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Symplectic analysis of dynamic properties of hexagonal honeycomb sandwich tubes with plateau borders

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ABSTRACT

A new type of hexagonal honeycomb sandwich tube with plateau borders are introduced in this work and the Symplectic analysis with its high computational efficiency and high accuracy is applied to obtain the structural dynamic properties. The effects of material distribution (β) and relative density ($\overline{\rho}$) on the dynamic properties of the structure are also studied. Based on the definition of the elastic constants and the homogenization method, the independent elastic constants are obtained. By introducing dual variables and applying the variational principle, the canonical equations of Hamiltonian system are constructed. The precise integration method and extended Wittrick–Williams algorithm are adopted to solve the canonical equations. The dispersion relations of sandwich tubes are obtained, and the effects of material distribution and relative density on the normalized frequencies of the sandwich tubes are investigated. The proposed homogenization method is verified by comparing with other researchers' works. Dispersion relations of the sandwich tubes are obtained. The material distribution parameter and the relative density have significant effects on the dynamic properties of the structures. This work expects to offer new opportunities for the optimal design of metallic honeycomb sandwich tubes and future applications in the engineering sector.

1. Introduction

Cellular materials offer opportunities of obtaining unique structures and have been widely used for the lightweight sandwich beams or panels in the aerospace industry and other engineering applications [1]. A huge body of fundamental research has been carried out on the mechanical behaviors [2,3] and the optimization of cellular topologies and dimensions [4–6]. The various structure topologies and the designable element dimensions provide a large space for obtaining the attractive multi-functional applications of cellular structures [7,8]. By selecting and optimizing the dimensions and topologies of the cellular materials, the sandwich structures can be used as energy-absorbing guards [9], heat transfer devices [10,11], thermal protection [12,13], sound insulation and wave propagation devices [14,15].

Hollow cylinder is an important type of structures and has been widely used in engineering. Meanwhile, the studies on the static and dynamic properties of hollow cylinder with two-dimensional (2D) lattice periodic sandwich core have been carried out by numerous researchers. The main advantage of the sandwich structure with cellular materials is high bending stiffness and rather low specific weight. The demand of the design and optimization of the structure is to achieve a higher

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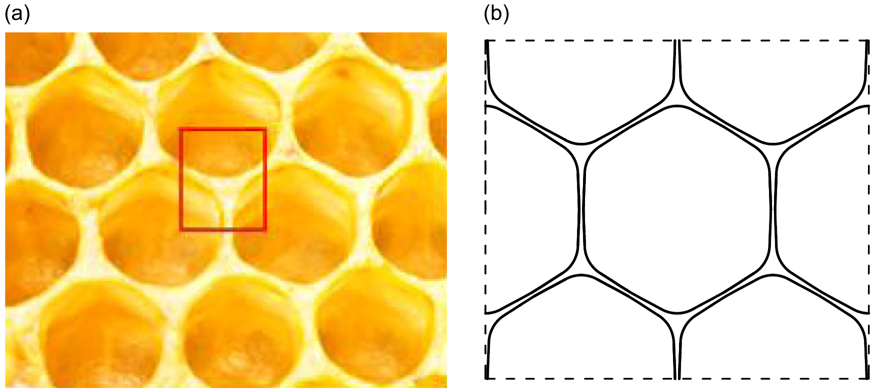

Fig. 1. (a) The natural honeycomb and (b) the ideal simplified model.

stiffness and a lower weight. One way to increase the stiffness of the structure is considering different material distributions with a constant mass [16]. Grade material like hollow-cylindrical-joint honeycomb [17] and hierarchical honeycomb [18] also show their capabilities in increasing the stiffness. It is known that the junctions of the cell walls bear more bending moments when the cell subjects to loading. A logical way is to locate more material near the cell wall junction to improve its bending strength capacities. In view of the traditional hexagonal honeycomb as shown in Fig. 1, the unit cell looks more like the hexagonal honeycomb with plateau borders [19]. This structure, much more close to the kind of honeycomb existing in nature, may exhibits some fascinating mechanical properties. Based on this point of view, we have great interest on the mechanical properties of such type of hexagonal honeycomb with plateau borders. While, a necessary step is to obtain its effective elastic constants. In most cases, the non-homogenized materials/structures are converted into the homogenized materials with many different homogenization methods [20–22]. An effective approach is using the definition of the elastic constants, which are used in this paper.

When the elastic constants are obtained, it is critical to find a precise prediction for the dynamic properties of honeycomb in enhancing the reliability of the design and ensuring the functions of the designed structures. Either the theoretical analysis or the numerical methods is feasible in analyzing the dynamic properties. Among the most common numerical methods, Symplectic algorithm with its potential advantages has already been used for calculating the dynamic properties of periodic structures, such as the dispersion analysis of carbon nanotubes [23], one-dimensional nonlinear periodic structures[24], and wave propagation problems in layered anisotropic media [25].

Motivated by the multi-functional design of the honeycomb structures and numerical efficiency of the Symplectic method, investigation on the dynamic properties of the hexagonal honeycomb sandwich tubes with plateau borders is conducted in this paper. The effects of material distribution and relative density on dynamic properties of the structures are evaluated by the Symplectic method.

The present paper is composed with five sections including Section 1 above. Section 2 describes the sandwich structures with the designed structural dimension and the homogenization process for obtaining the sandwich core's effective elastic constants. Section 3 presents a short review of Symplectic analysis method and describes the approach used for the analysis of dynamic properties of the sandwich structures. Section 4 compares and verifies the elastic constants obtained by the homogenization method in Section 2 and presents numerical results in terms of dispersion relations. Effects of the material distribution and relative density on the dynamic properties of sandwich tubes with honeycomb cores are also studied. Section 5 finally summarizes the main results of the work. The results obtained in this paper are expected to provide new opportunities for the optimal design of metallic honeycomb sandwich tubes.

2. The elastic properties of the sandwich core

To fully obtain the elastic relationship between the stress and the strain in a perfect regular honeycomb material, only five independent elastic constants, namely E_1, ν_{12}, E_3, $\overline{\rho}$ and G_{13}, are needed to be determined, according to Zhu's work [16]. In this section, the deriving process of the elastic constants is described. Meanwhile, the dimension of the structure is defined and described before the calculating procedure.

2.1. The profile and dimensional parameters of the unit cell

The cross-section including a combination of the core layer and the inner and outer shells, is schematically illustrated in Fig. 2, where $A_p = \frac{1}{2}(t_1 + 2R_p)^2 \sin\left(\frac{\pi}{3}\right) - \frac{1}{2}\pi {R_p}^2$ and $A_e = 3\int_{R_p/2}^{L/2} t(s)\mathrm{d}s$ are the inner and outer radii of the cylinder, meanwhile $A_t = \frac{3}{4}\sqrt{3}l^2$ and r_2 are the inner and outer radii of the core. The unit cells in hexagonal honeycomb configurations are composed of straight lines or flat plate elements connecting the nodes or nodal lines. A typical unit cell of hexagonal