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Fabrication and mechanical behaviors of corrugated lattice truss composite sandwich panels

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ABSTRACT

To get a strong, stiff and weight-efficient structure, a novel carbon fiber reinforced composite (CFRC) lattice truss sandwich panel (LTSP) was designed and fabricated. The lattice core is made up of orthogonal corrugated lattice trusses (CLTs) and manufactured by mould pressing method. Compression and shearing experiments were carried out to reveal the strength and failure modes of the structure. A coupled compression-shear failure mode was observed in compression and the compression strength of the lattice truss structure is over 13 MPa. In shearing, the enlarged area of the node enhances the shear strength to 3.4 MPa. Structural models were built to evaluate the strength in compression and shearing. Failure maps were supplied to instruct optimal design of the CFRC LTSP.

1. Introduction

Benefited from light but strong carbon fibers and stretching-dominated topology, CFRC lattice truss composite structure (LTCS) is weight-efficient for its high specific stiffness and strength [1–3]. This structure has the potential to enhance innumerable applications ranging from aerospace structures to marine structures to civil infrastructure. In last two decades, Octet truss [1], tetrahedral truss [4], pyramidal truss [5], Kagome lattice [6], hierarchical lattice [7], woven lattice [8], IsoTruss® [9,10] and Isogrid [11–15] have been developed. Interlacing method [2,3], mould pressing method [4,16], cutting method [17], filament winding method [9–15] and woven method [8] have been developed to fabricate the LTCS. Usually shear strength of the CFRC LTSP is limited by the node failure. According to previous works [4,16], the shear strength is usually smaller than 1 MPa. To enhance the shear strength, nodes were epoxy bonded and buried in milled facesheet pockets [17]. Through this way, the shear strength can be greatly improved but the facesheet is severely damaged. Another efficient way to enhance the anti-shear ability is enlarging the node area, such as corrugated topology for the lattice truss structure.

In this paper, a novel CFRC LTSP was designed and manufactured. To enhance the interfacial shear strength, corrugated lattice truss core structure was developed. Mould pressing method and co-curing scheme were applied to make the sandwich panel. Mechanical behaviors of the structure were revealed by experiments and theoretical analyses.

2. Structure and fabrication

2.1. Structure

The sandwich panel has two facesheets and an orthogonal corrugated lattice truss structure performing as the core, as shown in Fig. 1. Compared with other lattice truss structures, corrugation design lets the skin and the core have enough adhesive area to guarantee the interfacial strength. The truss member has plate-like structure, whose width enlarges the adhesive area and improves the anti-shear resistance of the truss member. Bi-directional corrugation design avoids the cross-linking of the orthogonal members at the nodes. Simplified node structure greatly reduces stress concentration at the nodes. Relative density of the lattice truss structure, ρ^*, is given by

$$\rho^* = 8bt_c\left(\frac{c}{\sin\alpha} + a\right)\frac{1}{cd^2}, \qquad (1)$$

where b (10 mm) and t_c (2 mm) denote the width and thickness of

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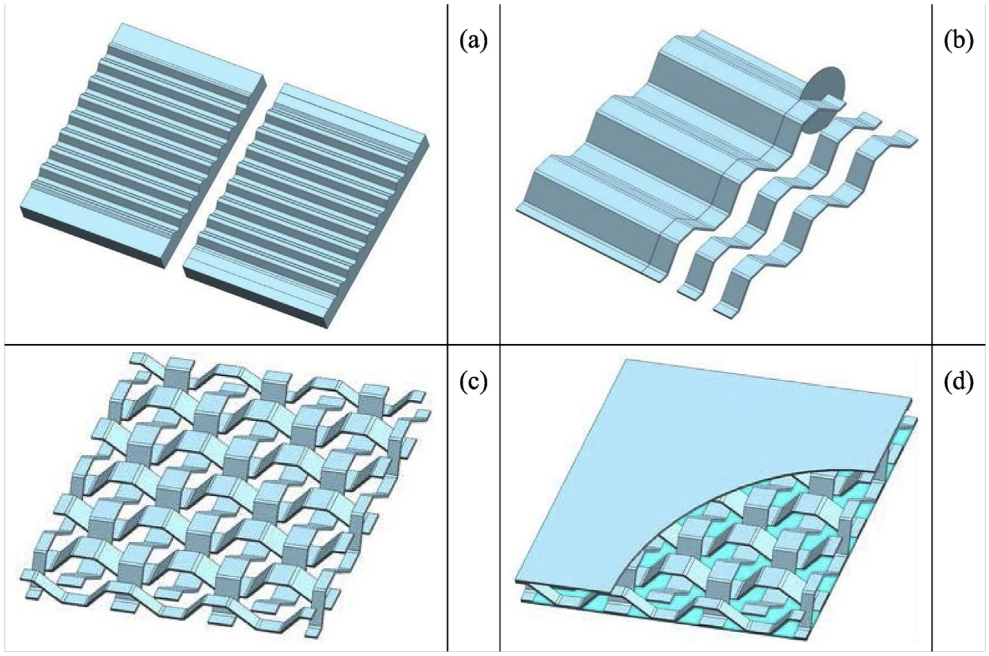

Fig. 1. Corrugated lattice truss sandwich panel (CLSSP): (a) mould-pressing method, (b) corrugated strip cut from corrugated panel, (c) corrugated-truss core and (d) corrugated lattice truss sandwich panel.

the corrugated lattice strut, respectively. c (10 mm) is the thickness of the truss core of the sandwich panel. α (45°) is the inclination of the corrugated strut and a (10 mm) is the adhesive length of the strut. Cell dimension, d, is 40 mm, as shown in Fig. 2. The relative density is designed to be 0.2 to avoid strut fracture and testify the shear failure strength of the adhesive layer enlarged by the corrugation topology.

2.2. Fabrication

T700/Epoxy-resin carbon fibers were applied to fabricate the structure. Tensile strength of the carbon fiber is 4300 MPa and the Young's modulus is 240 GPa. In fabrication, mould-pressing method was applied to make the LTSP, as shown in Fig. 1. The CFRC LTSP was solidified using twice co-curing scheme.

Corrugated mould was firstly designed, as shown in Fig. 1(a). Prepreg carbon fiber layers of $[0°/0°/\pm45°/0°/0°/\pm45°/0°]_s$ were placed into the mould and then pressed and solidified in a hot-press to form a corrugated panel. The corrugated panel was cured at 120 °C for 4 h. Then the cured panel was cut into narrow strips, as shown in Fig. 1(b). The strips were woven periodically to form the lattice truss structure, as shown in Fig. 1(c). Then the lattice truss was epoxy bonded with the CFRC facesheets with seven layers of $[0°/90°/0°/90°/0°/90°/0°]$, as shown in Fig. 1(d). The sandwich panel was co-cured at room temperature for 12 h under a uniform compression force of 1.75 kN. After co-curing and removing the mould, the LTSP was fabricated.

3. Experiments

3.1. Flatwise compression

Flatwise compression experiments were carried out at a loading rate of 0.2 mm/min, as shown in Fig. 3, where two failure modes and two typical deformation curves were observed. For A1 and A2, the compression strength is 10.1 MPa and 9.8 MPa, respectively. These two panels fail at adhesive shear failure and truss member compression failure successively. When loaded to about 96.6 kN or 6.7 MPa, the adhesive layer between y-axis directional corrugated trusses and the skin delaminated, induced by the interlayer shear stress. The bonded x-axis directional corrugated trusses were still compressed to over 140 kN and then failed at strut compression. Delamination of the laminated strut controls the strut strength in compression. The failure is ductile as the deformation has plateau

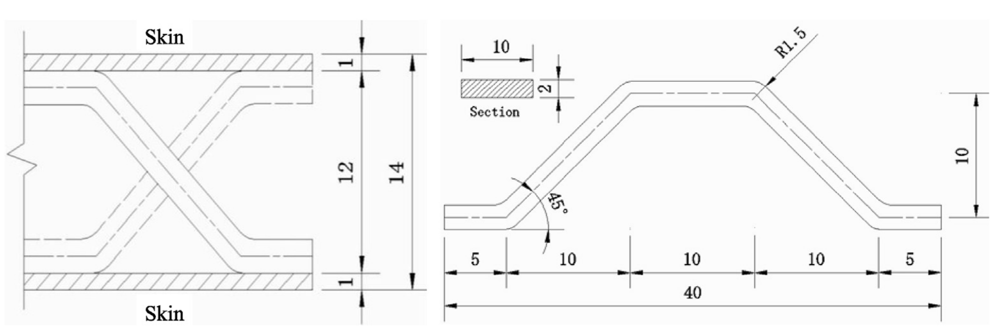

Fig. 2. Geometrical dimensions (unit: mm) of unit cell of CLSSP.