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Improved manufacturing method and mechanical performances of carbon fiber reinforced lattice-core sandwich cylinder

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ABSTRACT

Filament winding and twice co-curing processes were applied to make advanced carbon fiber reinforced composite (CFRC) sandwich cylinder with lattice cores. Split metallic moulds were designed and adopted for easy demoulding after winding the lattice core. The cylinders were designed with a small tapering to assure tight contact between the lattice core and the inner skin. To avoid local failure at the end of the cylinder, flange structures were placed continuously from the fibers of skins and lattices. Axial compression was carried out to reveal the mechanical behaviors of the fabricated sandwich cylinder. The experiment shows that the advanced making technology shows the promise of lattice sandwich cylinder (LSC) avoiding instability, local buckling, local cracking and debonding.

1. Introduction

Stiffened and sandwich cylinders have been the candidates for decades in aircrafts, satellites, rockets, space launchers and other lightweight stiff structures [1–7]. Vasiliev et al. [1–3] have reviewed the development and application of the anisogrid composite lattice structure. Huybrechts et al. [4] also introduced the progress of hybrid tooling and filament wound method to make grid-stiffened cylinders. Consisting of a thin outer skin and a repetitive equilateral triangular pattern of stiffening ribs, isogrid (or Kagome) stiffened structures [8–10] have been frequently adopted in stiffness critical components that resist buckling. Agarwal and Sobel [11] have concluded that in a range of load indices that are representative of most aerospace applications, the sandwich structures appear to be the most efficient. Sandwich cylinder with honeycomb or foam cores have been applied in aerospace systems. Although lattice truss core will further enhance the stiffness and bucking-resistance, the structure is seldom applied. Fan and et al. [12,13] realized a CFRC sandwich cylinder with Kagome core by filament winding and twice co-curing processes. According to their axial compression test, the load capacity and the stiffness of the sandwich cylinder reach 524.6 kN and 161.8 kN/mm, respectively, several times stiffer and stronger than the referenced stiffened cylinder with similar dimensions and a slightly lower mass [12]. The global buckling load of the cylinder is enhanced due to higher compression stiffness of the sandwich structure. Restrained by the double skins, the local buckling of ribs disappears. The twice co-curing method ensures the adhesive strength between the skins and the lattice core. Before the work of Fan et al. [13], the lattice sandwich cylinder was manufactured through winding the lattice structure around a foam mould, which was left inside after the winding [1]. Recently, Dr. Xiong manufactured a sandwich composite cylinder with interlocked metallic lattice truss cores and carbon fiber reinforced skins [14].

In the first manufacture of the lattice sandwich cylinder (LSC), failures were focused at the edge of the cylinder, including crack and mono-cell buckling of skins near the ends as shown in Fig. 1(a). The skins delaminated at the ends, as shown in Fig. 1(b). Structure and fabrication of the cylinder end must be re-designed and improved. To restrict the local crack and mono-cell buckling, skins near the ends should be gradually thickened. To restrict the delamination initiated from the ends, fibers of the inner skin could not be cut off and should be continuously laid over the ends and extended to the outer skin. Flange should be a good choice [8]. With flanges, stiffened cylinder made by Kim [8] had no local failure at the ends. Without flanges,

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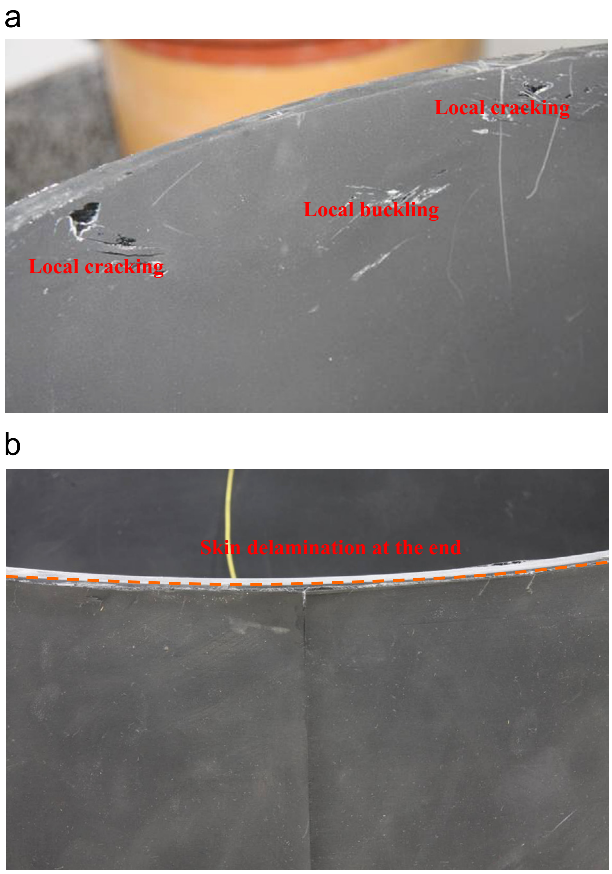

Fig. 1. Typical failure modes for the first made lattice sandwich cylinder: (a) Local buckling and cracking and (b) skin debonding at the end.

stiffened cylinder made by Kidane et al. [9] had a serious local buckling at the end. The present work has proposed an improved manufacture method for the CFRC sandwich lattice cylinders of larger dimensions. The mechanical properties of LSC would be validated experimentally.

2. Improved design and fabrication

According to the former study, it can be concluded that LSC is an ideal light weight structure with high stiffness and load capacity. The study also gives us good suggestions to design a LSC of larger dimensions, such as increasing the skin thickness, decreasing the density of the lattice through thinning the rib and lengthening the grid, strengthening the ends of the cylinder etc., especially for cylinders with large diameter and height. In this paper, a cylinder with a diameter of 1200 mm and height of 1600 mm was designed. Thickness of the cylinder wall is 20 mm, with a lattice core layer of 17 mm thickness. Skin thickness of the improved LSC is enlarged to 1.5 mm, layered by 9 plies of [0°, $+60^\circ$, -60°] or [90°, $+30^\circ$, -30°] orientations, which ensures the skin is quasi-isotropic. The lattice layer consists of 18 circumferential ribs, 36 helical ribs along 60^0 orientations and 36 helical ribs along -60° orientations. Each rib has a thickness of 2.5 mm. Neighboring parallel ribs have a distance of 90 mm. Aspect ratio of the lattice rib is 20.8, larger than 15.3, the ratio for the firstly made LSC. The rib of the improved LSC is more slender. The CLS would be fabricated from carbon fibers in the form of prepreg tow and unidirectional tape. The T700 carbon fibers and the bisphenol epoxy resin system would be used.

In designing and making LSC, there are four key technologies, including twice co-curing method; demoulding design; tapering design and flange design.

The key of the fabrication is to control the configuration of skins and lattice ribs. To reduce the risk of buckling caused by initial waviness, the tension of filament winding must be strictly controlled. Metal grooves were adopted for lattice ribs. Another

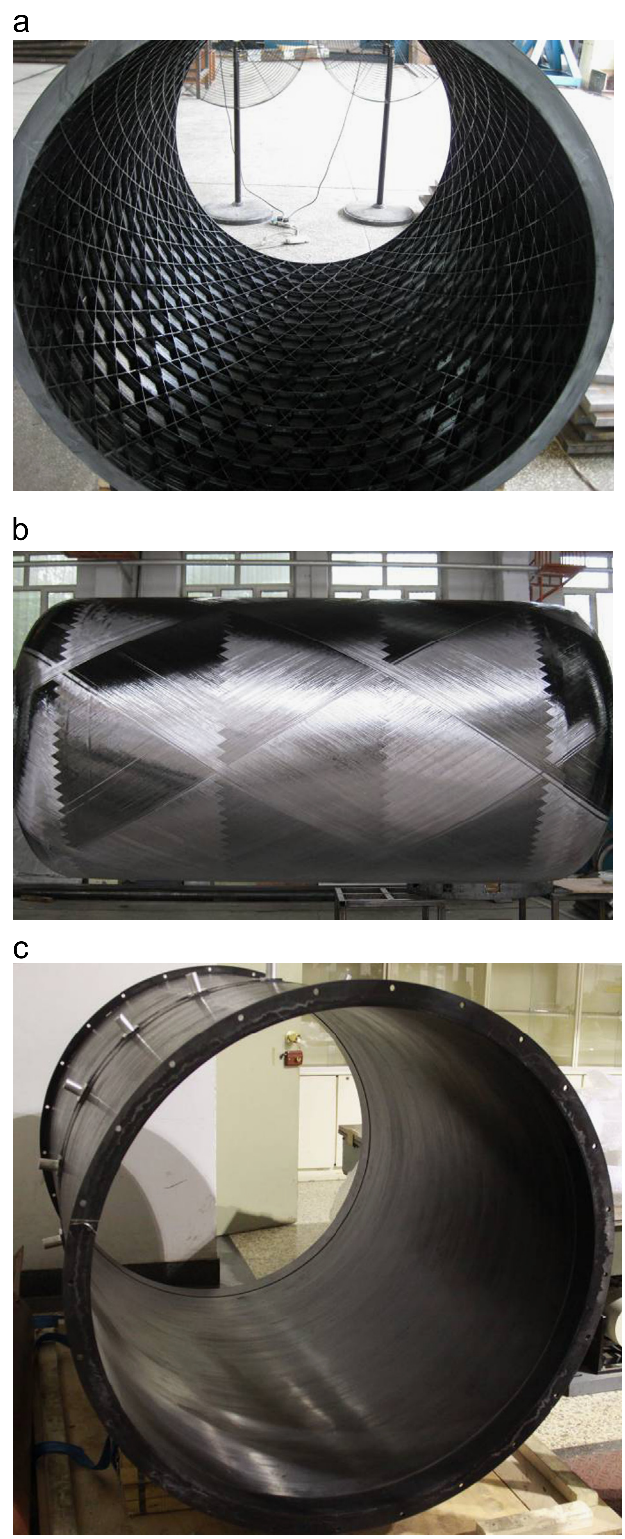

Fig. 2. Manufacture of sandwich cylinder: (a) Completed stiffened cylinder with outer skin and lattices; (b) filament wound inner skin; and (c) completed sandwich cylinder.