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Review

New approach to study nonlinear dynamic response and vibration of sandwich composite cylindrical panels with auxetic honeycomb core layer

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ABSTRACT

The main goal of this study is using analytical solution to investigate the nonlinear dynamic response and vibration of sandwich auxetic composite cylindrical panels. The sandwich composite panels have three layers in which the top and bottom outer skins are isotropic aluminum materials, the central auxetic core layer – honeycomb structures with negative Poisson's ratio using the same aluminum material. The panels are resting on elastic foundations and subjected to mechanical, blast and damping loads. Based on Reddy's first order shear deformation theory (FSDT) with the geometrical nonlinear in von Karman and using the Airy stress functions method, Galerkin method and fourth-order Runge–Kutta method, the resulting equations are solved to obtain expressions for nonlinear motion equations. The effects of geometrical parameters, material properties, elastic Winkler and Pasternak foundations, mechanical, blast and damping loads on the nonlinear dynamic response and the natural frequencies of sandwich composite cylindrical panels are studied.

1. Introduction

Most natural materials are characterized by a positive Poisson's ratio, namely they are observed to contract (expand) laterally when stretched (compressed) longitudinally. Nonetheless, the classical theory of elasticity does not preclude the existence of materials with negative Poisson's ratio, known as 'auxetic' after [1]. Auxetic materials are a special and a fascinating material. One example of important applications of auxetic structures in aerospace engineering or in civil engineering is the absorption of powerful impacts such as explosive waves, so they are often used as the outer layer, safeguarding structures inside.

Therefore, recently, auxetic materials have received special attention of a lot of authors in the world. Qiao and Chen [2] studied the impact resistance of uniform and functionally graded auxetic double arrowhead honeycombs, double arrowhead honeycombs (DAHs) are auxetic cellular materials with negative Poisson's ratio (NPR). Grujicic et al. [3] investigated the multi-physics modeling of the fabrication and dynamic performance of all-metal auxetic-hexagonal sandwich-structures. Zhang et al. [4] considered the dynamic thermo-mechanical and impact properties of helical auxetic yarns. Assidi et al. [5] presented the composites with auxetic inclusions showing both an auxetic behavior and enhancement of their mechanical properties. Burlayenko and Sadowski [6] obtained the effective elastic properties of foam-filled honeycomb cores of sandwich panels. Grima et al. [7] investigated the hexagonal honeycombs with zero Poisson's ratios and enhances stiffness. Liu et al. [8] presented the wave propagation in a sandwich plate with a periodic composite core. Wan et al. [9] investigated the study of negative Poisson's ratios in auxetic honeycombs based on a large deflection model. Greaves et al. [10] studied Possion's ratio and modern materials. Zhang et al. [11] investigated the influence of cell micro-structure on the in-plane dynamic crushing of honeycombs with negative Poisson's ratio.

Milton [12] considered the composite materials with Poisson's ratios close to. Tian and Chung [13] studied the wave propagation in sandwich panel with auxetic core. Analytical expressions

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for the dynamic crushing strength of hexagonal honeycombs were derived by Hu and Yu [14]. Strek et al. [15] investigated the finite element analysis of auxetic obstacle deformation and fluid flow in a channel. Strek et al. [16] investigated the effective mechanical properties of concentric cylindrical composites with auxetic phase, the computational analysis of sandwich-structured composites with an auxetic phase [17] and the dynamic response of sandwich panels with auxetic cores [18]. Gabriele Imbalzano et al. [19] studied the three-dimensional modeling of auxetic sandwich panels for localized impact resistance. Thê-Duong Nguyen and Duc [20] considered evaluation of elastic properties and thermal expansion coefficient of composites reinforced by randomly distributed spherical particles with negative Poisson's ratios. Jopek and Strek [21] investigated the thermal and structural dependence of auxetic properties of composite materials. Duc and Cong studied [22] studied the nonlinear dynamic response and vibration of sandwich composite plates with negative Poisson's ratio in auxetic honeycombs. In [23], Duc considered generally and comprehensively about nonlinear static and dynamic stability of FGM plates and shells.

Cylindrical panels play the important part in the modern industries. Therefore, research on static and dynamic response of these structures have received special attention of a lot of authors in the world. Duc et al. [24] investigated the vibration and nonlinear dynamic response of imperfect three-phase polymer nanocomposite panel resting on elastic foundations under hydrodynamic loads. Duc and Quan [25] presented nonlinear buckling and postbuckling of eccentrically stiffened FGM cylindrical panels resting on elastic foundations and subjected to mechanical loads. Duc and Tung [26] proposed the nonlinear response of pressure-loaded functionally graded cylindrical panels with temperature effects. In 2013, Duc [27] also studied the nonlinear dynamic and vibration of eccentrically stiffened FGM double curved shallow shells.

In recent years, the safety of building and structures of infrastructure have become hot issues in all over the world because the negative dynamic loads caused of increasing in terrorist activities, accidental blast. As the results, the composite auxetic material under blast load has gained interests and been studied more. Tan et al. [28] presented the blast-wave impact mitigation using negative effective mass density concept of elastic metamaterials. Adhikary et al. [29] considered the influence of cylindrical charge orientation on the blast response of high strength concrete panels. Zhai et al. [30] investigated the experimental and numerical investigation into RC beams subjected to blast after exposure to fire. Yao et al. [31] presented the experimental and numerical study on the dynamic response of RC slabs under blast loading. Lam et al. [32] studied the response spectrum solutions for blast loading. Imbalzano et al. [33] investigated the auxetic composite panels under blast loadings. Ding and Ngo [34] studied the dynamic response of double skin façades under blast loads. Duc et al. [35] presented the nonlinear dynamic response and vibration of imperfect shear deformable functionally graded plates subjected to blast and thermal loads.

From above literature review [1–17], we can see that there are no studies about dynamic response and vibration of auxetic cylindrical panels yet. Moreover, auxetic plates and shells are complex structures, all published studies on auxetic structures as mentioned above use the Finite element method.

The most significant contribution of this work is using new approach – analytical solution to study nonlinear dynamic response and vibration of sandwich composite panels with negative Poisson's ratio in auxetic honeycombs. This method is more complicated than numerical methods in the aspect of mathematics, especially when using FSTD, but the advantage is that the dynamic response is expressed explicitly through material parameters, geometric parameters of the structure and load, and therefore we can actively control the behavior of the structure by selecting those parameters appropriately.

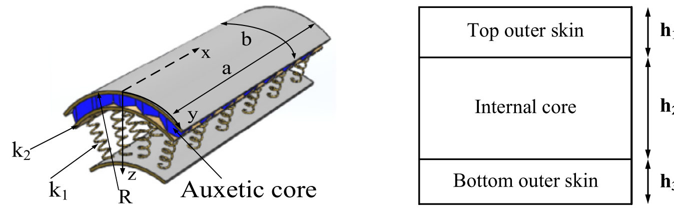

Fig. 1. (left) Model of sandwich composite cylindrical panels on elastic foundations with negative Poisson's ratios in auxetic honeycombs core layer. (right) Dicretization of the sandwich cylindrical panel.

By using analytical approach, this work focuses on studying the nonlinear dynamic response and vibration of the sandwich composite cylindrical panels with negative Poisson's ratio in auxetic honeycombs core structures on elastic foundations subjected to blast and other mechanical loads. The sandwich composite cylindrical panels used in the work have three layers in which the top and bottom outer skins are isotropic aluminum materials, the central core layer has auxetic honeycomb structures using the same aluminum material. The governing equations are derived within the framework of Reddy's first order shear deformation theory, taken into account the von Karman nonlinearity and using the Airy stress function, Galerkin method and fourth-order Runge–Kutta method. The work also analyses and discusses the effects of material and geometrical properties, elastic foundations and mechanical, blast and damping loads on the natural frequency and the nonlinear dynamic response of the composite cylindrical panels.

2. Sandwich composite cylindrical panel with auxetic core layer model

2.1. Model

Consider a sandwich cylindrical panel with auxetic core of radius of curvature R, length of edges a, b and uniform thickness h resting on elastic foundations. A coordinate system (x, y, z) is established, in which the (x, y) plane is in the middle surface of the panel and is z in the thickness direction (Fig. 1, left). The auxetic core which has three layers in which the top and bottom outer skins are isotropic aluminum materials; the central layer has honeycomb structure using the same aluminum material (Fig. 1, right). The bottom outer skin thickness is h_1, internal honeycomb core material thickness is h_2 and top outer skin thickness is h_3, and the total thickness of the shell is $h = h_1 + h_2 + h_3$.

The reaction–deflection relation of Pasternak foundation is given by

$$q_e = k_1 w - k_2 \nabla^2 w \tag{1}$$

In which $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$, w is the deflection of the cylindrical panels, k_1 and k_2 are Winkler foundation modulus and shear layer of Pasternak foundation, respectively.

2.2. Honeycomb core materials

The sandwich composite cylindrical panels having the auxetic honeycomb core layer with negative Poisson's ratio are introduced in this work. Unit cells of core material discussed in the paper are shown in Fig. 2 where l is the length of the inclined cell rib, h is the length of the vertical cell rib, θ is the inclined angle, α and β define the relative cell wall length and the wall's slenderness ratio, respectively, which are important parameters in honeycomb property.