STATISTICAL CHARACTERIZATON OF SOFT TISSUE INELASTIC MATERIAL PARAMETERS AND APPLICATION TO THE MATERIAL FAILURE OF THE AORTIC ARCH

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Introduction

Arterial walls can be interpreted as fibre-reinforced materials composed by an isotropic ground matrix with embedded wavy collagen fibrils forming symmetric helices [Holzapfel, 2000]. The stiffening process in the stress-strain response leads to an almost infinitely rigid behaviour associated with the limit of the collagen fibrils extensibility [Fung, 1993].

The bearing capacity of the tissue is bounded and a set of degradation phenomena happen when the strains imposed to the arterial wall reach certain limit. We can assume that the degradation evolution is related with the breakdown of interactions between the collagen fibrils, the rearrangement of the fibril network or the displacement of the network junctions [Buehler, 2006]. Inelastic phenomenological models devoted to reproducing the material failure of arterial walls need to relate their material parameters with this mesoscopic, collagen fibrils degradation [Tang, 2009].

In this work we present a statistical characterization of the material parameters that rules the inelastic dissipation of a regularized damage model developed by the authors. This model is tested with the study of two boundary value problems with inhomogeneous deformation and finally is applied to the analysis of the material failure of the descending aorta.

Methods

We assume a decoupled behavior in the matrix and the fibers that allows us to express the free energy density function as:

$$\Psi = U(J) + \sum_{\alpha=m,f1,f2}(1-d_\alpha)\overline{\Psi}_\alpha \qquad (1)$$

where $\overline{\Psi}_{m,f1,f2}$ characterize the isochoric behaviour for the undamaged materials and $d_{m,f1,f2}$ are the reduction factors.

Dissipation associated with this damage model can be expressed as:

$$\mathcal{D}_{INT} = \sum_{\alpha=m,f1,f2} \dot{d}_\alpha \overline{\Psi}_\alpha \geq 0 \qquad (2)$$

This value of the dissipation can be related with the size of the finite element discretization following the smeared crack approach. This strategy allow us to regularized the material softening by introducing a new material parameter, G_f, with dimensions of superficial density of fracture energy [de Borst, 1993].

Finally, onset of the inelastic domain can be determined with the help of a threshold stress σ_u given by the uniaxial tension test.

Consequently, inelastic behaviour associated with softening is characterized by defining only two parameters $\{G_f, \sigma_u\}$ for each phase (matrix and fibres). These material parameters are fitted to data available from in-vitro experiments on human aorta samples. Axial and circumferential tensile numerical tests are performed to study the accuracy of the parameter identification.

Results

Two tests are performed to assess the capabilities of the proposed numerical approximation: the traction of a perforated plate and the inflation of a tube. Finally, the analysis of the material failure of the descending aorta is presented.

Discussion

Statistical characterization of the material parameters is a way to properly reproduce the inelastic behaviour of a material as highly hierarchical as the cardiovascular tissue. This approximation has been successfully applied to the study of the descending aorta. However, the model presents numerical instabilities that have to be overcome with careful use of the arc-length methods.

References

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