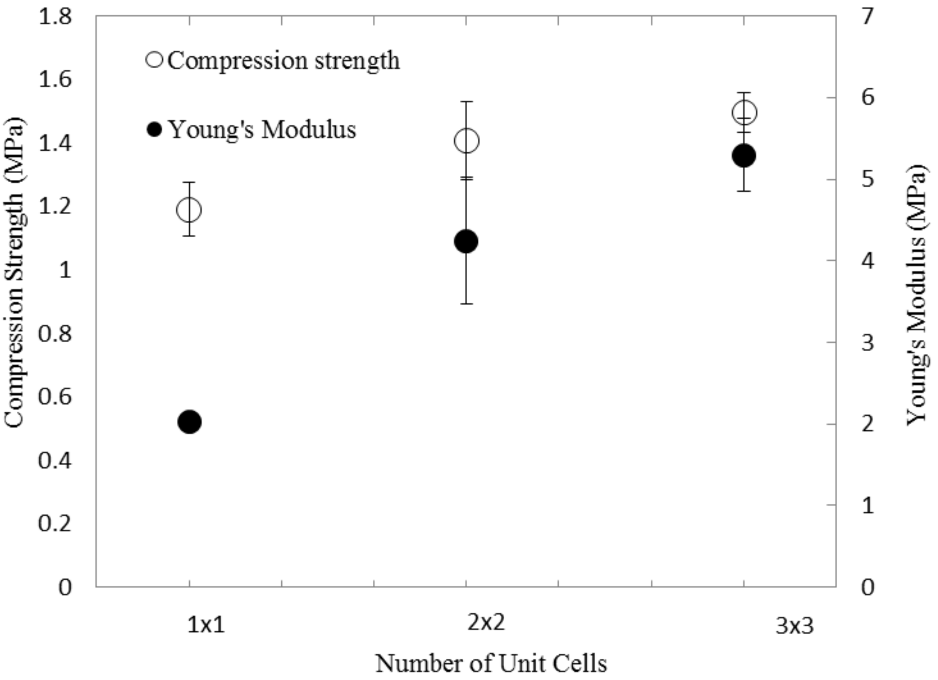


Figure 4. Compressive strength and stiffness as a function of the number of unit cells in the (a) GFRP and (b) CFRP.

3.4. Energy absorption capacity

This part of the investigation focused on understanding the influence of the number of unit cell on energy-absorbing characteristics. The energy absorption of composite contour core structure were calculated by integration of the nominal stress–strain curves up to a nominal strain of 0.8.The corresponding energy/unit mass (specific energy) is given by

$$E_m = E_I / M$$

Where M is the mass of the core, E_m and E_I are specific energies and the energy absorption (calculated by integration of the nominal stress–strain traces before densification) respectively. The calculated energy absorption per unit mass of the CFRP and GFRP cores are listed in Table1, taking the mean of three test for each configuration. Figure 5 show the variation of the specific energy absorption with the number of the unit cells for both the CFRP and the GFRP cores respectively. It is interesting to note that the specific energy increases with the number of unit cells. It is observed that specific energy was almost 20 to 30 % greater in the CFRP than in the GFRP with increasing numbers of unit cells. For example, the specific energy of the (3x3) CFRP cells was 8.73 kJ/kg whereas that for the equivalent GFRP was 6.32 kJ/kg. The fractured specimens were observed under a microscope, where cracks and surface whitening effects were observed in both the GFRP and CFRP cores. The process of the crack growth absorbs energy, contributing to energy absorption in these structures.

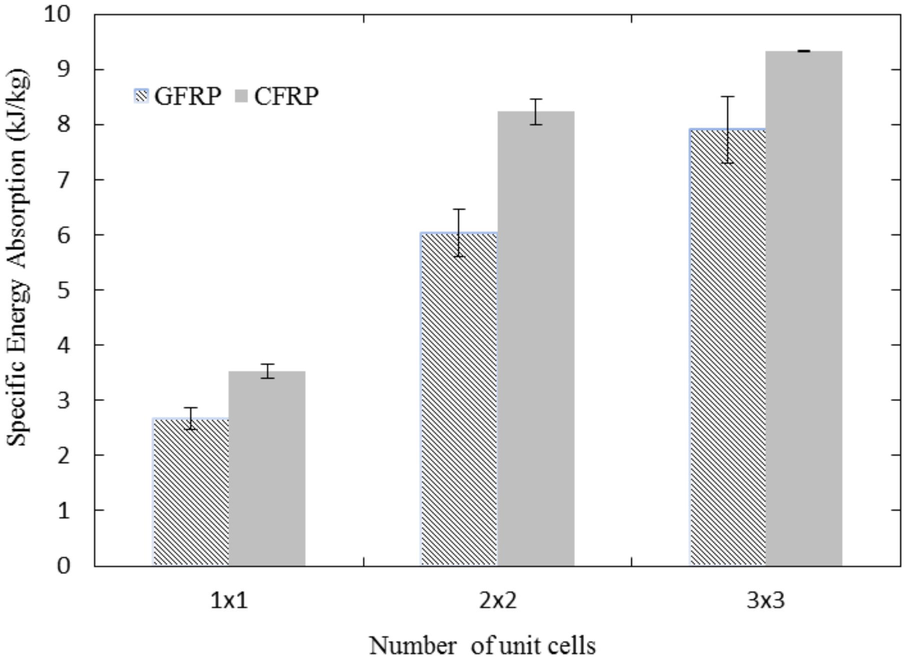


Figure 5. Comparison of the energy abortion of the GFRP and CFRP as a function of number of unit cell

Material	No. of Unit Cells	No. of plies	Mass (g)	Energy (J)	SEA(kJ/kg)
GFRP	1x1	5	0.60	1.98	2.94
	2x2	5	2.23	11.22	5.02
	3x3	5	5.19	32.81	6.32
CFRP	1x1	2	0.51	2.60	5.72
	2x2	2	1.70	14.52	8.60
	3x3	2	4.26	34.28	8.73

Table 1. Properties and characteristics of the core structures.

4. Conclusions

In this paper, contoured cores, manufactured using an aluminium mould, have been used to produce a range of lightweight structures. The static compressive behaviour of the composite core structures were investigated experimentally. The main focus of the research was on material type and the number of unit cells. The compressive response of the CFRP and GFRP cores exhibited a plateau in the stress-strain curve between nominal strains of 0.1 to 0.8. An increased nominal stress and stiffness was observed in sandwich structures based on the contoured cores. It was found that the CFRP contour core parts offer a higher energy absorption per unit mass, for a given core size.

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