The role of fiber plasticity on the onset of macroscopic instabilities in soft biological composites

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Abstract

The main objective of this work is to shed light on the role of fiber plasticity on the onset of macroscopic instabilities in soft biological materials. For simplicity, we restrict our analysis on a class of two-phase laminates which are regarded as 2-D approximations of the actual fiber-reinforced composites of interest. We first develop a general homogenization framework, allowing for finite elastic and plastic strains in the constituent phases of the laminate, as well as for arbitrary 3-D loading conditions. This framework is then used to study the onset of long-wavelength instabilities in these composites, as captured by the loos of ellipticity (LOE) of their homogenized or macroscopic behavior. Attention is focused on plane-strain loading conditions on a plane perpendicular to the layers. For the special case of uniaxial loading along the direction of the layers, it is shown that the condition for macroscopic LOE simplifies considerably and admits the interpretation that, just like hyperelastic laminates, elastoplastic laminates loose macroscopic ellipticity when their incremental strength in shear transverse to the layers vanishes for the first time. The effect of fiber plasticity is modeled by taking the elastically stiffer phase (fibers) to exhibit elastoplastic behavior and the other phase (matrix) to be a purely elastic solid. A detailed study of the macroscopic behavior of these laminates is carried out for the case of non-monotonic loading conditions along the fiber direction, consisting of an initial tensile loading stage, followed by unloading to the macroscopically unstressed state, and a final compressive loading stage. Fiber plasticity is found to have a softening effect on the transverse shear modulus of the laminate under increasing loading and a hardening effect under decreasing loading, whereas elasticity has the opposite effects. Thus, the effects of local elastic and plastic deformations compete with each other at every stage of the deformation where both mechanisms are active, and whether or not the laminate will ultimately loose macroscopic ellipticity depends crucially on the relative strengths of these effects. It is found that macroscopic LOE may occur under positive (extensive) macroscopic strains along the fiber direction, during the compressive loading stage. It is also found that macroscopic LOE may take place under either purely elastic or elastoplastic incremental deformations, depending on the maximum strain applied during tension, the volume fraction and local material properties of the constituent phases.

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