VIBRATION AND DAMPING PERFORMANCES OF CARBON FIBER COMPOSITE PYRAMIDAL TRUSS SANDWICH PANELS EMBEDDED WITH VISCOELASTIC LAYERS

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Abstract

The vibration and damping performances of carbon fiber composite pyramidal truss sandwich panels with viscoelastic layers embedded in the face sheets were investigated in this paper. carbon fiber composite pyramidal truss sandwich panels containing different thickness of viscoelastic layers were manufactured using a hot press moulding method. Analytical models based on modal strain energy approach were developed using ABAQUS software to estimate the damping property of the hybrid sandwich structures. A set of modal tests were carried out to investigate the vibration and damping characteristics of such hybrid sandwich panels with or without viscoelastic layers. The numerical simulation results showed good agreement with the experimental tests. The damping loss factors of hybrid sandwich panels increased distinctly compared with previous sandwich panels due to the viscoelastic layer embedded in the face sheets.

1. Introduction

Cellular sandwich structures with periodic lattice truss cores have advantages of application in engineering load-bearing structures because of their high specific strength, stiffness and potential of multi-functional applications [1-5]. Generally, lattice truss cores have many kinds of topologies such as tetrahedral, pyramidal and Kagome configurations [6-9] shown in Fig.1. Compared to metallic or alloy materials, using fiber-reinforce composites in sandwich structures usually can obtain an efficient weight reduction without strength and stiffness penalties. It needs to be pointed out that most of research effort about the carbon fiber lattice truss core sandwich structures focuses on the manufacturing techniques and mechanical properties under compression, shear, bending and impact loading [10-14]. However, to the authors' knowledge, the vibration and damping characteristics of lattice truss sandwich structures have not been studied previously.

As we all know, premature failure of critical components can be caused if the structures served under the resonant vibration. The problem of reducing the amplitudes of the vibrations is of vital importance for the structural design. Owing to the main contribution of the viscoelastic properties of polymeric composites, fiber-reinforced composite materials commonly have 10-100 times the damping of metals [15-19]. In addition, the hybrid structures of composite sandwich materials mixed with a viscoelastic layers [20-22] can provide an effective way to achieve higher damping of the structure. The purpose of this article is to study the vibration and the damping properties of carbon fiber composite pyramidal truss sandwich panels and such panels embedded with viscoelastic layers.

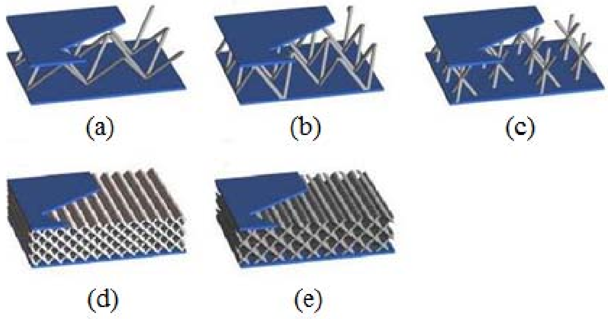


Fig.1 (a) Tetrahedral (b) Pyramidal (c) Kagome (d) Diamond (e) Prism

In the present study, the dynamic responses and damping characteristics of hybrid carbon fiber composite pyramidal truss sandwich panels were investigated. The analytical models based on modal strain energy approach were proposed to estimate the damping property of the structures. Modal experiments were performed to study the vibration and damping characteristics of such hybrid sandwich panels and finite element models were developed to predict the structural modal parameters. The influences of different thickness of viscoelastic layers on the vibration property were investigated and the conclusion would be drawn in the last.

2. Analaysis Models

2.1. Modal strain energy approach

The initial works on the damping analysis of fiber-reinforced composite materials have been developed by Adams and Bacon [23-27]. The numerical analyses considering the transverse shear effect have shown good agreement with experimental results. Then, the established damping model of FRP composites by Adams and Bacon named modal strain energy approach was adopted by following authors in order to develop the damping analysis of various composite structures. In the following section, the modal strain energy approach was applied in a finite element formulation to solve for the damping properties of the hybrid carbon fiber composite pyramidal truss sandwich panels contained viscoelastic layers.

The concept of this method is that the damping characteristics of a structure can be defined by the ratio of the energy dissipated to the energy stored during a stress cycle. For all-composite pyramidal truss core sandwich panels, the damping characteristics are obviously anisotropic which is different with isotropic materials. Hence, the total structural damping loss factor can be expressed as:

$$\eta = \frac{\sum_{k=1}^{n} \eta_{ij} U_{ij}^{\ k}}{\sum_{k=1}^{n} U_{ij}^{\ k}} (i, j = 1, 2, 3) \tag{1}$$

where η_{ij} and $U_{ij}^{\ k}$ are the damping loss factors of composite parent material and strain energy components of the element k relative to the stress component σ_{ij}. As shown in Fig.2, number 1 is the fiber direction, 2 is transverse to this direction and 3 is the through-thickness direction. Their relationships can be written as the following equation:

$$U_{ij}{}^{k} = \frac{1}{2}\int \sigma_{ij}{}^{k} \varepsilon_{ij}{}^{k} dV^{k} \tag{2}$$

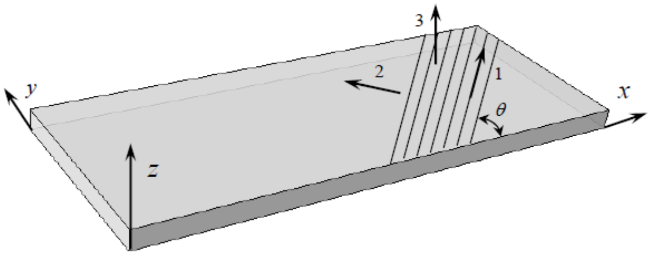


Fig.2 Definition of the fiber direction.

Thus, the contributions of strain energy components corresponding to stress components can be expressed as:

$$SE_{ij} = \frac{\Delta U_{ij}}{\Delta U_{total}} \left(i, j = 1,2,3\right) \tag{3}$$

where ΔU_{ij} is the total strain energy component corresponding to the stress component σ_{ij}, ΔU_{total} is the total strain energy of the system. SE_{11} SE_{22} and SE_{33} are the contributions of tension-compression deformation in the 1, 2 and 3 direction of the fiber-reinforced structures, respectively. SE_{12}, SE_{13} and SE_{23} are the contributions of shearing deformation in the planes (1,2), (1,3) and (2,3), respectively.

The procedure for evaluating damping of composite sandwich structures was performed using commercial finite element software ABAQUS 6.10. The natural frequencies, mode shapes and the properties (such as stress, strain and volume) of each element can be obtained by the Lanczos eigensolver [28]. For the anisotropic property of the composite structure, it was necessary to further decompose the total strain energy into several different components associated with different stress components. Unfortunately, only the total strain energy outputs were shown in the finite element analysis results. During the solution procedure, the total number of elements and the volume of each element were extracted firstly. Correspondingly, various stress and strain components of each element were exported to calculate and cumulate various strain energy and dissipated energy components of the whole model. Finally the damping loss factors of parent material were used to obtain the damping loss factors of the model by the data post-processing on the basis of modal strain energy approach.

2.2. Damping properties of hybrid sandwich panels

The damping loss factor of such structures can be defined as:

$$\eta = \frac{\sum_{k=1}^{n} \eta_{ij} U_{ij}{}^{k} + \sum_{p=1}^{m} \eta_{v} U_{v}{}^{p}}{\sum_{k=1}^{n} U_{ij}{}^{k} + \sum_{p=1}^{m} U_{v}{}^{p}} (i, j = 1,2,3) \tag{4}$$

where η_v and $U_v{}^p$ are the damping loss factor for viscoelastic material and strain energy of element p.

The transverse shear strain energies played a major role in damping properties compared with in-plane strain energies, so the damping performance of such structure was obtained by finite element method considering the transverse shear effects and stress effects through the thickness of laminate. Similar method was also taken into account for such hybrid sandwich panels with viscoelastic layers.

3. Experiments

Hybrid sandwich panels with and without viscoelastic layers were arranged in the form of structure with one edge fixed and with the others free. In order to investigate the relationship between the thickness of viscoelastic layer and damping performance of such structures, the thickness of viscoelastic layers were designed. Different impact points and measuring points were arranged to detect all vibration modes of the structure. The first six modes were considered in the modal experiments.

The experimental equipment used in this work was shown in Fig.3. First of all, impact points were evenly arranged on the specimen, and the force hammer was used to impact the points in proper order after finished the relevant setup and the average values on the each point were obtained after impacting three times. Then signals gotten from force transducer (model SN30979, sensitivity 12.25mV/N) and acceleration transducer (model SN46550, sensitivity 10.07 mV/m/s2) were processed by the DEWETRON dynamic signal analyzers.

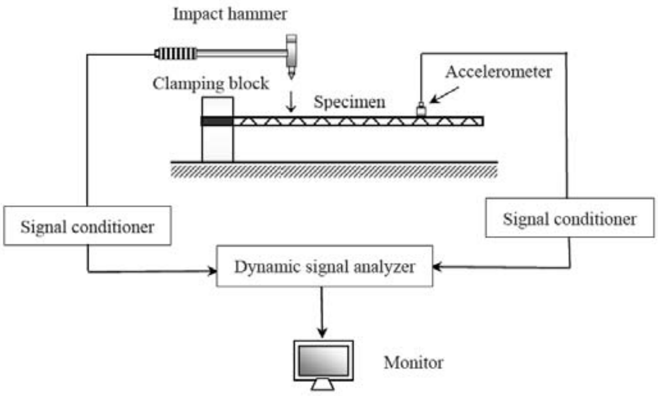


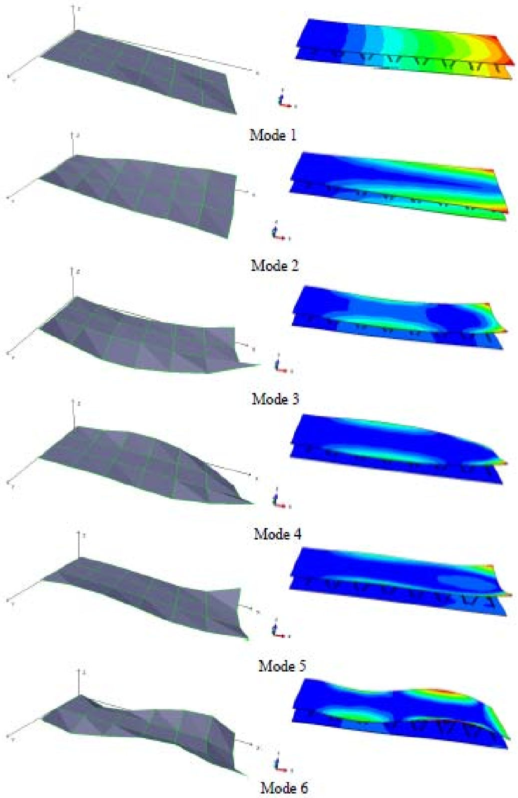
Fig.3 The equipment for modal experiment

4. Simulations

The damping loss factors of parent materials for hybrid carbon fiber composite sandwich panels were then used to predict the relative damping characteristics of such hybrid sandwich panels. The solution procedure of the damping loss factors of the model was shown below. The frequency extraction procedure was implemented in ABAQUS/Standard using the Lanczos eigensolver. A 3D solid model was developed to establish the structure, element C3D8R (8-node, reduced integration) was used to mesh the model and a mesh convergence study was carried out to ensure that the mesh refinement in the sandwich panels was fine enough. The contribution of face sheets and pyramidal truss cores on the damping characteristics was firstly explored. And the dynamic responses of such sandwich panels were derived by using a mode superposition method.

5. Results and discussion

The Fig.4 showed the first six modal shapes of hybrid sandwich panels deduced from experiments results. The measured results showed a good agreement with the numerical predictions. Mode 1 was a transverse bending mode, mode 2 was a twisting mode and other modes were the results of their different superposition. The first six order natural frequencies and modal damping loss factors of such hybrid sandwich panels were investigated combining modal test and modeling prediction based on modal strain energy approach. The results of first six order natural frequencies and damping loss factors for hybrid sandwich panels embedded with different thickness of viscoelastic layers were given in Fig.5 and 6. Compared to experiment results, the inevitable difference for simulation prediction of the damping loss factors was due to the boundary condition, joint damping and frictional damping. It was found that the damping loss factor of the sandwich panels without viscoelastic layer in the range of 0.7% to 2% were much higher than conventional materials and structures. Additionally, the values of damping loss factor corresponds to the twist mode were always higher than the transverse bending mode. The reason was that greater shearing deformation could be induced by twist mode to dissipate more energy.



(a) Experiment results (b) Modelling results

Fig.4 The first six modal shapes deduced from experiment and finite element analysis.

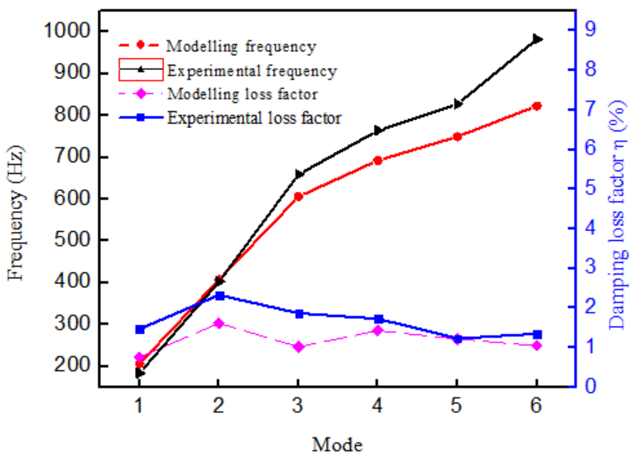


Fig.5 Comparisons of the natural frequencies and damping loss factors by the experimental and modelling results for the sandwich panel without viscoelastic layer.

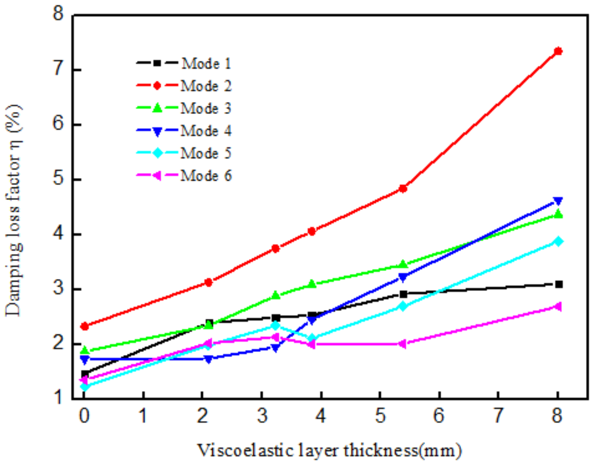


Fig.6 Damping loss factors by the experimental results for sandwith panels embedded with different thickness of viscoelastic layer.

According to the modal strain energy approach, damping loss factor of such hybrid composite sandwich panels depended on the damping loss factor of its parent materials and corresponding strain energy components. Fig.7 showed the contribution of facesheets and pyramidal truss cores on the damping characteristics of the total structure. The results showed that the damping contribution of facesheets played a more important role on the damping performance of the structure than the pyramidal truss cores. With the increase of the thickness of viscoelastic layer, damping loss factors of the sandwich panels increased accordingly without significantly changing its natural frequencies. Compared to the damping of the structure without viscoelastic layer, the largest increase of damping could be observed in such sandwich panels with 0.75 mm thickness viscoelastic layer that the damping loss factor could reach 6.75%. Epoxy resin which penetrated into the viscoelastic damping layers could improve the stiffness of the structure to a certain degree during hot press molding fabrication, and the modal natural frequencies slightly increased in high-order modes with the increase of the thickness of viscoelastic layer.

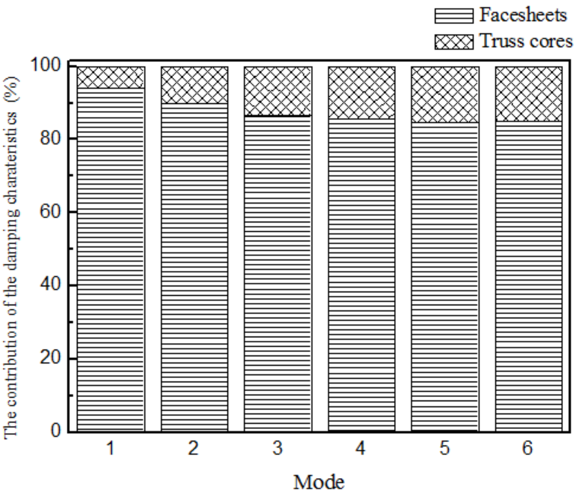


Fig.7 The contribution of facesheets and pyramidal truss cores on the damping characteristics of the composite sandwich panel without viscoelastic layer.

6. Conclusion

Experimental and numerical methods were carried out to study the vibration and damping performances of hybrid carbon fiber composite pyramidal truss sandwich panels containing viscoelastic layers. Such hybrid sandwich panels were fabricated by hot press molding and different thickness of viscoelastic layers were embedded in the middle of face sheets during the placement of carbon fiber composite prepregs. The strategy of numerical simulation combining data post-processing was used to estimate the damping loss factor of such hybrid sandwich panels. It was shown that the modeling based on modal strain energy approach provided a good way to estimation the damping characteristics of such hybrid sandwich panels. This work provided a way to study the damping characteristics of hybrid composite sandwich panels with truss cores during multifunctional applications.

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