Vibration based damage localization of composite bi-directional corrugated sandwich cylindrical panels

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1. Introduction

Composite cellular sandwich structures are widely applied in aerospace, marine, automotive and building industries as critical components due to their excellent specific stiffness, strength and other multi-functional performance [1-3]. So far, engineers have developed a number of cellular sandwich structures with different kinds of advantageous topologies such as closed cell foam, honeycomb, corrugated and lattice truss cores [1-4]. Compared with other lightweight cellular sandwich structures, corrugated core sandwich structures have received increasing attention, due to the advantage of their simple configurations, mature fabrication technologies and low fabrication cost [2-3]. Unfortunately, many types of defects such as debonding between face sheets and sandwich cores, damage of the sandwich cores, missing individual trusses, etc. are always inevitable because of the complex fabrication process, which may significantly influence the structural response and degenerate the load-carrying capability. On account of their increasing application, it is quite important to generate corresponding methods for evaluation and detection of damage in complex composite sandwich structures, which form the basis of structural health monitoring (SHM) [5-8]. Recently, non-destructive evaluation approaches based on modal vibration measurement have drawn great attention to and have been recognized as a low-cost, feasible and promising method for evaluating and detecting damage among all the existing techniques [7].

In this study, glass fibre composite bi-directional corrugated sandwich cylindrical panels (BCSCPs) with and without defects are designed and fabricated by a hot press moulding approach. Then damage index based on a modified modal flexibility curvature method is proposed. Numerical simulation and experiment are carried with single and multiple damages are conducted. Finally, the sensitive of different kinds of damage localization is conducted.

2. Damage identification approach

In this study, based on the modal flexibility curvature method, we use the Modal flexibility curvature variation (MFCV) as the damage index that can be expressed as:

$$MFCV_{\mathrm{i}} = \left|U_{\mathrm{id}}^{\mathrm{aa}} - U_{\mathrm{iu}}^{\mathrm{aa}}\right| + \left|U_{\mathrm{id}}^{\mathrm{cc}} - U_{\mathrm{iu}}^{\mathrm{cc}}\right| \quad (1)$$

where $U_{\mathrm{iu}}^{\mathrm{aa}}$ and $U_{\mathrm{id}}^{\mathrm{aa}}$ are the modal flexibility curvature of point i in axial direction for the undamaged and damaged structures, respectively. $U_{\mathrm{iu}}^{\mathrm{cc}}$ and $U_{\mathrm{id}}^{\mathrm{cc}}$ are the modal flexibility curvature of point i in circular direction for the undamaged and damaged structures, respectively.

The modal flexibility curvature of the structure can be expressed as:

$$[U] = [K]^{-1} = [\phi^m][\omega^2]^{-1}[\phi^m]^T \quad (2)$$

where [K] and $[\phi^m]$ are the stiffness and modal mass matrices, ω is angular frequency.

3. Experiment

The parent material used in experiments is glass fibre reinforced orthogonal plain weave fabrics with thickness 0.20mm and the constitutive engineering constants are listed in Table 1.

Table 1 The material properties of glass fibre reinforced orthogonal plain weave fabrics

Symbol	Value	Property
E_{11}, E_{22}	15786MPa	In-plane stiffness
E_{33}	11000MPa	Out-of-plane
$\upsilon_{12}, \upsilon_{13}$	0.1	Poisson's ratio
υ_{23}	0.135	Poisson's ratio
G_{12}	1300MPa	Shear modulus
G_{13}, G_{23}	1200MPa	Shear modulus
ρ	1386kg/m^3	Density

The inner, outer shells and corrugated core are manufactured through a hot press moulding method, then the core and plate are connected with each other by adhesive bonding, then will be put into the incubator to be cured for 2h at 130℃. Finally, the glass fiber BCSCPs are cut into desired dimension shown in Fig 1. There are two damage forms: debonding between the face sheets and core and the damage of the corrugated lattice cores are considered in the present work.

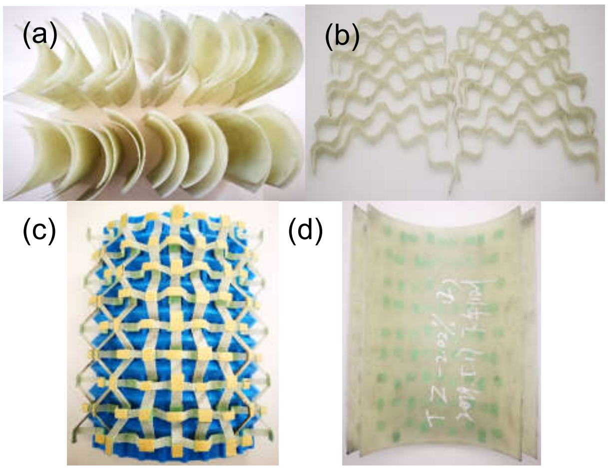


Fig.1 (a) inner and outer shells, (b) corrugated lattice ribbons, (c) assembly process, (d) BCSCP.

For the experimental tests, the Doppler laser vibrometer (PSV-400) is employed to investigate the modal characteristics of the glass fiber BCSCPs, which is shown in Fig. 2. After all the specimen with free-free boundary conditions are investigated by the model tests, the experimental results including natural frequencies, mode shapes, frequency response functions (FRFs) are obtained and compared to the numeral results estimation.

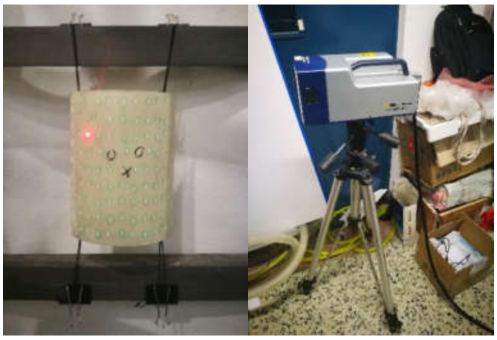
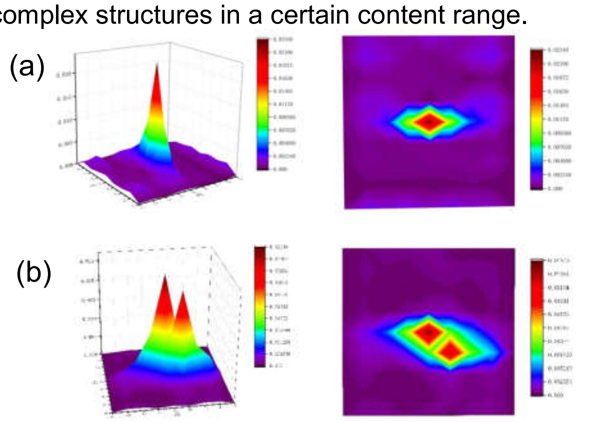


Fig.2 The typical specimen and the Doppler laser vibrometer (PSV-400) for modal tests.

4. Key results

Fig.3 shows the numerical MFCVs of the BCSCPs with debonding damage under 1.01%, 2.02%, 3.03% and 4.04% defect coefficient. It is found that the MFCV damage index is feasible and effective to achieve damage localization for such complex structures in a certain content range.



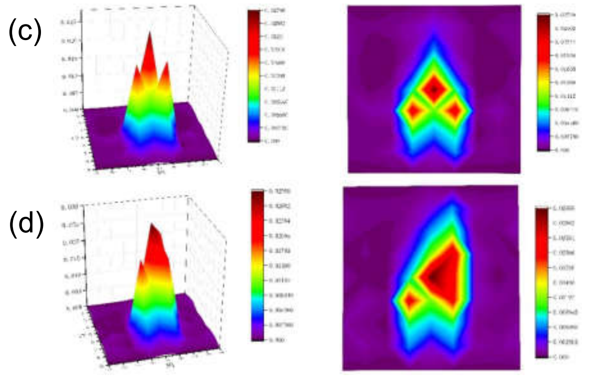


Fig.3 Numerical MFCVs of the BCSCPs with debonding damage under (a) 1.01%, (b) 2.02%, (c) 3.03% and (d) 4.04% defect coefficient.

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