FABRICATION OF CARBON FIBER REINFORCED COMPOSITE TRUSS CORE SANDWICH STRUCTURES

L. Ma*, L.-Z. Wu

Center for Composite Materials, Harbin Institute of Technology, Harbin 150080, China
**mali@hit.edu.cn*

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Abstract

Sandwich structures made from carbon fiber reinforced composite truss core provide new opportunities for lightweight, high strength structural design. Three kinds of fabrication methods of such novel lightweight sandwich structures proposed by Center for Composite Materials, Harbin Institute of Technology was presented. Analytical and experimental investigation have also been carried out to explore the mechanical response of carbon fiber composite truss core sandwich panel.

1 Introduction

Sandwich structures are widely used in lightweight construction especially in aerospace industries because of their high specific strength and stiffness. Metallic sandwich structures with aluminum alloy foam, various honeycombs and lattice truss are being developed for structures that require high strength and blast resistance [1-5]. Recently, sandwich structures fabricated by carbon fiber reinforced composite have been proved to be high strength with low density, their lightweight attributes have been revealed, as well as their potential for multifunctionality [6-9]. Significant progress has been made recently in manufacturing methods and understanding the structural behavior of carbon fiber reinforced composite sandwich structures.

In this context, sandwich structures made from carbon fiber reinforced composite truss core provide new opportunities for lightweight, high strength structural design. Three kinds of manufacture method of carbon fiber composite truss core sandwich structures will be introduced. Analytical and experimental investigation have also been carried out to explore the mechanical response of carbon fiber composite truss core sandwich panel.

2 Press molding co-curing processing method

Continuous carbon fiber reinforced epoxy resin composite was used to fabricate the pyramidal lattice truss core sandwich structure because of its low density and high stiffness/strength. Figure 1 shows the schematic illustration of the fabricating process of the pyramidal truss core sandwich structure [10, 11]. A set of molds with special structures were designed. The detailed fabricating process was as follows: (1) The mold surfaces were cleaned with acetone and coated with a mold release agent, and then the molds were assembled in order. (2) The upper face of the molds was covered with *m* plies of carbon/epoxy (T700/3234) prepreg, where the number *m* was determined in terms of different aims. (3) The truss was rolled into the circular cross section from a sheet of prepreg with the rod axis along the fiber direction so that its stiffness and strength could be utilized efficiently, and then inserted into the circular hole in the molds through the *m* plies of predrilled prepreg. The ends of the trusses were split into many parts, which are then pressed upon the prepreg tightly. (4) Additional *m* plies of prepreg were laid on the prepreg laid earlier. Thus, the truss ends were embedded in the mid-plane of the face-sheet. The lower face-sheet was fabricated in the same way. (5) The preformed sandwich structures were cured at 125℃ in an autoclave under a pressure of 0.5 MPa for an hour. The resin was melted and redistributed in the curing process, joining the trusses with the face-sheets. The sandwich structures were formed after the curing of resin. (6) The molds were removed, and the fabricated truss core sandwich structures were cut into the required dimensions. The photograph of fabricated sandwich structure is shown in Figure 2.

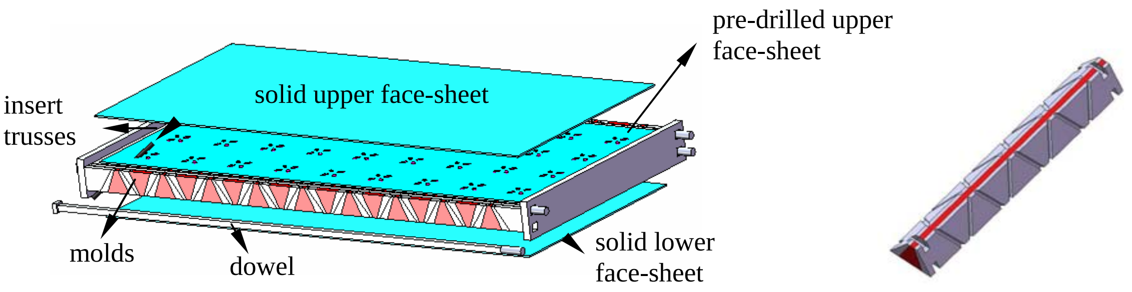

Figure 1. (a) Schematic illustration of press molding co-curing processing of the pyramidal truss core sandwich structure, (b) A piece of mold with unit cells

Figure 2. Photograph of a fabricated pyramidal lattice truss core sandwich structure

The out-of-plane compression tests of pyramidal truss core sandwich structures were performed at ambient temperature in accordance with ASTM standard C365 [12]. Three typically measured compressive nominal stress *vs.* strain curves are plotted in Figure 3. In all cases, bedding-in effect during the early stage of deformation was detected and an initial linear response was observed which was consistent with the parent material properties. Typically, the peak stress occurred at the point where node rupture but not core member crushing was first observed and then the stress decreased suddenly. Subsequently, continued loading resulted in node rupture successively and followed by a stress plateau. The plateau stress was about half to two thirds of the peak stress.

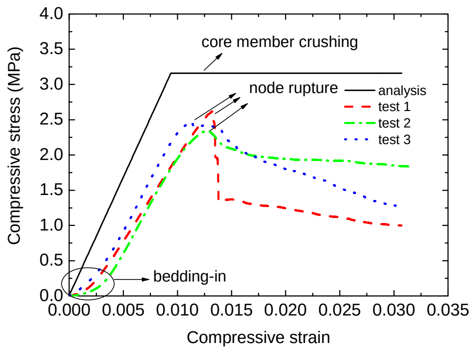

Figure 3. out-of-plane compressive response of sandwich panels with carbon fiber pyramidal truss cores

The shear response of the pyramidal truss core sandwich structure was measured via single lap shear test in accordance with ASTM standard C273 [13]. Three typically measured shear stress *vs.* strain curves are plotted in Figure 4. The shear stress *vs.* strain response exhibits an initially linear behavior followed by a nonlinear regime. The linearity is in accordance with the properties of the carbon fiber reinforced composite, and the nonlinear response is due to premature failure prior to the onset of an expected peak load. The premature failure is mainly caused by the progress of microcrack in trusses and nodes with the increased stress, which can be demonstrated by a brisk fracture sound in the loading process. With the progress of microcrack, the mechanical properties of composite materials degrade gradually. The peak stress is achieved at the onset of the macroscopical node rupture. At high strain, the load capacity of the pyramidal truss core sandwich structure decreases, which is consistent with continuous node rupture.

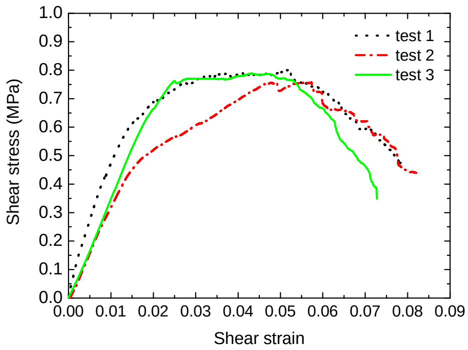

Figure 4. Shear response of sandwich panels with carbon fiber pyramidal truss cores

3 Press molding glue joint processing method

Figure 5 shows the schematic of the manufacturing method of composite pyramidal lattice cores [14]. The mold consists of four different parts: (1) up web frames, (2) down web frames, (3) blocks and (4) the base tooling-which were made of chrome steel. The expansion blocks used in the process are cast silicon rubber and were laid into the space between the base tooling and down web frames. The slender unidirectional fiber reinforced laps were cut from the prepreg sheets using scissor. Then, the laps were put into the strut compaction at 0° play angle to build the composite pyramidal truss structures. Thus, in each strut of the fabricated truss core, the fibers are aligned in the direction of truss struts. Prior to processing, a release agent was brushed on the mold surfaces to allow easy separation of the structures from the mold after curing. The composite was cured in a hot-press at constant pressure 0.5 MPa and temperature 130℃ for 1.5h. The composite pyramidal lattice cores were detached from the mold after the solidification of the resin. Figure 6 shows an example of the created composite pyramidal lattice structure.

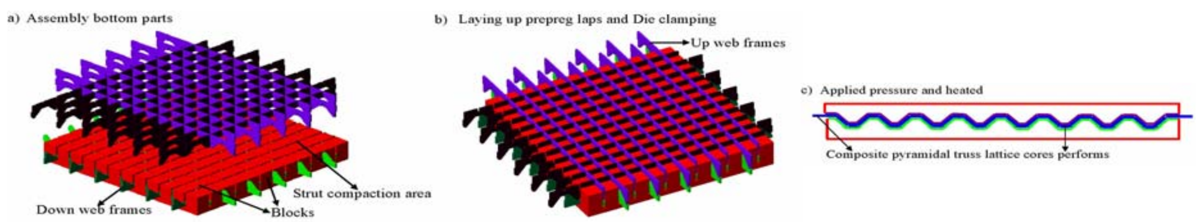

Figure 5. Sketch of the carbon fiber composite pyramidal truss core manufacturing technique

Figure 6. Photograph of a fabricated pyramidal lattice truss core sandwich structure

The compressive stress-strain response of three pyramidal truss sandwich panels is shown in Figure 7. The initial linear response of the structures is followed by a nonlinear regime due to the progressive failure of struts or debonding. After reaching a peak stress, the stress decreases with further crushing and a series of local failure events leads to a reduction in the overall strength of the core.

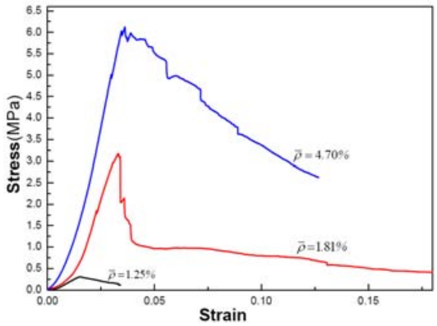

Figure 7. out-of-plane compressive response of sandwich panels with carbon fiber pyramidal truss cores

The measured shear stress and strain curves are summarized on Figure 8. In all cases an initial linear response is observed and followed by a regime where the stress versus strain response is nonlinear. Typically the peak stress occurs at the point when failure of the truss is observed as marked by the circle in Figure 8. Subsequently, the stresses decrease with increasing strain with the serrations in the stress versus strain curve associated with a series of failure events in the pyramidal truss core specimens.

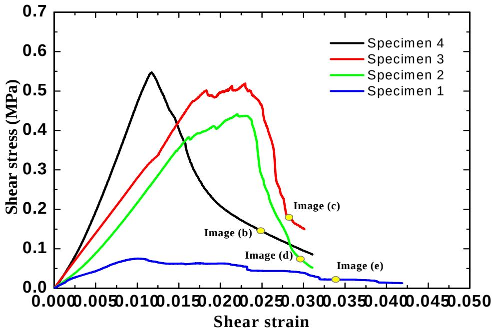

Figure 8. Shear response of sandwich panels with carbon fiber pyramidal truss cores

4 Hybrid truss concepts for carbon fiber composite pyramidal lattice structures

Fabrication of the hybrid composite pyramidal lattice sandwich structures is based on the press molding co-curing processing method introduced in section 2. The process has been adapted here for production of hybrid truss lattice structures. First, unidirectional carbon fiber/epoxy prepregs (T700/3234) were laid up and wrapped around the core rods to form hybrid trusses. The stacking sequence was $[0_2]$ for wood-core trusses and $[0_2/90_2]$ for rubber-core trusses. Here, 0 represents the carbon fiber-truss axis angle, and 90 is the circumferential direction. Such hybrid trusses were inserted into the cylindrical cavities of assembled molds, as shown in Figure 9a. Then, plies of carbon fiber prepreg were perforated such that the holes matched the truss positions. The perforated prepreg plies were laid over the hybrid trusses, and the carbon fiber composite shells at the ends of each hybrid truss were peeled from the rods and subsequently embedded between two plies of the perforated prepreg (Figure 9b). Next, the excess silicone rubber in each hybrid truss was removed, and unidirectional prepreg plies were overlaid and stacked to produce face sheets on the top and bottom surfaces of the steel molds. Finally, the assembly was cured in a hot press at 125℃ and 0.5 MPa for 2h. After removing the molds, carbon fiber composite pyramidal lattice sandwich structures with hybrid trusses were obtained [15]. Figure 10 shows the fabricated composite pyramidal lattice structures with wood-core trusses and rubber-core trusses, respectively.

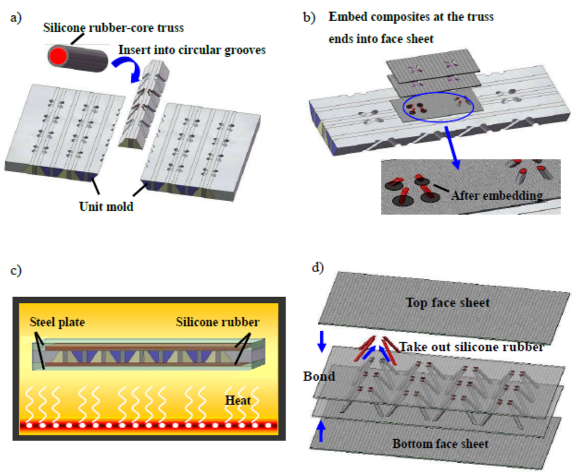

Figure 9. Illustration of the fabrication approach for carbon fiber composite pyramidal lattice core sandwich structures with hybrid trusses

Figure 10. (a) Wood–core truss (b) silicone rubber-core truss and their corresponding carbon fiber composite pyramidal lattice structures.

Carbon pyramidal lattice structures with wood-core trusses and those with solid trusses were tested in one group for comparison. The representative through-thickness nominal compressive stress-strain response for these two carbon pyramidal lattice structures is shown in Figure 11. The curve of the wood-core truss lattice structure exhibits characteristics similar to those of counterpart carbon pyramidal lattice structures featuring solid truss construction of carbon fiber composites. After an initial linear response, a peak stress is observed at a relatively small strain (~0.02-0.05), which coincides with failure of trusses. As loading continues, the stress decreases, accompanied by further crushing, and core "softening" behavior is observed. The governing failure mode is tube wall fracture for the wood-core truss structure, while elastic buckling is the characteristic failure mode for the slender solid truss counterpart. The compressive modulus and peak strength of the wood-core truss structure are lower than those of the solid truss structure, and this is attributed to the much lower volume fraction of carbon fiber composite in the truss members.

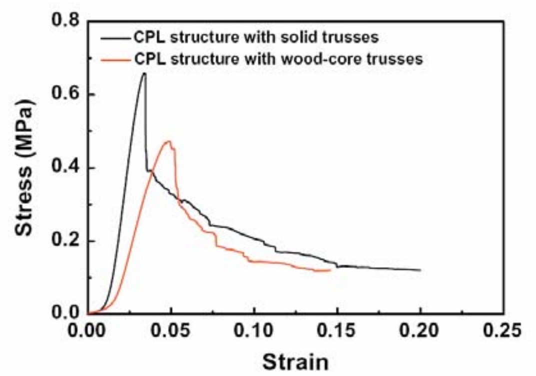

Figure 11. Compressive stress-strain responses for carbon fiber composite pyramidal lattice structures with wood-core trusses and solid trusses

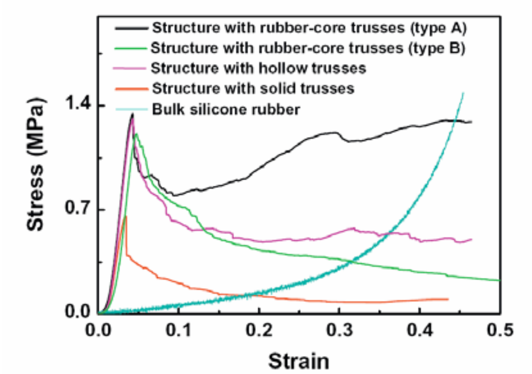

Figure 12. (a) Compressive stress–strain curves of carbon fiber pyramidal lattice structures with rubber-core trusses compared with those without filling rubber

Rubber-core truss Carbon pyramidal lattice structures incorporating circumferentially fibers (Type A) and those with only 0 fibers (Type B) were tested and compared with the carbon pyramidal lattice structures without filling rubber. The hollow truss structures were similarly constructed and fabricated using the same stacking sequences as those in the rubber-core structures of Type A. The compressive stress-strain curves are shown in Figure 12. The compressive response of solid truss carbon pyramidal lattice, and that of bulk silicone rubber which exhibits typical elastomeric behavior are also included for reference. The compressive behavior of the carbon pyramidal lattice sandwich structure with rubber-core trusses after incorporating circumferentially fibers (Type A) differs from that of the corresponding structure of Type B or that without filling rubber. Initially, the response is linear elastic and resembles the behavior of carbon pyramidal lattice structures composed of carbon fiber. For carbon pyramidal lattice structures of Type A and that of hollow truss carbon pyramidal lattice structures, a peak strength is reached, followed by a stress drop associated with tube wall failure. Moreover, the compressive modulus and peak strength values for these two kinds of structures are comparable, indicating that the rubber contributes little to the stiffness and strength at this stage. Subsequently, unlike the long stress plateau shown by hollow truss lattice structures (where the stress gradually decreased with increasing strain), a gradual strain hardening period appeared in the stress plateau for the hybrid truss carbon pyramidal lattice structure. During this period further crushing of the structures occurred, starting at a strain of ~0.1. The constrained rubber inside the truss resists the deformation and buckling of the structures, leading to the strain hardening region (the strain from 0.1 to about 0.5). The response of rubber-core truss carbon pyramidal lattice structure of Type B, which failed by fiber splitting of composite tube, is similar to that of hollow truss and no strain hardening period appeared.

Acknowledgements

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