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Sandwich-walled cylindrical shells with lightweight metallic lattice truss cores and carbon fiber-reinforced composite face sheets

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ABSTRACT

We manufactured sandwich-walled cylindrical shells with aluminum pyramidal truss core of constant curvature employing an interlocking fabrication technique for the metallic core. The skins were made of carbon-fiber reinforced composites and co-cured with the metallic truss core. Thereafter, we carried out axial compression tests on some representative samples to investigate the failure modes of these structures and compared with an analytical failure map developed to account for Euler buckling, shell buckling, local buckling between reinforcements and face-crushing. The experimental data closely matched the analytically predicted behavior of the cylinders. In particular, we found that local buckling and face crushing modes can exist together and are the most important modes of failure of the fabricated structure.

1. Introduction

Cellular structures have well-known advantages over their traditional homogenous counterparts ranging from higher strength-weight ratio to exceptional buckling resistance in addition to effective energy absorption, shock mitigation, dynamic resistance and heat insulation [1–8]. However, sandwich panels traditionally made from foam and honeycomb cores with close-cells [9] cannot accommodate free fluid movement through them. Therefore, this limit on flow circulation imposes significant restrictions in their thermal and transport properties, preventing their deployment as functional structures. Therefore, fabrication of sandwich panels having open-cell cores with interconnected void spaces have been suggested for extending structures for functional applications [10]. In this context, fiber reinforced composite sandwich panels with lattice core construction are of particular interest for aerospace and marine applications [11,12]. Significant advances in the manufacturing of the low-density lattice structures themselves, such as aluminum alloys [13–15], steel wires [16], polymers [17], self-propagating polymers [18], hollow-tube micro lattices [19] as well as fiber reinforced composites [20,21] have given even greater flexibility in adapting these structures to various operating conditions and design restrictions.

There impressive advances must be contrasted with the fact that many structural components used in aerospace applications involve a curved geometry such as fuselage gloves, barrel sections, fuel tanks, some types of landing gear doors in space exploration vehicles and airplane fuselage [22]. Therefore, the flat topology of lattice truss core constructions is one of the key factors limiting their application in such structures underscoring the need for greater geometric flexibility. The current work extends the envelope of research by describing a novel yet practical manufacturing technique for fabricating cylindrical metallic lattice truss-core sandwich structures along with axial compression tests on some representative specimens. Sun et al. [23] investigated the response of carbon fiber composite sandwich cylinders with 2D Kagome core using theoretical analysis. Chen et al. [24] used an improved fabrication method to restrict skin delamination and crippling of sandwich cylinder with 2D kagome cores. A three-dimensional lattice-truss core construction unlike traditional 2D [25–28] or flat core design [29,30] not only yields an additional structural feature of the sandwich core but also steps forward in the direction of increasing multi-functionality. This is brought about by better flexibility in managing the core space topology, key to achieving better fluid transport and thermal management [31]. We note that to best knowledge of the authors, no research work concerning sandwich cylindrical shell with 3D lattice truss cores which is open cell in all direction in the core.

The fabrication technique employed in this study is an innovative interlocking mechanism to achieve the three dimensional pyramidal geometry of the core. Thereafter, composite curved face sheets were made using a hot press method and assembled with the core using a number of primary and reinforcing patch face

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sheets to strengthen the sandwich structure. A failure mechanism map was constructed from theoretical considerations and used to devise axial compression tests on a number of specimens with different configurations of the curved face sheets. The corresponding mechanical response and failure behavior is discussed and conclusions follow.

2. Fabrication and testing

For this research work, we fabricated and tested three cylindrical specimens. Fig. 1(a) shows the skeletal structure of the longitudinal and transverse ribs which was used to construct the pyramidal core of the cylindrical shell under investigation. For one of the specimens, the face sheet was manufactured from prepregs made of 3234/G803 carbon fabrics and 3234 epoxy resin (Beijing Institute of Aeronautical Materials, China) and for the remaining two, T700 carbon fibers and the same epoxy resin as mentioned before was employed. The properties of a carbon fabric composite (3234/G803) and unidirectional prepreg (T700/3234) are listed in Tables 1 and 2, respectively. The metallic core consisting of longitudinal and transverse ribs was mass produced from *7075* aluminum whose mechanical properties are listed in Table 3 using a wire cutting method. These ribs were assembled using an interlocking method with caulking groove to form the core material illustrated in Fig. 1(b). A typical assembled pyramidal truss core is depicted in Fig. 1(c).

Table 1
Properties of unidirectional lamella (*T700/epoxy composites*).

Properties	Value
Tensile strength (MPa)	756
Tensile modulus (GPa)	69
Compression strength (MPa)	557
Compression modulus (GPa)	64
In-plane shear strength (MPa)	11.8
In-plane shear modulus (GPa)	4.2
Interlayer shear strength (Mpa)	68
Poisson's ratio	0.064
Density (kg/m^3)	1550

The fabrication of face sheets was done via hot press. A mold was made of three concentric semi-circular cylinders with the inner and outer face sheet prepregs fitting into the corresponding inner and outer annular regions as shown in Fig. 2(a and b). This construction ensured a proper match between the height and circumferential span of both inner and outer face sheets. The same fabrication setup was used to prepare all of the three specimens for our experiments. The face sheets were made in several parts due to difficulty in monolithic co-curing of the entire structure. The individual components of the face sheet assembly are shown in Fig. 3(a–c). The largest components of the face sheet assembly are called the principal face sheets which sweep about 170° circumferential spans each on either side (inner and outer) of the

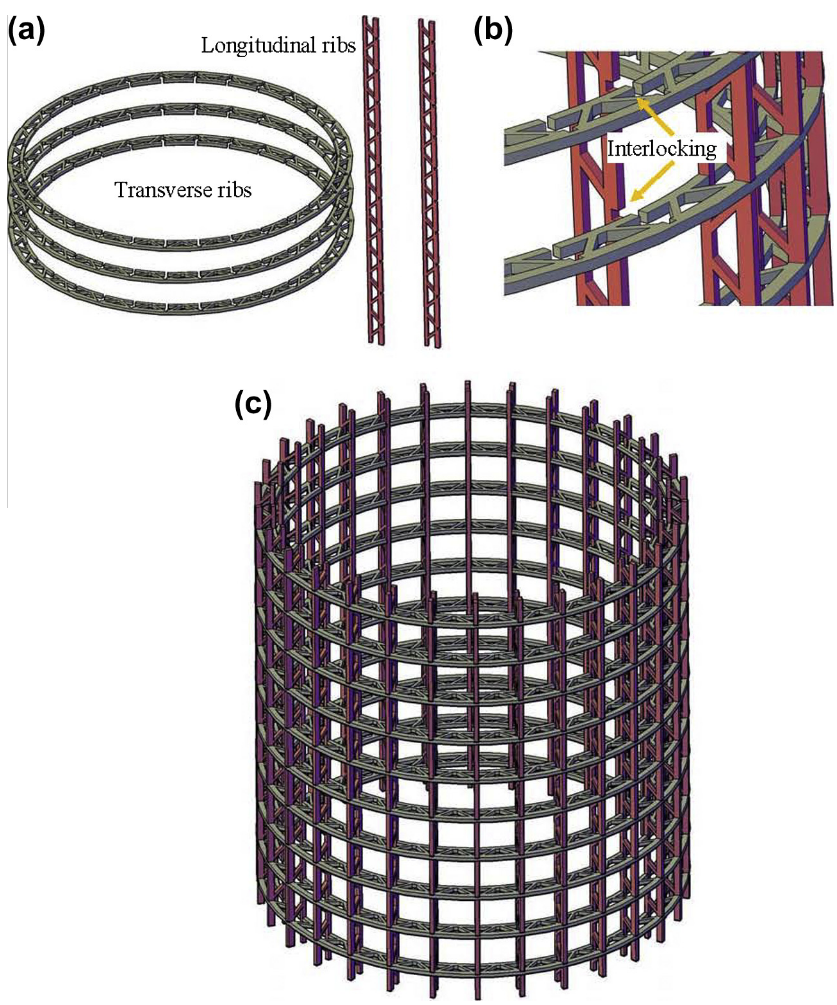

Fig. 1. Individual components of the pyramidal truss core (a) transverse and longitudinal reinforcements, (b) interlocking process of both reinforcements and (c) schematic sketch of the assembled pyramidal truss cores. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)