Research paper

Modeling failure of soft anisotropic materials with application to arteries

K.Y. Volokh

Faculty of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel

ARTICLE INFO

Article history:
Published online 26 January 2011

Keywords:
Fiber-reinforced composite
Anisotropy
Soft matter
Artery
Failure
Energy limiters

ABSTRACT

The arterial wall is a composite where the preferred orientation of collagen fibers induces anisotropy. Though the hyperelastic theories of fiber-reinforced composites reached a high level of sophistication and showed a reasonable correspondence with the available experimental data they are short of the failure description. Following the tradition of strength of materials the failure criteria are usually separated from stress analysis. In the present work we incorporate a failure description in the hyperelastic models of soft anisotropic materials by introducing energy limiters in the strain energy functions. The limiters provide the saturation value for the strain energy which indicates the maximum energy that can be stored and dissipated by an infinitesimal material volume. By using some popular constitutive models enhanced with the energy limiters we analyze rupture of a sheet of arterial material under the plane stress state varying from the uniaxial to equal biaxial tension. We calculate the local failure criteria including the maximum principal stress, the maximum principal stretch, the von Mises stress, and the strain energy at the moment of the sheet rupture. We find that the local failure criterion in the form of the critical strain energy is the most robust among the considered ones. We also find that the tensile strength – the maximum principal stress – that is usually obtained in uniaxial tension tests might not be appropriate as a failure indicator in the cases of the developed biaxiality of the stress–strain state.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

The arterial wall is an anisotropic inhomogeneous structure undergoing large deformations. These features make the phenomenological modeling of the arterial wall a challenging task. Nonetheless, huge progress has been made in the constitutive theories of arteries and, in a wider perspective, of soft biological tissues: Fung (1993); Humphrey (2002); Cowin and Humphrey (2002); Holzapfel and Ogden (2003, 2006, 2010). Some issues, however, require further elaboration. Among them is a theoretical description of failure.

Two approaches to predict failure of soft materials and biological tissues are used in the literature. The first – the strength-of-materials approach – is based on a pointwise criticality condition. According to this approach, a structure is analyzed by using constitutive models that do not include a failure description – the intact material models – and failure is claimed when a local failure criterion is obeyed at a material point. There are various local criteria as, for example, the maximum von Mises stress; the maximum principal stress; the maximum strain energy etc. Evidently, the strength-of-materials approach is simple yet restrictive because the...