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Axisymmetric post-buckling behavior of saturated porous circular plates

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ABSTRACT

This study aimed to investigate axisymmetric post-buckling behavior of a circular plate made of porous material under uniformly distributed radial compression with simply supported and clamped boundary conditions. Pores are saturated with fluid and plate properties vary continuously in the thickness direction. Governing equations are obtained based on classical plate theory and applying Sanders nonlinear strain-displacement relation. Shooting numerical method is used to solve the governing equations of problem. Effects of porosity coefficient, pore distribution, pore fluid compressibility, thickness change and boundary conditions on the post-buckling behavior of the plate are investigated. The results obtained for post-bucking of homogeneous/isotropic plates and critical buckling load of porous plates are compared with the results of other researchers.

1. Introduction

Porous materials are composed of two components; a solid matrix and fluid within matrix pores that can be liquid or gas. Porous materials exist in nature such as stone, wood and bone and may be made artificially such as metal, ceramic and polymer foams and they are used as structural components in various industries such as aerospace, transportation, building, etc.

Biot [1] who is the pioneer in developing the theory of poroelasticity, studied buckling of a fluid-saturated porous slab under axial compression and showed that critical buckling load is proportional to pore compressibility. Magnucki and Stasiewicz [2] investigated buckling of a simply supported porous beam and showed porosity effect on the strength and buckling load of the beam. Buckling and bending of a rectangular porous plate with varying properties across the thickness and under in-plane compression and transverse pressure were studied by Magnucki et al. [3]. Magnucka-Blandzi [4] examined buckling of a circular porous plate and showed that the critical load linearly decrease with increase porosity of the plate; he also studied dynamic stability of a circular plate made of metal foam and showed porosity effect on critical loads with numerical results [5]. He continued his research in this field and investigated rectangular sandwich plate with metal foam core and simply supported boundary condition. In this study, he considered the middle plane of the plate as symmetry plane and by numerical method obtained critical buckling loads for a set of sandwich plates [6]. Jasion et al. [7] obtained global and local buckling for sandwich beam and plate with metal foam core by experimental, numerical and analytical methods, and compared the obtained results. Wen [8] obtained an analytical solution for saturated porous plate with an incompressible fluid and showed that there is a significant interaction between the solid and flow. Closed-form solution for buckling of porous circular plate saturated with fluid and with three different types of pore distribution in thickness direction including nonlinear nonsymmetric, nonlinear symmetric and monotonous and based on classical plate theory (CPT) under mechanical and thermal loads was obtained by Jabbari et al. [9,10]. Buckling of porous circular plates integrated with piezoelectric layers was investigated under mechanical and thermal loads and based on CPT by [11–13] and under thermal load and based on first-order shear deformation plate theory by [14].

Buckling analysis of porous plates with functional properties is similar to functionally graded material (FGM) plates to some extent. Woo and Meguid [15] obtained an analytical solution in terms of Fourier series for the coupled large deflection of FG plates and shallow shells under transverse mechanical loads and a temperature field. Closed-form solution for the critical buckling temperature of a rectangular FG plate was obtained under different types of thermal loads and based on classical and higher-order shear deformation plate theories by Javaheri and Eslami [16,17]. They showed that classical plate theory overestimates buckling temperatures. They also examined Buckling of FG Plates under in-plane Compression and based on CPT [18]. Najafizadeh and Eslami [19] presented buckling of a circular plate with functional properties under uniform radial compression. Ma and Wang [20] investigated axisymmetric post-buckling of an FG circular plate under uniformly distributed radial compressive load. They also [21] studied bending and thermal post-buckling of an FG circular plate based on classical nonlinear von Karman plate theory. The governing

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equations were solved with the shooting method. Effects of material constant and boundary conditions on temperature distribution, nonlinear bending, critical buckling temperature and thermal post-buckling behavior were indicated. They [22] studied the relationships between axisymmetric bending and buckling of FG circular plates based on third-order plate theory (TPT) and CPT. They compared TPT solutions with first-order plate theory (FPT) and CPT solutions and showed that TPT solutions are almost the same as FPT solutions and FPT is sufficient to consider shear deformation effect on the axisymmetric bending and buckling of FG plate. Post-buckling of FG circular plate with geometric imperfection under transverse mechanical load and transversely non-uniform temperature rise was studied by Li et al. [23]. Effects of geometric imperfections on buckling and post-buckling of FG plates were studied by many researchers such as [24–26]. Post-buckling of an FG circular plate under asymmetric transverse and in-plane loadings was studied by Fallah et al. [27].

To the authors' knowledge, there is no study in previous works regarding post-buckling of porous circular Plates. Therefore in this study, mechanical post-buckling of a saturated porous circular plate is investigated. It is assumed that mechanical properties vary continuously in the thickness direction. Based on classical plate theory and Sanders assumption, governing equations of the problem are obtained as a system of differential equations and shooting method is used to solve them. Both clamped and simply supported boundary conditions are considered. The effects of geometric parameters, poroelastic material parameters and boundary conditions on the post-buckling behavior of plate are investigated.

2. Governing equations

2.1. Mechanical properties of poroelastic plates

In this study, a circular plate with radius b and thickness h is considered, which is made of porous material and its pores are saturated with fluid. Cylindrical coordinate axes are located on the mid-plane of the plate and z axis is in the thickness direction. Plate properties vary continuously along the thickness. For pore distribution in the thickness direction, three different cases are considered [2,9,10]. At first case, pore distribution is nonlinear symmetric and the middle plane of plate is its symmetry plane and moduli of elasticity, which depend on pore distribution, are as follows

$$E(z) = E_0\left[1-e_1 cos\left(\pi\frac{z}{h}\right)\right] G(z) = G_0\left[1-e_1 cos\left(\pi\frac{z}{h}\right)\right] e_1=1-\frac{E_1}{E_0}=1-\frac{G_1}{G_0} \quad (1)$$

where e_1 is the porosity coefficient of the plate ($0 < e_1<1$); E_1 and E_0 are Young's moduli at the middle plane ($z = 0$) and the upper and lower surfaces of the plate ($z = \pm h/2$), respectively; G_1 and G_0 are shear moduli at ($z = 0$) and ($z = \pm h/2$), respectively. The relationship between elastic modulus and shear modulus is $E_j=2G_j(1 + \nu), j = 0,1$ and Poisson's ratio (ν) is assumed to be constant across the plate thickness. At second case, pore distribution is nonlinear nonsymmetric and moduli of elasticity are expressed as follows

$$E(z) = E_0\left\{1-e_1 cos\left[\left(\frac{\pi}{2h}\right)\left(z+\frac{h}{2}\right)\right]\right\} G(z) = G_0\left\{1-e_1 \cos\left[\left(\frac{\pi}{2h}\right)\left(z+\frac{h}{2}\right)\right]\right\} \quad (2)$$

in which E_1 and E_0 are Young's moduli at the lower surface ($z = -h/2$) and the upper surface ($z = +h/2$) of the plate, respectively; G_1 and G_0 are shear moduli at the lower and upper surfaces, respectively. At third case, pore distribution is monotonous and moduli of elasticity in this case, are:

$$E(z) = E_0(1-e_1) G(z) = G_0(1-e_1) \quad (3)$$

In the asymmetrical case, there is mechanical coupling between extensional forces and curvatures and between bending moments and extensional strains, but in the symmetrical and monotonous cases, such couplings are neglected [14]. Variations of shear modulus with porous distribution in the thickness direction are shown in Fig. 1 for nonlinear nonsymmetric distribution, in Fig. 2 for nonlinear symmetric distribution and in Fig. 3 for monotonous distribution.

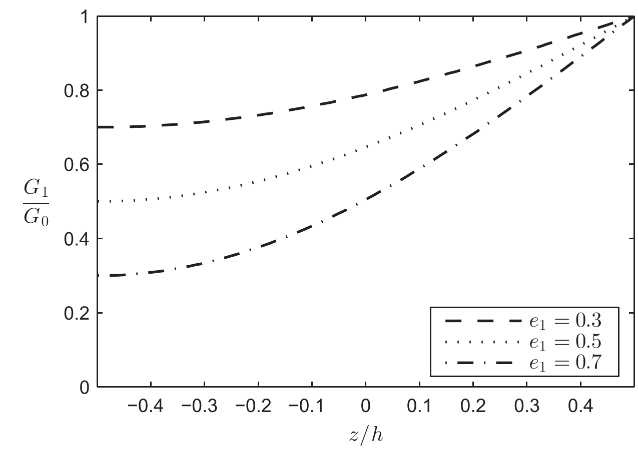

Fig. 1. Variation of shear modulus through the dimensionless thickness for nonlinear nonsymmetric pore distribution for different values of e_1.

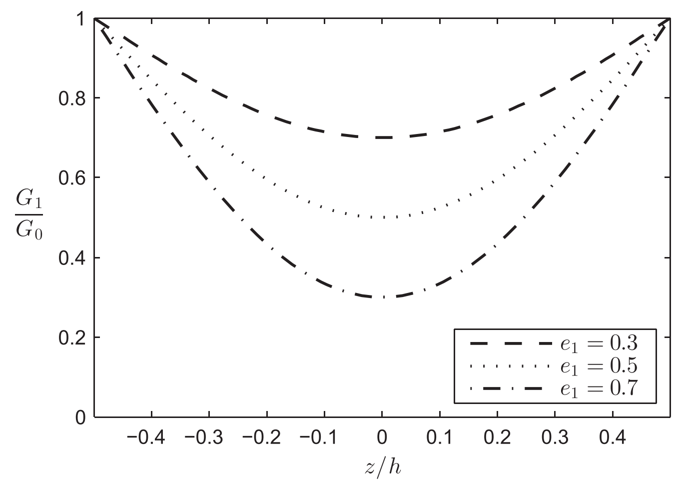

Fig. 2. Variation of shear modulus through the dimensionless thickness for nonlinear symmetric pore distribution for different values of e_1.

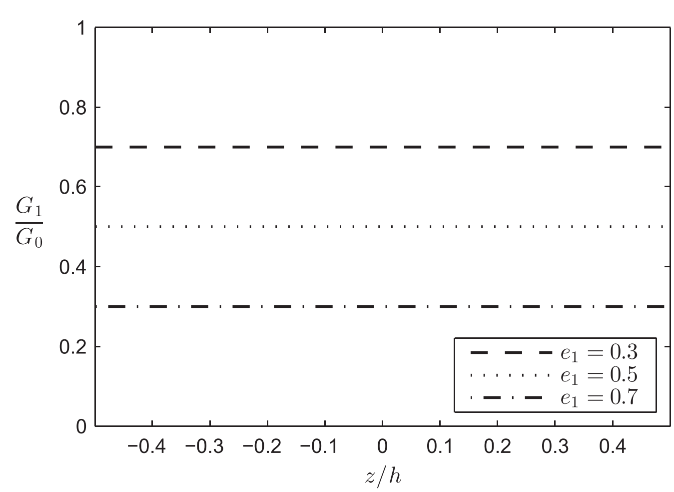

Fig. 3. Variation of shear modulus through the dimensionless thickness for monotonous pore distribution for different values of e_1.