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# Elastic behavior of glass-like functionally graded infinite hollow cylinder under hydrostatic loads using finite element method

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ABSTRACT

A glass-like (viscoelastic) functionally graded cylinder is studied by using finite element method to investigate the mechanical responses. A subroutine is developed by using ANSYS parametric design language (APDL) to simulate two nonlinearities, which are the variation of material properties with respect to time and position. The cylinder is made of two different viscoelastic materials, namely, pure material one at inner and pure material two at outer surfaces. The material properties are assumed to be presented by simple power law distribution and moreover, bulk and shear moduli are varying with respect to time using the kernel functions depicted regarding Prony series. It is shown that the hoop stresses take the same values at the mean radius (middle of the thickness) for different values of time and grading index. It is found that the radial stress decreases to certain values for specific grading index and then by increasing the grading index it increases to maximum value that related to pure material cylinder. It is shown that unlike the zero axial stress in pure material cylinders, it varies along the thickness from minimum to maximum at inner and outer surfaces, respectively. It is concluded that the viscoelastic functionally graded (VFG) materials play an important role in steady and transient response of hollow cylinder under hydrostatic load.



## 1. Introduction

A material with elastic and viscous parts is defined as viscoelastic material. Generally, viscous property changes with respect to time, whereas the elastic deformation occurs instantaneously due to applied load. The brittle materials such as glass or glass-like materials by having different properties due to heating and cooling process can be modeled as viscoelastic materials [1–3]. The brittle materials with high values of modulus of elasticity can be applied to reinforce the pure metal structures. This arrangement of two different materials introduces advance material named functionally graded materials (FGMs). FGMs are combination of at least two materials which vary smoothly as a function of location along certain dimension(s) of the structure by considering variation of volume fraction of components [4–8]. Application of FGMs can be seen in pipes in oil and gas industry, under water equipments, aerospace instruments, storage cylinders, hollow rotating shafts and winding of composite pressure vessels and so on. Because of increasing application of FGMs and viscoelastic materials, new methodologies need to be developed to characterize, analyze and design structural components made of these materials.

A number of investigations dealing with mechanical loads like hydrostatic, dynamic as well as thermal loads have been published in the scientific literature [9–12]. In recent years, Vinogradov and Milton [9] studied the creep of a composite consist of two linear viscoelastic materials and subjected to a constant hydrostatic or anti-plane loading. Aydlner and Üstündag [10] investigated the residual stresses in a bulk metallic glass cylinder. They induced thermal tempering to the model and analyzed the stress generation. Lee [11] examined the thermomechanical response of a viscoelastic thin-walled cylinder under instant internal pressure while uniform temperature increased gradually by using a time-domain boundary element analysis. Seoudi et al. [12] solved the two-dimensional elastic wave equations of the viscoelastic cylinders to investigate the periodic deformations of the cylinders. Golden and Graham [13] studied a dynamic response of viscoelastic rolling cylinder using the non-inertial approximation. Different types of advanced materials are used for cylindrical shapes for different purpose, for example biological tissues with viscoelastic behavior in biomechanics field as well as functionally graded (FG) cylinder used in oil and gas transportation.

Many studies have been done FG cylinders due to internal pressure [14–20]. Sepiani et al. [14] studied the cylinders with combination of FG and pure material shell as inner and outer, respectively, to obtain the free vibration and buckling results while cylinders subjected to fatigue loads. Theoretical formulations were

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