VIBRATION DAMPING OF HYBRID COMPOSITE CORRUGATED SANDWICH CYLINDRICAL PANELS

Jin-Shui Yang, Li Ma*, Ge Qi and Lin-Zhi Wu
Center for Composite Materials, Harbin Institute of Technology,
Harbin 150001, PR China
* Corresponding author (mali@hit.edu.cn)

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ABSTRACT

To further improve the vibration damping behavior of carbon fiber composite sandwich structures without too much redundant weight, empty and foam filled corrugated sandwich cylindrical panels (CSCPs) are designed and their corresponding modal characteristics are investigated experimentally and numerically. Axial and circular CSCPs (ACSCP sand CCSCPs) are simultaneously manufactured by a hot press moulding and post-assembly approach. It has been demonstrated that foam filled CSCPs can obviously improve the structural damping compared to the empty CSCPs without significant change of the corresponding natural frequencies. Furthermore, the experiment results are coincident with that of the finite element analysis (FEA) calculations.

1 INTRODUCTION

Composite sandwich structures comprised of two face sheets and a core material are attractive load carrying constructions widely used for modern engineering field in aerospace, aircraft, automotive, building and other applications due to their higher specific stiffness, strength, damage tolerance and blast resistance [1-3]. It is highlighted that lightweight and high rigidity often result in structures with low damping, which can lead to undesirable phenomena with high resonant amplitude and noise. Some researchers have conducted a lot of study on the modal vibration behaviors of the fiber composite sandwich core structures [4-8]. Though the damping loss factor of fiber reinforced polymer composites is much greater than that of the metallic materials, it is still not sufficient for effective structural vibration and noise control.

To further improve the vibration damping behavior of carbon fiber composite sandwich structures without too much redundant weight, empty and foam filled corrugated sandwich cylindrical panels (CSCPs) are designed and their corresponding modal characteristics are investigated experimentally and numerically in the present work.

2 FABRICATION

Hybrid composite ACSCP and CCSCP with and without polyurethane foam are manufactured by a hot press moulding and post-assembly approach [7]. The basic material and the filling material used in the present work are carbon fiber reinforced orthogonal weave fabrics (LS-3K) with thickness 0.25 mm (Shanghai Lishuo New Material Technology Co., Ltd, PR China) and polyurethane foam (HPF) containing two parts of liquid ingredients (Dongguan Huixin Industrial Co., Ltd. PR China), respectively. The mechanical properties of the present materials are listed in Table 1.

Property	Symbol	LS-3K	HPF
Young's modulus (Mpa)	E_1, E_2	49100±2400	57.98±3.52
Shear modulus (Mpa)	G_{12}	3800±200	—
Poisson's ratio	ν_{12}	0.31±0.01	0.30±0.02
Density (kg/m^3)	ρ	1523.3	73.22

Table 1: The mechanical properties of the used materials.

Specimen	Symbol	H (mm)	t_f (mm)	M (g)
Empty ACSCP	EA-1	152.0±1.0	0.50	84.3±4.0
	EA-2	152.0±0.0	0.75	94.1±0.2
	EA-3	153.5±0.5	1.00	107.1±4.2
Foam filled ACSCP	FA-1	152.0±1.0	0.50	101.9±5.1
	FA-2	152.0±0.0	0.75	112.4±1.2
	FA-3	153.5±0.5	1.00	124.7±5.4
Empty CCSCP	EC-1	154.5±0.5	0.75	84.7±1.7
	EC-2	154.0±2.0	1.00	96.1±1.7
Foam filled CCSCP	FC-1	154.5±0.5	0.75	102.0±1.7
	FC-2	154.0±2.0	1.00	114.7±1.3

Table 2: Specifications of the hybrid sandwich cylindrical panels tested.

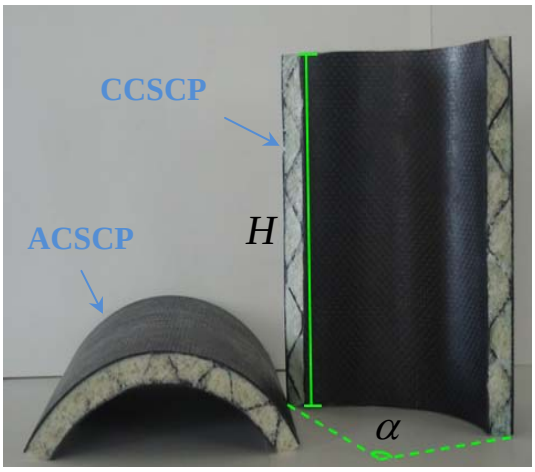

Fig. 1: Sample images of foam filled CSCPs.

The typical images of the foam filled corrugated sandwich cylindrical panels are presented in Fig. 1. The geometrical parameters of representative unit cells for the axial corrugated and circular corrugated cores are also displayed in Fig. 2.

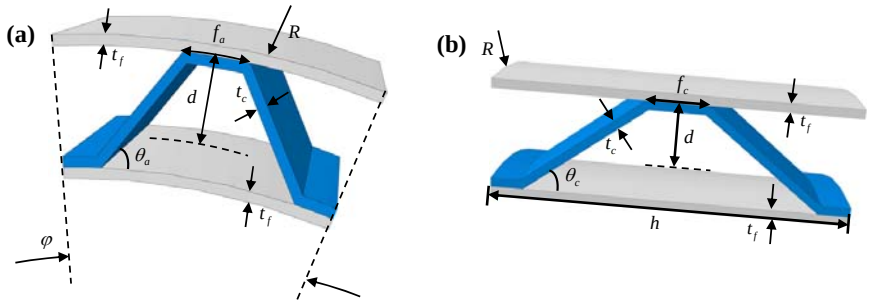

Fig. 2: Representative unit cells of (a) axial corrugated and (b) circular corrugated cores.

3 MODAL EXPERIMENTS

The hammer impulse technique is employed to investigate the modal characteristics of the hybrid composite corrugated sandwich cylindrical panels, which is shown in Fig. 3 (a). Free-free boundary condition is adopted for the test specimen, which is hung on the steel bracket through a rubber rope.

The input excitation is applied on the specimen by an impact hammer with a force recording function, and the output response could be captured by an acceleration transducer. Then these digital signals are transferred by the dynamic signal analyzers (DEWETRON GmbH, Austria). By using Fast Fourier Transformation (FFT) and modal circle fit method [6], the frequency response functions (FRFs) can be obtained and the modal parameters including natural frequencies, modal shapes and damping factors can be finally evaluated. The first four modes are considered in the present modal testing. It is worth mentioned that multi-input single-output method is adopted to obtain the integrity modal parameters of the present lightweight structures shown in Figure. 3 (b). Each of the input points are guaranteed to be tested at least three times and the coherence function is used to evaluate the reliability of testing signals, which is shown in Fig. 3 (c).

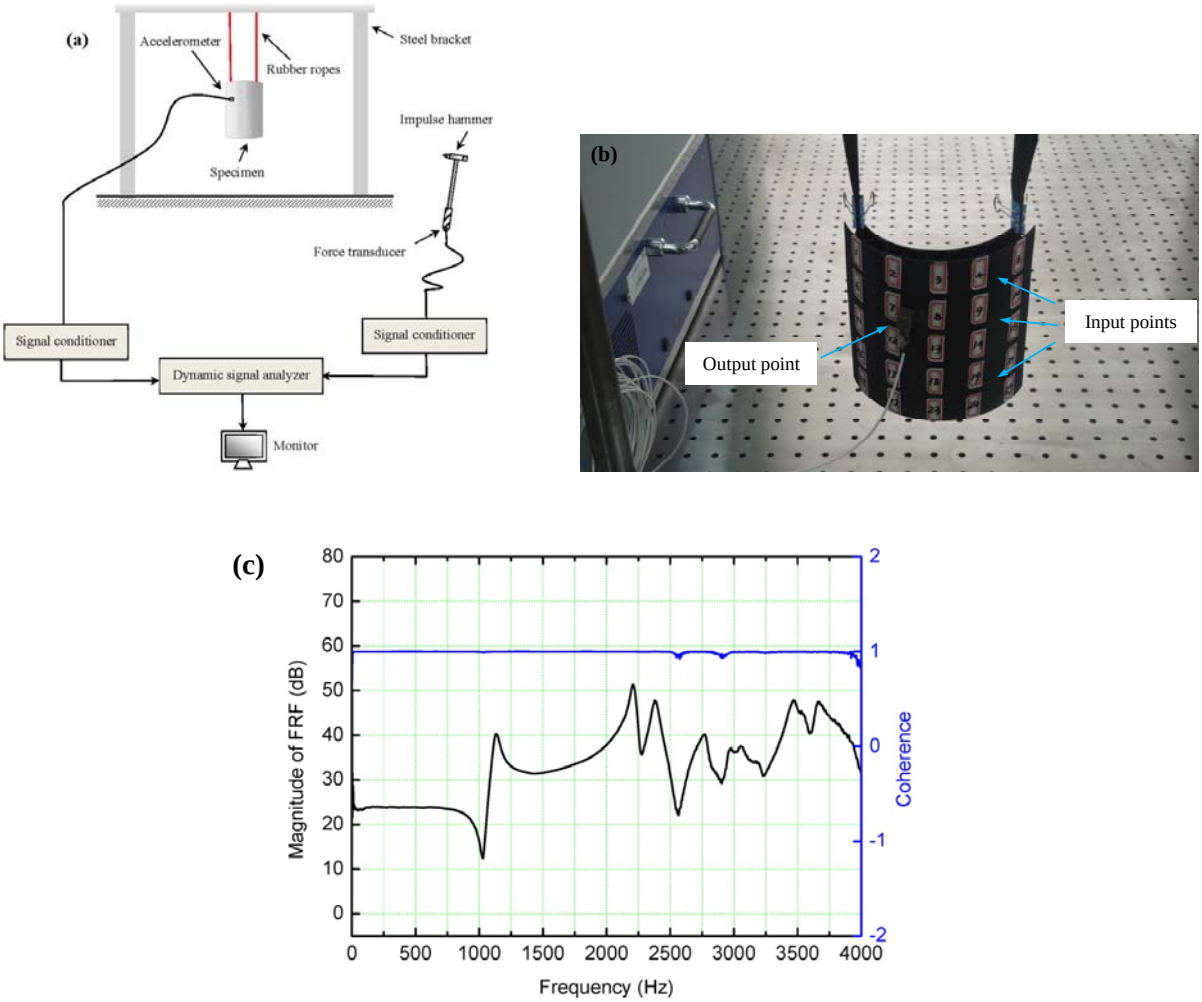

Fig. 3: (a) The modal experimental setup, (b) input points and outpoint arranged for the specimen and (c) typical frequency response curve with coherence function.

4 FINITE ELEMENT MODELS

Finite element analyses for the vibration responses of both empty and foam filled corrugated sandwich cylindrical panels are performed using a commercial finite element code ABAQUS/Standard version 6.13. The face sheets and the actual corrugated core members are modeled as shell bodies and meshed as S8R elements (8-node doubly curved thick shell elements with reduced integration) since they are much thinner than the total thickness of the sandwich. The filled foam is established by a 3D solid model and meshed as C3D8I elements (8-node linear brick, incompatible modes). Perfect bonding between the face sheets, the corrugated cores and the foam is assumed during the calculation.

A mesh convergence analysis is conducted to ensure that the selected mesh strategies are independent of mesh size. Then the modal parameters of the present structures including natural frequencies, mode shapes, modal stresses, strains, strain energy magnitudes, etc. can be finally obtained through a linear perturbation analysis.

5 RESULTS

The comparison of the corresponding natural frequencies obtained from experiment and FEA are shown in Fig. 4. Fig. 5 shows the experimental frequency response functions (FRFs) of the empty and foam filled corrugated sandwich cylindrical panels.

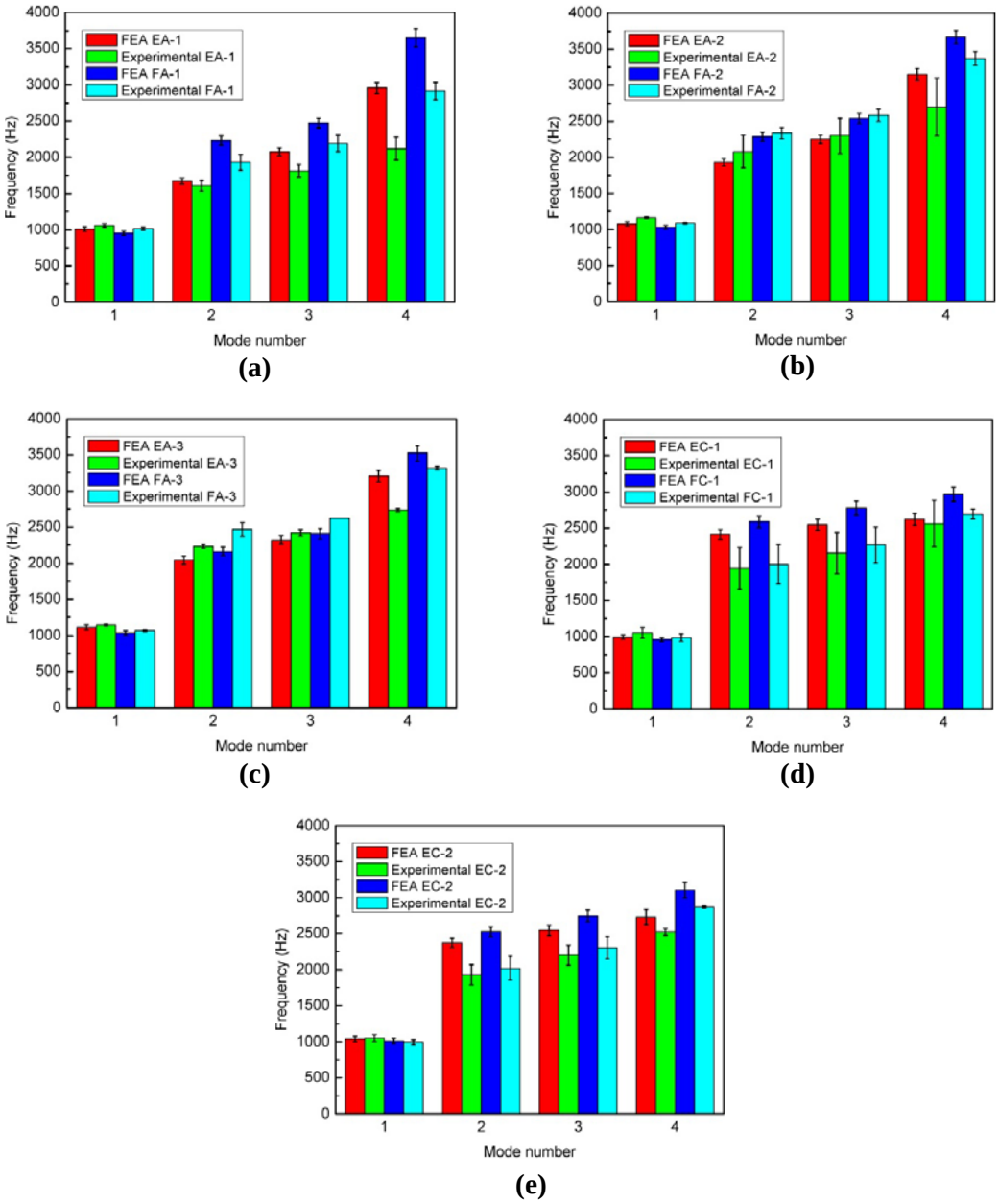

Fig. 4: Comparison of the natural frequencies obtained from experimental and FEA for the empty and foam filled CSCPs.

The results show a good agreement between the FEA models and experimental tests. It is demonstrated that foam filled CSCPs can obviously improve the structural damping compared to the empty CSCPs without significantly changing the corresponding natural frequencies.

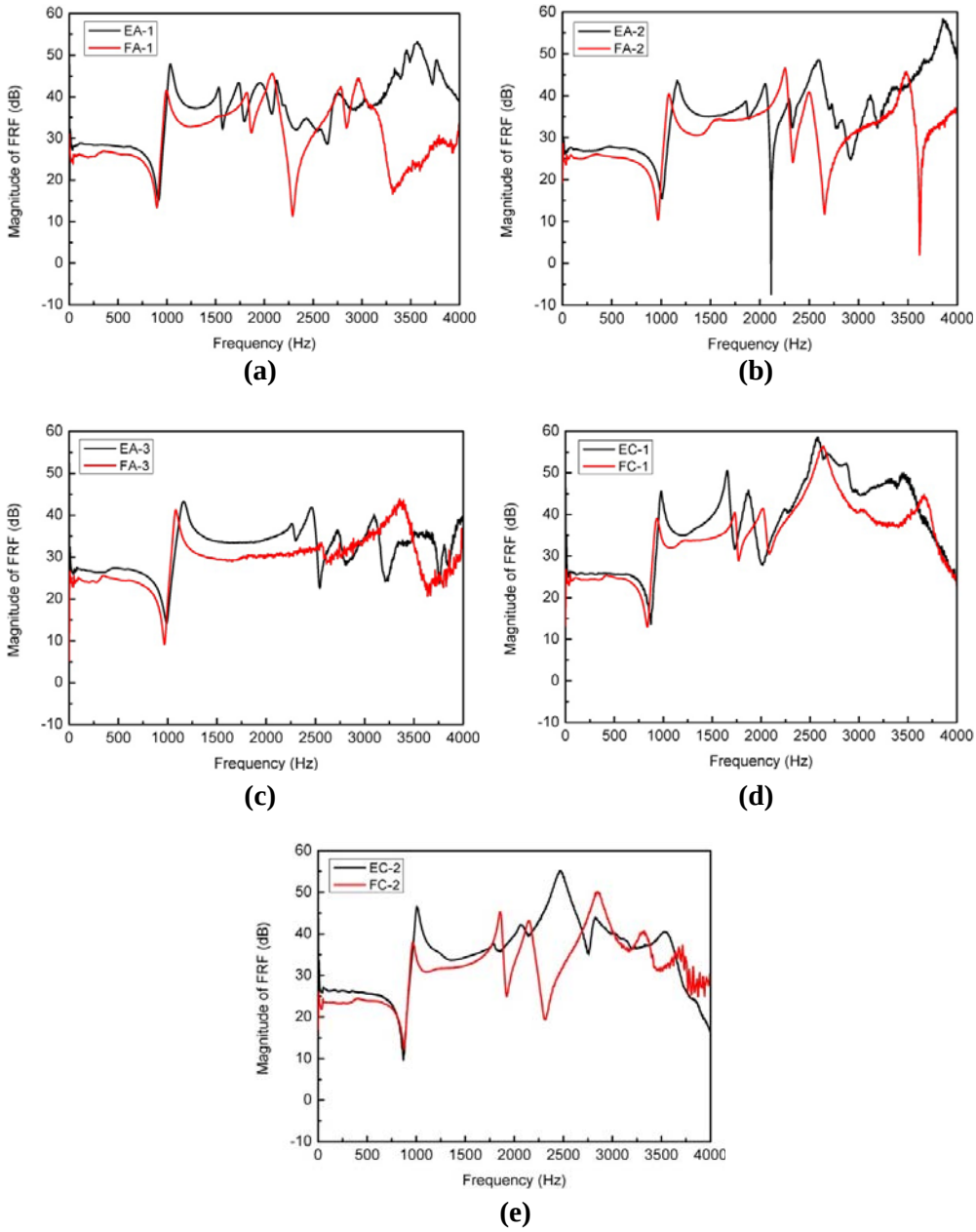

Fig. 5: Experimental frequency response functions (FRFs) of the empty and foam filled CSCPs.

6 CONCLUSIONS

In this paper, the modal behaviors of empty and foam filled ACSCPs and CCSCPs have been studied experimentally and numerically. A hot press moulding and post-assembly approach is adopted to fabricate the samples with different geometrical sizes. Then the hammer impulse technique and FEA method are used to investigate their modal responses. The results show a good agreement between the FEA models and experimental tests. It is demonstrated that foam filled CSCPs can obviously improve the structural damping compared to the empty CSCPs without significantly changing the corresponding natural frequencies. It is observed that higher damping loss factors are always induced by the torsional modes because of much higher levels of modal strain energy dissipation that can be involved. The ACSCPs generally can obtain higher natural frequencies and are more sensitive to the face sheet thickness compared to the CCSCPs with the same dimensions.

ACKNOWLEDGEMENTS

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