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Computational Stability Analysis of Periodic Electroactive Polymer Composites across Scales

E. Polukhov, D. Vallicotti & M.-A. Keip

Institute of Applied Mechanics (CE), Chair I, University of Stuttgart, 70569 Stuttgart, Germany

Abstract

This paper is devoted to the multi-scale stability analysis of periodic electroactive polymer composites at finite deformations. A particular focus is on the investigation of macroscopic loss of strong ellipticity and microscopic bifurcation-type instabilities. Macroscopic homogenized quantities are determined by use of computational homogenization over selected representative volume elements (RVE). The quasi-incompressible nature of the electroactive polymers is taken into account by considering a four-field variational formulation at micro-level. This formulation includes continuous interpolations of displacement fields and electric vector potentials as well as discontinuous interpolations of pressure and dilatation terms, yielding a saddle-point principle for coupled problems. Static condensation of the terms related to the element-wise constant pressure and dilatation results in a positive definite global microscopic stiffness matrix until a microscopic instability occurs. The microstructure is embedded into a macroscopic driving procedure that imposes periodic mechanical and electrical boundary conditions on the surface of the RVEs. It is known that at certain finite deformations the initial periodicity of microstructures might be altered due to microscopic bifurcation-type instabilities. To incorporate microscopic instabilities and to determine the critical periodicity of microstructures, Bloch-Floquet wave analysis in the context of a finite element discretization is implemented. The macroscopic instabilities, which are related to the long-wavelength microscopic instabilities, are determined by checking the loss of strong ellipticity at macro-scale. The proposed setting is used to study the multi-scale stability analysis of electroactive polymer composites with embedded fibers. The influence of fiber volume fraction and aspect ratio of fiber cross sections on instabilities are investigated in detail. Critical periodicities and bifurcation modes are demonstrated for selected boundary value problems.

KEY WORDS: homogenization, variational formulation, electro-mechanics, incompressibility, multi-scale stability, rank-one convexity, buckling, electroactive polymer composites

1. Introduction

Dielectric electro-active polymers (dielectric EAPs) exhibit electrostrictive response to externally applied electrostatic loading, see for example Bar-Cohen & Zhang [6]. Such phenomenon can be observed placing an elastomer between deformable electrodes. Upon application of an electric stimulus, thinning of the EAP structure in field direction and extension in transverse directions are observed. Associated materials have been experimentally explored in e.g. Kornbluh et al. [33, 34] and Pelrine et al. [57, 58].

Moreover, dielectric EAPs have advantageous properties such as light weight, fast coupled response, tractable deformation state and easiness of fabrication, see Bar-Cohen [5], Bar-Cohen & Zhang [6], Carpi [13] and references therein. These properties allow EAPs to be applied in biologically inspired engineering designs (e.g. to mimic the movement of animals and insects), as artificial muscles, and in robotics as sensors or actuators. However, due to low dielectric constants high activation fields are needed to induce large mechanical deformation. Investigations show that electro-mechanical coupling can be enhanced by tuning dielectric elastomers with fibers or inclusions of various geometrical and physical properties, see Zhang et al. [98], Huang et al. [28], Tian et al. [84], Ponte Castañeda & Siboni [61], Siboni & Ponte Castañeda [74], Lopez-