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Fabrication and testing of composite corrugated-core sandwich cylinder

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ABSTRACT

To get a strong, stiff and weight efficient cylindrical shell, carbon fiber reinforced corrugated-core sandwich cylinders (CSCs) were designed and made. The corrugated-core is made up of corrugated cylindrical shell and manufactured by mould hot pressing method. Split forming and integral filament winding forming methods were applied to make the CSC separately. Effects from non-wrapped and wrapped cylindrical ends were investigated individually. Uniaxial compression tests were performed to reveal the strength and failure mode. Split forming method makes the CSC stiffer but integral filament winding forming method makes the CSC stronger. With non-wrapped ends, the cylinders fail at end delamination and the load carrying capacity is 289.7 kN and 373.7 kN, respectively. The load is improved to 415.6 kN and 491.4 kN, respectively, when the cylinder is end-wrapped. Skin fracture controls the failure of the CSCs with wrapped ends and makes them stronger. Meanwhile, the load carrying ability of the CSC is stronger than lattice truss-core sandwich cylinders (LTSCs). Benefiting from the high axial load carrying ability of the CFRC corrugated shell, strength of the designed CSC failing at skin fracture improves at a magnitude of 50% compared with the referenced LTSC.

1. Introduction

In recent years, carbon fiber reinforced composites (CFRCs) have become more accepted for aerospace applications. Isogrid stiffened cylinders (ISC) have been applied in the interstage of rockets of Russia [1]. During NASA's recent efforts to develop new launch vehicles, composite materials were considered and baselined for a number of structures, including dry barrel sections, which are primarily loaded in longitudinal compression. Buckling-critical launch-vehicle structures require structural concepts that have high bending stiffness and low mass. Fluted-core, sandwich construction is one such concept [2–7]. Two different fluted-core composite designs were considered [2–7]: a subscale design and a full-scale design sized for a heavy-lift-launch-vehicle interstage.

In China, researchers developed various CFRC grid-core sandwich cylinders (GSCs). Fan et al. [8] and Chen et al. [9] made CFRC GSCs with Kagome grid cores. Sun et al. [10] proposed the equivalent analysis and failure prediction method of the GSC. Zhang et al. [11] and Han et al. [12] investigated the free vibration behavior of the GSC. Sun et al. [13] revealed the effects of circular cutouts on mechanical behaviors of the GSC. Jiang et al. [14,15] adopted interlocking method to fabricate CFRC orthogrid-core sandwich cylinder (OSC). Li et al. [16] and Hu et al. [17] developed a novel CFRC LTSC, whose core layer is a three-dimensional (3D) lattice truss structure. Diameter of the cylinder is 625 mm. The cylinder is 375 mm long. Skin thickness of the cylinder is 1.0 mm. Thickness of the truss core is 10 mm. The mass of the cylinder including two flanges is 4.9 kg. Collapse at skin fracture, compression strength of the cylinder is 328.03 kN [16]. Xiong et al. [18] made and tested mechanical behaviors of CFRC sandwich cylindrical shells with corrugated cores. The radius is 58 mm and the length is 180 mm. The peak load is 130.5 kN. Limited by the radius, the method proposed by Xiong et al. [18] to make CSC should be developed [14,16,19,20] to make large-diameter cylinder.

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In this paper, CFRC CSCs were designed and manufactured. Compression behaviors of the cylinder were revealed by experiments.

2. Corrugated-core sandwich cylinders

2.1. Structure

The corrugated-core sandwich geometry considered in this paper is shown in Fig. 1. The sandwich structure comprises of two laminated skins and a corrugated core. In compression, the corrugated core could also supply high load carrying ability as the facesheets. In bending the facesheets carry tension and compression loads, and the core keeps the facesheets separated while carrying the through-thickness shear loads.

To design the CSC, the LTSC published by Li et al. [16] and the OSC published by Jiang et al. [14] are selected as referenced cylinders. The LTSC with a designed mass of 4.9 kg has strengthened end flanges and fails at skin fracture when the load reaches to 328 kN [16]. The OSC with a designed mass of 4.6 kg has un-strengthened ends and fails at end delamination when the load reaches to 302.8 kN [14]. These cylinders have identical dimensions and close masses. As listed in Table 1, the diameter of the cylinder ($2r$) is 625 mm, and the length (H) is 375 mm. The thickness of the skin (t_f) is 1.0 mm. The thickness of the corrugated-core (c) is 8 mm.

Table 1
Designed dimensions of the cylinder.

Dimensions	A1	B1
Outer diameter, $2r$	625 mm	625 mm
Cylindrical height, H	375 mm	375 mm
Skin thickness, t_f	1 mm	1 mm
web thickness, t_c	1 mm	1 mm
Core thickness, c	8 mm	8 mm
Cell number	53	53
Cell dimension, d	35.84 mm	35.84 mm
Core relative density, ρ_c^*	0.151	0.151
Mass	4.7 kg	4.2 kg

Thickness of the web (t_c) is 1.0 mm. Inclination of the web (θ) is 45°. There are 53 corrugation cells circumferentially and the cell dimension (d) is 35.84 mm.

T700/Epoxy-resin carbon fibers were applied to fabricate the cylinder. Tensile strength of the carbon fiber is 4300 MPa and the Young's modulus is 240 GPa.

2.2. Fabrications

2.2.1. Corrugation core

In fabrication, mould-pressing method was firstly applied to make the corrugation, as shown in Fig. 2(a) and (b). Prepreg carbon

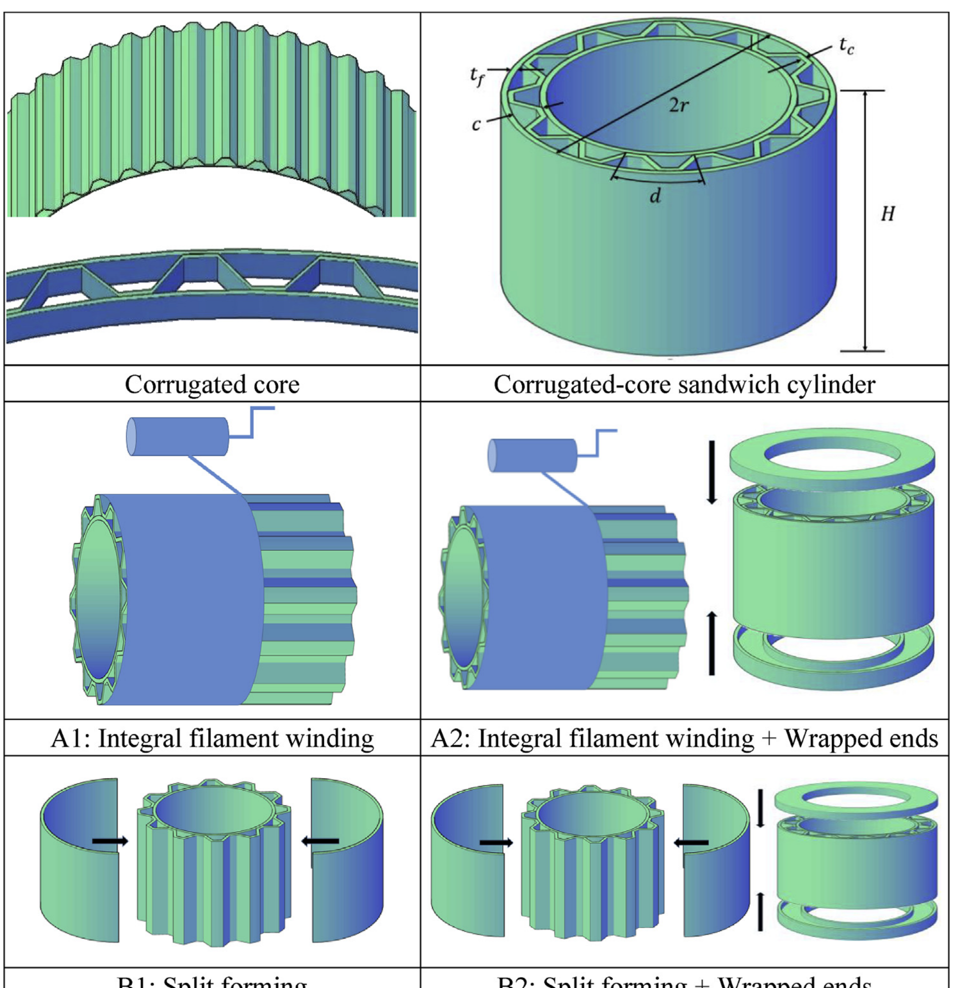

Fig. 1. Corrugated-core sandwich cylinder and construction measurements.