Abstract

Fluid-filled elastomers find applications in soft, body wearable, electronics devices, optics, soft pressure transducers, vibration damping and impact protection. The deformation behavior of these materials is complex and would depend on elastomer properties, fluid properties, loading rate, porosity, pore size, pore shape, and pore end conditions. In this work, closed-form analytical estimates are derived for the effective behavior of a special class of fluid-filled elastomers composed of an incompressible, hyperelastic matrix having periodic and random microstructure with aligned circular pores. The pores are taken to be fully filled with incompressible, power-law fluids. The analytical estimates are validated using three-dimensional numerical simulations carried out in COMSOL multiphysics software. The analytical estimates for pressure and velocity fields in the fluid, deformation of the matrix, viscous dissipation in fluid, and stored energy in the solid match well with the results obtained from numerical simulations. In the case of Newtonian fluid-filled elastomers, for small deformations and small porosities, while the storage modulus is linearly proportional to the shear modulus of the elastomer and inversely proportional to the porosity, the loss modulus is seen to be linearly proportional to the product of loading frequency and fluid viscosity and inversely proportional to the product of porosity and square of the ratio of pore radius to pore length. The equivalent spring stiffness of the fluid-filled composite is independent of fluid behavior whereas the equivalent damping coefficient depends on applied loading frequency for power-law fluids but not for Newtonian fluid-filled elastomer. The mathematical framework is extended to estimate the behavior of fluid-filled composites under general in-plane loadings. Validation of estimates for general in-plane loadings is carried out for equi-biaxial, pure shear compression, angular shear and combined normal and shear loadings. The behavior of the composite under impact loading shows the applicability of the composite for impact mitigation. The analytical estimates for macroscopic behavior of fluid filled composites with aligned circular pores presented here can be used to design new class of materials with desired stiffness and damping by selecting appropriate elastomer stiffness, fluid viscosity, porosity, pore size and pore aspect ratio.

Keywords: Porous elastomer, Fluid-structure interaction, Homogenization, Impact protection, Constitutive modelling, Variational method