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Compression and bending performances of carbon fiber reinforced lattice-core sandwich composites

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ABSTRACT

To restrict debonding, carbon fiber reinforced lattice-core sandwich composites with compliant skins were designed and manufactured. Compression behaviors of the lattice composites and sandwich columns with different skin thicknesses were tested. Bending performances of the sandwich panels were explored by three-point bending experiments. Two typical failure mechanisms of the lattice-core sandwich structures, delaminating and local buckling were revealed by the experiments. Failure criteria were suggested and gave consistent analytical predictions. For panels with stiff skins, delamination is the dominant failure style. Cell dimensions, fracture toughness of the adhesives and the strength of the sandwich skin decide the critical load capacity of the lattice-core sandwich structure. The mono-cell buckling and the succeeding local buckling are dominant for the sandwich structures with more compliant skin sheets. Debonding is restricted within one cell in bending and two cells in compression for lattice-core sandwich panels with compliant face sheets and softer lattice cores.

1. Introduction

Sandwich structures assembled by fiber reinforced skins and light-weight cores have potential in naval and aeronautical applications since they offer high stiffness/strength-to-weight ratio [1–3]. Agarwal and Sobel [4] have suggested that in a range of load indices that are representative of most aerospace applications, the sandwich structures appear to be the most efficient in stiffness critical components that resist buckling. The cores of sandwich panels are conventionally made of foams or honeycombs. Recent researches have shown the higher weight efficiency of lattice structures [5–8]. Li et al. [5] revealed the structural response of all-composite pyramidal truss core sandwich columns in end compression. Euler macrobuckling, core shear macrobuckling, facesheet microbuckling, facesheet wrinkling, face sheet crushing and other failure styles were discussed. Always node rupture is fatal to CFRC pyramidal truss core sandwich columns. Xiong et al. [6] revealed the bending performance of CFRC sandwich panels with pyramidal truss cores. Fracture of the struts is the weakness of the bended structure.

In the lattice structures, the geometry of isogrid/Kagome structures is frequently adopted in stiffness critical components that resist buckling [9–11]. Vasiliev et al. [9,10], Vasiliev and Razin [11] have reviewed the development and application of the anisogrid composite lattice structure. Han and Tsai [12] introduced interlocked grid structures. To get a shear-resistant lattice grid, the Kagome-grid shown in Fig. 1 presents itself as the optimal choice. The interlocked Kagome lattices reinforced by carbon fibers were manufactured and tested [13]. Comparisons showed that carbon fiber reinforced grids are stiffer and stronger than carbon foams and aluminum lattices. The carbon fiber reinforced Kagome-core sandwich panels were assembled with bonded laminate skins by Fan et al. [14]. It has been revealed that debonding would be the main weakness of the carbon fiber reinforced composite (CFRC) sandwich panels, different from the failure styles revealed by Li et al. [5] and Xiong et al. [6]. The strength of the CFRC face sheets and grid cores are higher than the adhering strength. Therefore, the adhesion always fails at first. Even after the delaminated cores were shearing fractured, the skins were intact, which suggested that the skins could be thinner. The adoption of more compliant skin sheets and softer lattice cores might restrict the debonding failure.

On the basis of the previous work [14], this work would present a softer CFRC Kagome lattice, with an ideal dimension of 180 mm and 173.2 mm in length and width, respectively, as shown in

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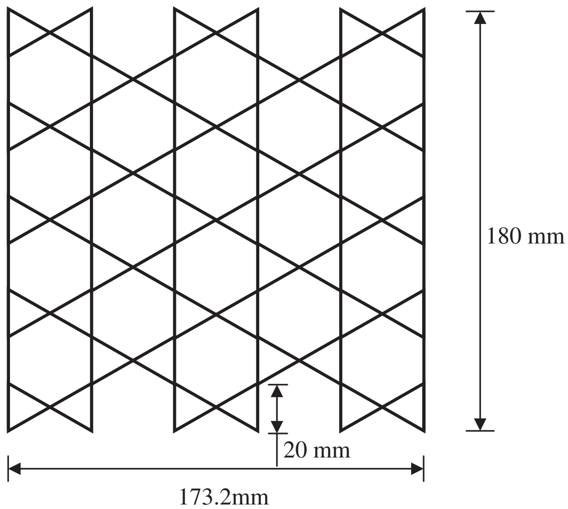

Fig. 1. Structure and dimensions of the Kagome lattice.

Fig. 1. Refined lattice-core sandwich panels with thinner skins and softer lattice cores were designed and manufactured, with a dimension of 400 mm and 130 mm in length and width, respectively, as shown in Fig. 2. Core thickness is 18 mm. Then the mechanical behaviors of the CFRC Kagome lattices were tested to reveal their strength. Strong lattice core would restrict the core shear but Kagome cells would induce monocell-buckling, skin crippling and delamination, which then would be testified by a further study on the mechanical behaviors of the CFRC lattice-core sandwich panels through edgewise compression and three-point bending experiments. Theoretical analysis would also be suggested to predict the failure styles and provide reasonable design suggestions.

2. Compression behaviors of the lattice grids

2.1. Tested lattice structures

The interlocked CFRC Kagome-grid has three stacks of ribs, as shown in Fig. 1. The reinforced laminate ribs of [0/±45/0] construction are made of T300 carbon fibers. The slots were interlocked and adhered by resins, which was demonstrated in the revision. They have a thickness, t_r, of 0.5 mm and a width, c, of 18 mm. The length of struts in a representative unit cell, $l/2$, is 20 mm. With such dimensions, the relative density of the grid core is just 0.043, a half of the Kagome lattice made by Fan et al. [14]. To avoid edge effects as discussed by Fan et al. [15], edges of the panel are strengthened with glass fiber reinforced composite (GFRC) cloth. The actual length and width of the tested Kagome lattice panel are 185 mm and 175 mm, respectively, a little greater than the design lattice. The total thickness of the Kagome lattice panel is 18 mm.

2.2. Flatwise compression

Flatwise compression test was performed at a rate of 0.5 mm/min. The tested curve, as shown in Fig. 3, includes three stages: elastic deformation, load drop caused by rib tearing after the peak load and the deformation plateau. The peak load is 175.4 kN. The Young's modulus is about 115.47 MPa and the strength is about 5.63 MPa. Ribs of the lattice were broken off at the slots as shown in Fig. 4. As reported by Fan et al. [14], with a relative density of 0.086, the strength of the CFRC lattice is about 22.7 MPa to 26.1 MPa. The modulus is about 1.1 GPa to 1.6 GPa [14]. Having different plies, the modulus of the softer lattice is much smaller, which would be determinant to the local buckling behavior of the face sheet of the sandwich panel. Crushing of the rib lets the lattice structure have a deformation plateau with a stress level of 3.5 kN, about 62% of the peak load. As shown in Fig. 3, two dimensional (2D) CFRC lattice may be ductile than 3D CFRC lattice truss structure. Suggested by Xiong and et al. [16], with a relative density of 0.047, the strength of three dimensional (3D) CFRC lattice trusses could be 6.1 MPa. They also reported another 3D lattice with a relative density of 0.12 only having strength of 0.84 MPa. The two dimensional lattice suggests a simple way to manufacture stable, strong and ductile lightweight structure.

2.3. Edgewise compression

Edgewise compression test was performed at a rate of 2 mm/min, as shown in Fig. 5. The tested curve is featured by zigzags as shown in Fig. 6. The peak load is 2.72 kN. The effective strength is 0.839 MPa. The effective stiffness is 222.65 MPa. After the initial peak load, elastic buckling led the first drop until one layer was

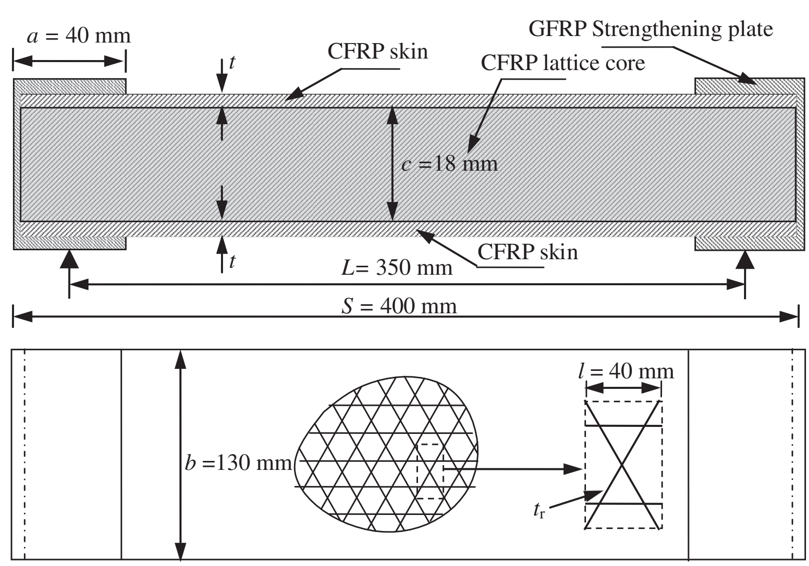

Fig. 2. Structure and dimensions of the lattice-core sandwich sample in mechanical tests.