Composite Structures 126 (2015) 1–15

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Free vibrations of functionally graded viscoelastic cylindrical panel under various boundary conditions

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ARTICLE INFO

Article history:
Available online 25 February 2015

Keywords:
Free vibrations
Exact solution
Functionally graded material
Viscoelasticity
Cylindrical panel

ABSTRACT

Polymeric foams are new materials which prefer special mechanical and thermal properties for mechanical designers. The best mathematical model for polymeric and metallic foams is functionally graded viscoelastic (FGV) materials. So, this paper has concentrated on presenting a reliable and accurate method for free vibration of FGV panels. For this purpose, Levy-type circular cylindrical panel consisting of FGV material is modeled based on Sanders first order shear deformation type theory, as geometrical model, and linear Zener model with variable properties through the thickness, as the best constitutive relation for FGV materials. Validity and accuracy of present method are approved by comparing it with finite element in different tables. Also, effects of various geometrical and material parameters on natural frequencies and decay rate are studied.

1. Introduction

The increasing need of industry to promoting the efficiency of machinery incorporating different criteria and aspects of engineering, including less weight and higher efficiency, has led into producing materials with complex characteristics. Smart materials, shape memory alloys, nanomaterials, biomaterials are the best examples of such materials. Metallic and polymeric foams are another example of such new materials which supply lightweight high mechanical strength property. These foams use in automotives, spacecraft, submarines and airplane, numerously, because they can increase resistance to the impact loading, reduce sound transmission and control mechanical vibrations in various machines [1–3]. From material viewpoint, these foams are classified in functionally graded materials (FGM) group. Functionally graded materials are non-homogeneous isotropic materials which their properties such as density and modulus of elasticity vary in one, two or three directions. Also, another main characteristic of such foams is their porosity. Over 90 percent void space in foams provides viscoelastic property for such materials. Fig. 1 shows both of the porosity and graded properties in an open cell polymeric foam structure. Using these materials in various bodies requires trustable method which can model functionally graded viscoelastic property beside geometrical difficulties, accurately. So, the first step is studying related research paper.

Low strength to weight ratio, aerodynamic form, and simple manufacturing process of cylindrical panel make them as the first selection for various engineering structures such as missiles and submarines. There are a lot of theories which are used for analysis of cylindrical panel. The first one is Love classical theory [4] presented in beginning of 19 century for thin plates and shells analysis. After that, researchers such as Donnell [5], Sanders [6], Novozillov [7], Naghdi [8], and etc combined their geometrical assumptions with classical linear elasticity theory and introduced their theories. Leissa presented a good collection for these theories and their application [9]. These shell theories has been based on some simplifying assumptions. According to most of them, the cylindrical shell must be relatively thin to take constant stresses within the thickness. Therefore, due to this assumption, the classical shell theories cannot present precise result for moderately thick and thick shells. But, first order shear deformation theory (FSDT) presented by Reissner [10] and Mindlin [11] provides a precise method respect to classical theories to solve thick shell problems. There are so many research papers which have combined classical or FSDT theory with mentioned geometrical theories and solved static or dynamics problems. But, among dynamic problems, free vibration is the most important part of every dynamics analysis. The related papers can be categorized in three groups: Papers which have analyzed vibration of viscoelastic panels, papers which have presented vibrational analysis of functionally graded panels, and papers which have concentrated on behavior of viscoelastic functionally graded panels.

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http://dx.doi.org/10.1016/j.compstruct.2015.02.031
0263-8223/

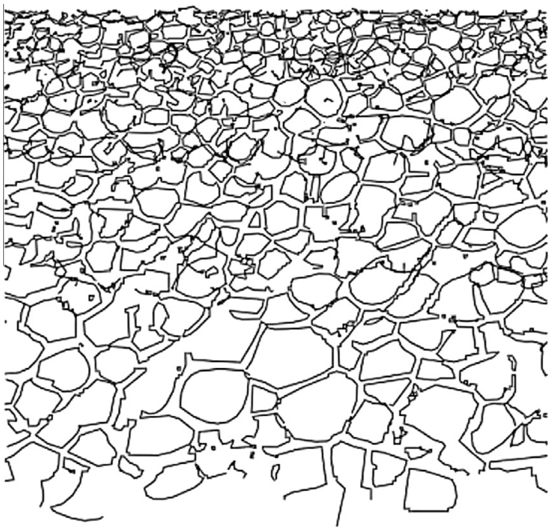

Fig. 1. Schematic view of an open cell polymeric foam_with_antisymmetric distribution.

In the area of free vibration of viscoelastic panel, Srinivas and Rao [12] presented exact solution for free vibration of simply supported viscoelastic plate. They used standard linear solid model beside the classical and first order shear deformation theory in their analysis. Mazumdar and Bucco [13] analyzed vibrational behavior of a shallow viscoelastic shell. They used Kelvin model and solved their problem by using iso-amplitude contour line concept. Cupiał and Nizioł [14] studied natural frequency and loss factor of a three layered composite plate with viscoelastic middle layer based on Mindlin plate theory. Also, Park and Schapery [15,16] applied a numerical method to present inter-conversions between linear viscoelastic material function based on Prony series. Their method is applicable to conversion between modulus and compliance functions in time, frequency, and Laplace domains. Chen et al. [17] presented time dependent response of laminated cylindrical panel with viscoelastic interface under static loading. Marynowski [18] studied behavior of an axially moving viscoelastic web using a two dimensional rheological element. He applied Galerkin method to thin plate model for this analysis. In 2008, Hatami et al. [19] developed an exact finite strip method and solved free vibration of an axially moving viscoelastic plate. Additionally, Marynowski [20] extended his previous work by considering Zener viscoelastic model and solving his problem for Levy-type boundary conditions in 2010. Bilasse et al. [21] preferred a complex mode finite element method for linear and nonlinear vibrational analysis of viscoelastic sandwich plate. Mohammadi and Sedaghati [22] introduced a new Taylor expansion based transverse displacement field to investigate optimum vibrational status of a sandwich cylindrical shell with viscoelastic middle layer. They developed their previous work by analyzing nonlinear vibrational analysis, too [23]. In 2012, Saksa et al. [24] investigated dynamic stability of axially moving viscoelastic panel by considering Kelvin–Voit model. Present literature survey shows that there is not any research which has analyzed vibrational behavior of viscoelastic cylindrical thick panel, exactly.

In the FG panel vibration analysis area, albeit, there is a lot of papers which have analyzed vibrational behavior of functionally graded cylinder and cylindrical panel but the majority of these researches considered metal–ceramic functionally graded materials in their analysis because of their high mechanical–thermal resistant and polymeric or metallic foams are less mentioned. Among them, vibrational analysis which were presented by Loy et al. [25], Pradhan et al. [26], Iqbal et al. [27,28], Civalek [29,30], Tornabene [31–35], Vel [36], Liew et al. [37,38], Hosseini-Hashemi et al. [39], Ebrahimi and Najafizadeh [40], Li and Liu [41], Malekzadeh and Ghaedsharaf [42], Su et al. [43,44], Ye et al. [45], Jin et al. [46], and Huang and Han [47] are research papers which reviewing them gives nice insight to the researchers in this field. Most of these researches either used numerical and semi-analytical methods such as DSC technique, FEM, GDQM and meshless FEM to solve their problems or considered simple boundary condition combinations like simply-supported plate.

Finally, there are some papers which have concentrate on behavior of polymeric and metallic foams by modeling them as functionally graded viscoelastic (FGV) materials. In 2001, Paolinu and Jin [48] analyzed shear fracture in functionally graded viscoelastic materials and presented a stress intensity factor for crack in such media. Mukhrejee and Paulino [49] studied reasons behind the success or failure of the correspondence principle for viscoelastic functionally graded materials. They showed for the inseparable class of non-homogeneous materials, the correspondence principle fails because of an inconsistency between the replacements of the modules and of their derivatives. Also, Jin [50] discussed the viscoelastic correspondence principle of linear viscoelasticity for functionally graded materials. In addition, Altenbach and Eremeyev [51,52] have presented a new plate theory for analysis of functionally graded viscoelastic plate. They used linear viscoelastic isotropic relations for their model. additionally, Dave et al. [53,54] presented a finite element method which considered gradation in viscoelastic parameters and used it to analyze asphalt concrete pavement. In 2012, Ashrafi et al. [55] presented a 2D boundary element approach to modeling viscoelastic functionally graded materials by developing a numerical implementation of the Somigliana identity for displacements. In 2013, Shariyat and Alipour [56] studied vibration and stress in a two directional FG circular plate with variable thickness which is on elastic foundation. They used a power series method for this analysis. From present literature survey it can be concluded that, most of the researchers used semi analytical methods such as FEM, DSC, and GDQ in their analysis. These methods are dependent on number of elements or grids. So, these methods are computationally more expensive respect to the exact methods. Also, in some cases such as traditional finite element methods, modeling of all type of material distribution are so difficult. Therefore, absence of a direct analytical method which can solve vibrational behavior of FGV thick cylindrical panel for Levy-type boundary condition combinations is evident. This paper has concentrated on presentation of an exact method which can solve vibrational behavior of thick VFG panel. Hence, a circular cylindrical panel, consist of functionally graded viscoelastic material is considered. Panel geometry is modeled based on Sanders shear deformation type theory. Its material properties vary through the thickness based on a power-law distribution function. Also, linear Zener model is considered for viscoelastic behavior. State space approach is developed and an exact solution is provided for Levy-type boundary conditions. Validity and accuracy of present method are approved by comparing present results with literature and results of 3D finite element model in various tables. Also, the effect of various geometrical and mechanical properties changes on natural frequency and decay rate are examined for various boundary conditions in different figures.

2. Mathematical formulation

Now, let us consider a circular cylindrical panel with length L, arc length S, panel angle θ, thickness h and middle surface radii of curvature R as shown in Fig. 2. Also, a coordinate system with perpendicular axes as x_1 in longitudinal directions, x_2 in circumferential axes, and z in radial direction has been considered as depicted in Fig. 2. In this paper, Hamilton principle is used to derive