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Modal response of all-composite corrugated sandwich cylindrical shells

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ABSTRACT

A series of all-composite axial and circular corrugated sandwich cylindrical shells is manufactured using a novel hot press moulding method. Modal testing is conducted to investigate vibration characteristics of such composite corrugated sandwich cylindrical shells with free–free boundary condition. In order to predict the structural vibration damping, a finite element model combined with modal strain energy approach is developed, which is adequately consistent with the experimental results. It is shown that the first several orders of vibration mode shapes are dominated by circumferential lobar modes. Circular corrugated sandwich cylindrical shells generally possess higher natural frequencies and damping loss factors than axial corrugated sandwich cylindrical shells since circumferential stiffness and damping capacity of the former are higher than those of the latter. Furthermore, the influence of the corrugated inclination angle, sandwich core thickness and different topological corrugated cores on the structural vibration and damping performances are thoroughly investigated, which might be helpful to guide the manufacturing and dynamic analysis of lightweight cylindrical shells in engineering.

1. Introduction

Sandwich structures with corrugated, tetrahedral, pyramidal and other periodic lattice cores are strong candidates for load-bearing structural application due to their superior weight specific stiffness and strength properties [1–5]. Extensive studies on metallic sandwich structures with various core topologies have been proposed with preparation and their mechanical properties including compression, shearing, bending, buckling, impacting and vibrating [6–10]. Besides, using fibre composite with superior weight specific performance to fabricate the aforementioned structures can further improve the weight specific stiffness and strength of these structures [11–13]. It has been known that such lightweight structures applied in aerospace and many other industries usually bear vibration which can lead to resonance. Thus, modal analysis of the structures is an indispensable part of the design procedures. Furthermore, in order to control the resonant response, it is also required to investigate the structural damping mechanisms. To date, most of research about composite corrugated sandwich structures mainly focuses on sandwich beams and flat panels [14–18]. However, to the authors' knowledge, only a few papers are reported for the vibration damping of composite sandwich cylindrical shells [19] and no paper is reported for corrugated sandwich cylindrical shells.

The aim of the present paper is to investigate the modal response of all-composite corrugated sandwich cylindrical shells including axial and circular corrugated cores. Firstly, two types of composite corrugated sandwich cylindrical shells are fabricated by a hot press moulding method. Then, modal tests are conducted to investigate the vibration and damping characteristics of such sandwich cylindrical shells. Next, a finite element model is developed to predict the modal characteristics of such sandwich cylindrical shells with free–free ends. To better predict the structural damping loss factors, a mixed numerical and experimental method is proposed to determinate the material damping properties, which is based on the modal strain energy approach. The influence of design parameters on the structural natural frequencies and damping loss factors is particularly investigated in the end.

2. Preparations

2.1. Mould design and fabrication procedure

Two different corrugated core configurations of all-composite sandwich cylindrical shells including axial and circular corrugated cores are manufactured through a hot press moulding method. Three kinds of steel moulds are developed to manufacture different parts the specimen with low cost and high quality. All components of the steel moulds and the detailed manufacturing process are shown in Fig. 1. For the axial corrugated cores, carbon fibre reinforced weave fabrics indicated by red colour are firstly stacked

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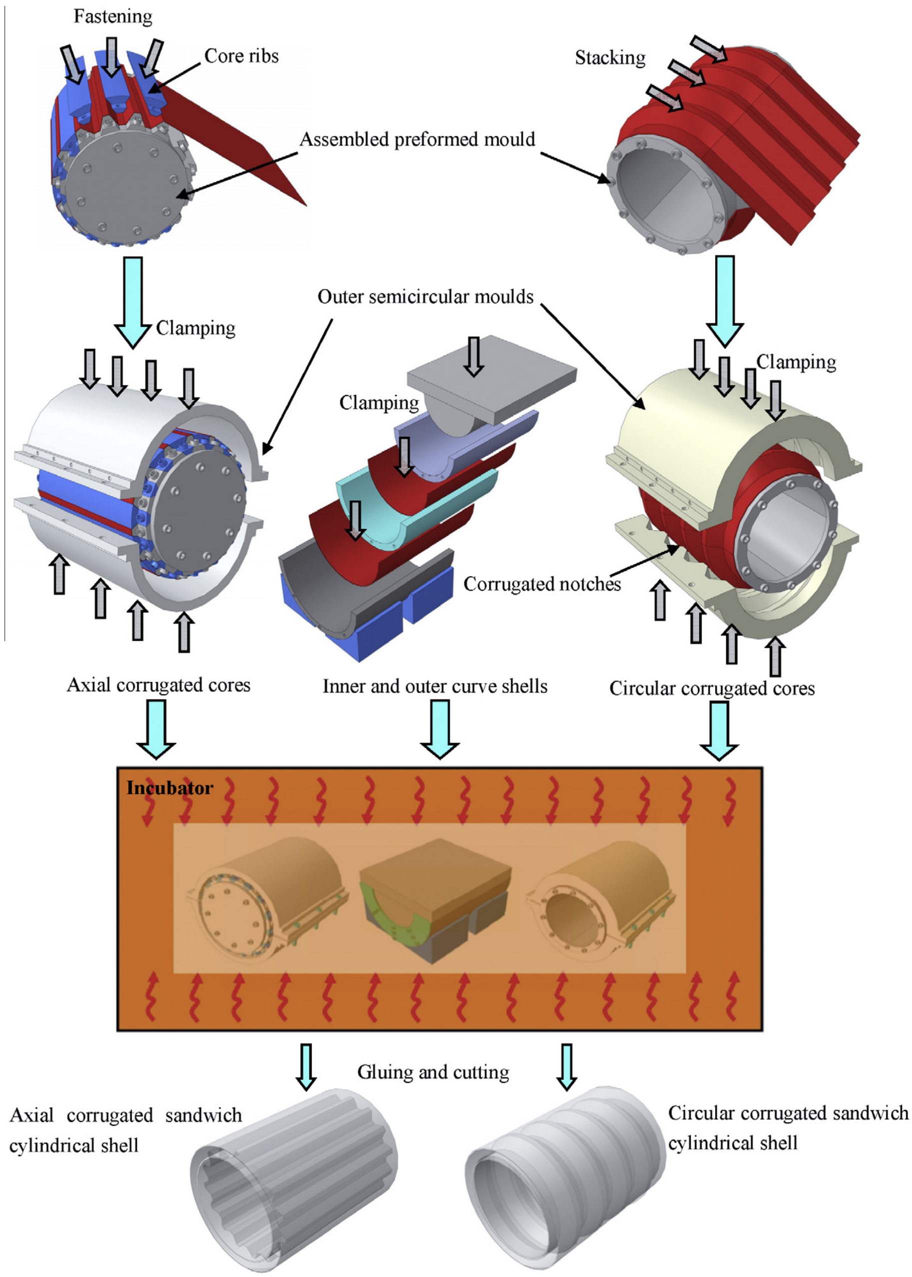

Fig. 1. Fabrication process of all-composite corrugated sandwich cylindrical shells.

on the assembled preformed mould and fixed by core ribs. Then the assembled preformed mould is clamped together with two outer semicircular moulds by tightening bolts to ensure enough pressure on the mould surface. The circular corrugated cores are manufactured in a similar way as the method for axial corrugated cores. The only difference is that the two outer semicircular moulds have original circular corrugated notches and it is unnecessary to use the core ribs. Meanwhile, the carbon fibre reinforced weave fabrics are stacked on the inner and outer semi-cylindrical shapes to form the partial inner and outer curved face sheets. To bond with corrugated cores tightly, both the inner and outer cylindrical shells are composed of three curved parts that are connected with each other by adhesive bonding. Three assembled moulds are put into the incubator to be cured for 2.5 h at 120 °C under a uniform preload pressure. Finally, the semi-finished all-composite corrugated sandwich cylindrical shells shown in Fig. 2, which are glued and could be cut into desired dimensions.

2.2. Specimen preparation

The parent material used in the experiments is carbon fibre reinforced orthogonal weave fabrics (LS-3K) with thickness 0.25 mm which is provided by Shanghai Lishuo New Material Technology Co., Ltd (Shanghai, PR China). The constitutive engineering constants are listed in Table 1. The outer radius and total height of the sandwich cylindrical shell are R = 71.0 mm and H = 156.0 mm, respectively. Corrugated cores and curved face sheets with different thicknesses t_s = 0.50 mm, 0.75 mm and 1.0 mm are considered in this study. Symbols of the corrugated sandwich cylindrical shells are denoted as $SP_i - t_s$ ($i = A, C$; $s = 1, 2, 3$). The subscripts A and C represent axial corrugated cores and circular corrugated cores, respectively, and the subscripts 1, 2 and 3 represent the thicknesses t_s = 0.50 mm, 0.75 mm and 1.0 mm, respectively. The geometrical parameters of representative unit cells for the axial corrugated and circular corrugated cores are shown in