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Effects of local damage on vibration characteristics of composite pyramidal truss core sandwich structure

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ABSTRACT

The effects of local damage on the natural frequencies and the corresponding vibration modes of composite pyramidal truss core sandwich structures are studied in the present paper. Hot press molding method is used to fabricate intact and damaged pyramidal truss core sandwich structures, and modal testing is carried out to obtain their natural frequencies. A FEM model is also constructed to investigate their vibration characteristics numerically. It is found that the calculated natural frequencies are in relatively good agreement with the measured results. By using the experimentally validated FEM model, a series of numerical analyses are conducted to further explore the effects of damage extent, damage location, damage form on the vibration characteristics of composite pyramidal truss core sandwich structures as well as the influence of boundary conditions. The conclusion derived from this study is expected to be useful for analyzing practical problems related to structural health monitoring of composite lattice sandwich structures.

1. Introduction

A sandwich structure consists of two thin external layers of high-strength material and a thick intermediate layer of lightweight material. The former are usually called the face sheets and the latter the core [1–5]. Composite sandwich structures have many advantages over conventional structural materials, such as high bending stiffness, low specific weight, and good thermal and acoustical insulation [6–9]. Sandwich structures can be classified as honeycomb, foam, and lattice truss core sandwich structures [10–14]. Lattice truss core sandwich structures have not only the advantages of super-light porous materials, but also such features as simple processing and regular shape. Thus, it is a potential substitute for aluminum alloy, composite materials, and light metallic foam which are widely applied in the fields of transportation, machinery (such as high-speed train, aircraft, high-grade machine tool) and so on [15–21]. Nevertheless, the current applications of lattice truss core sandwich structures are mainly limited to secondary components. Such "exploitation with caution" is caused by a proneness of lattice truss core sandwich structures to a variety of defects and damages because of their own structural complexity as well as the high influence of manufacturing process on the product quality. It is, therefore, important to explore the effects of local damage on their mechanical properties such as vibration characteristics.

Hu and Hwu [22] developed a one-dimensional model considering transverse shear effect and rotary inertia of the core for free vibration analysis of a honeycomb sandwich beam with an across-the-width delamination located at the interface between the top face and the core. With this model, the natural frequencies and vibration modes of the delaminated composite sandwich beam were obtained by solving the eigenvalues and eigenvectors of 12 simultaneous homogeneous algebraic equations. Based upon the general solution, the effects of the faces, the core, and the delamination of the beam on its free vibration behavior were studied thoroughly. Kim and Hwang [23] conducted a vibration test on a honeycomb sandwich beam composed of carbon/epoxy laminated composite faces and Nomex-aramid honeycomb core to investigate the effects of debonding on its natural frequencies and flexural rigidity. Burlayenko and Sadowski [24] studied the dynamic behavior of a sandwich plate with flexible core partially delaminated at the face/core interface numerically. The influences of debonding size, debonding location, and debonding type on the modal parameters of the damaged sandwich plate with various boundary conditions were also investigated. Baba and Thoppul [25] investigated the influence of face/core debonding on the vibration behavior of a composite sandwich beam made up of carbon/epoxy laminated

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faces and polyurethane foam core experimentally, and found that the face/core debonding causes reduction of the natural frequencies, whereas the damping loss factor increases due to the presence of debonding. Sokolinsky et al. [26] investigated the free vibration behavior of sandwich beam with locally damaged transversely flexible (soft) core. The results demonstrated that a local damage of small length, which is located in the span of a soft-core sandwich beam, leads to a significant reduction in the natural frequencies.

The above studies could provide foundation for the development of vibration-based nondestructive evaluation techniques and health monitoring approaches. However, up to now, the effects of local damage on the natural frequencies and vibration modes of composite lattice truss core sandwich structures have been rarely studied. In the present paper, the effects of local damage, in the form of missing part of the truss members, on the natural frequencies and the corresponding vibration modes of composite pyramidal truss core sandwich structures are studied both experimentally and numerically. The paper is organized as follows. In Section 2, the experimental specimens and the modal testing system are briefly described. The experimental outcomes are compared with the corresponding numerical results predicted by a FEM (finite element method) model in Section 3, and it is found that they are in good agreement with each other. By using the experimentally validated FEM model, a series of numerical analyses are carried out in Section 4 to further investigate the effects of damage extent, damage location, damage form on the natural frequencies

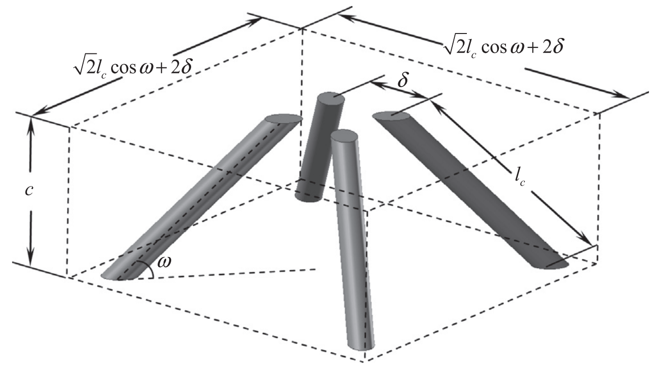

Fig. 2. Sketch of the unit cell of the pyramidal truss core.

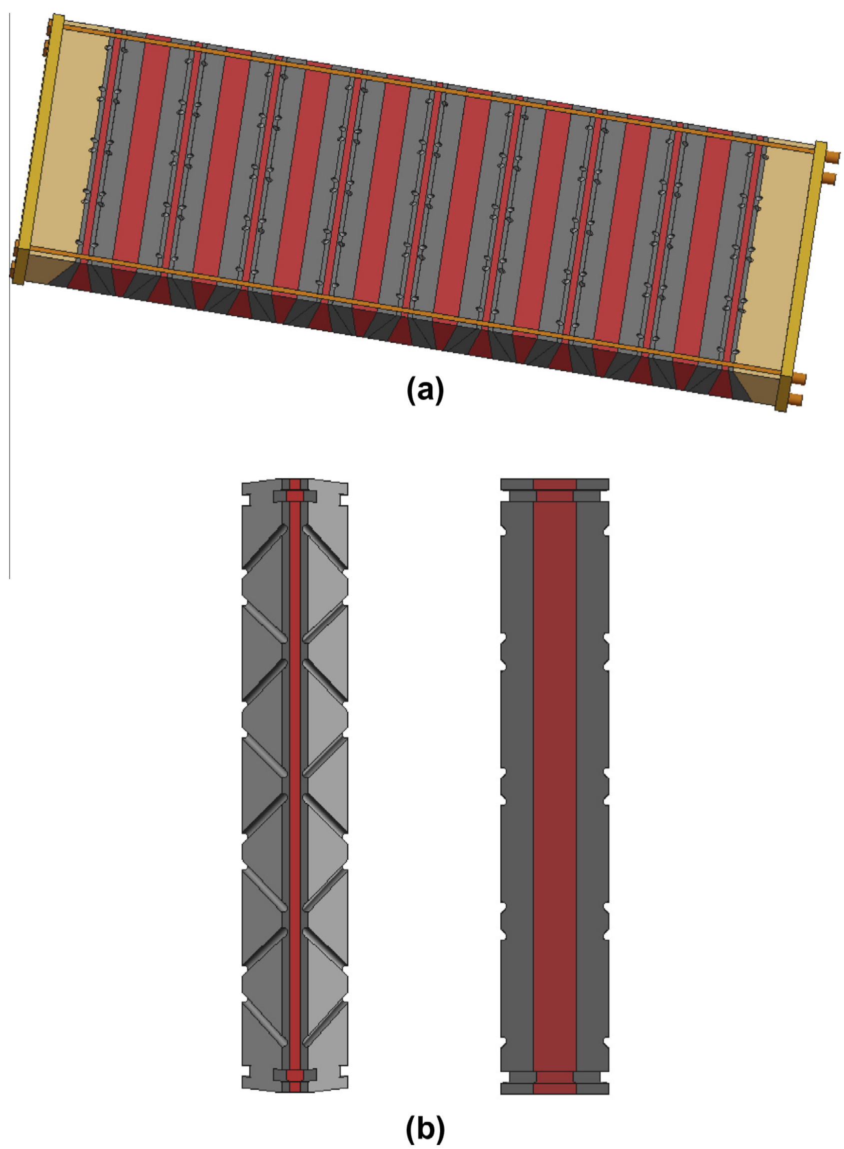

Fig. 1. Schematic diagram of the mold: (a) assembly drawing of the mold; (b) schematic diagram of single unit cell.