8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

Modeling of Damage Hysteresis in Overstretched Soft Biological Tissues

*** D. Balzani[1], S. Brinkhues[1], G. Sommer[2] and G.A. Holzapfel[2,3]**

[1] Institute of Mechanics
Univ Duisburg-Essen
Universitätsstr. 15
45117 Essen, Germany
daniel.balzani@uni-due.de

[2] Institute for Biomechanics
Graz Univ of Technology
Kronesgasse 5-I, 8010 Graz, Austria
sommer@TUGraz.at

[3] Dept of Solid Mechanics
School of Eng. Sciences
Osquars Backe 1, SE-100 44
Stockholm, Sweden
holzapfel@TUGraz.at

Key Words: *Biomechanics, Damage Hysteresis, Anisotropy, Overstretch, Soft Tissue, Simulation.*

ABSTRACT

A primary acute mechanism of balloon angioplasty seems to be associated with the balloon-induced overstretch of remnant non-diseased tissues in atherosclerotic arteries. The overstretch contributes to the lumen enlargement and a related numerical analysis may provide a sound platform for studying such effects. For this purpose it is necessary to model the material behavior of arterial tissues in the supra-physiological loading regime. Cyclic uniaxial tension tests indicate a distinct anisotropic softening effect along with pronounced hysteresis, cf. Fig. 1. A first isotropic approximation of damage in arterial walls is given in [5]. For the description of anisotropic damage based on the introduction of scalar-valued damage variables see [1], [2].

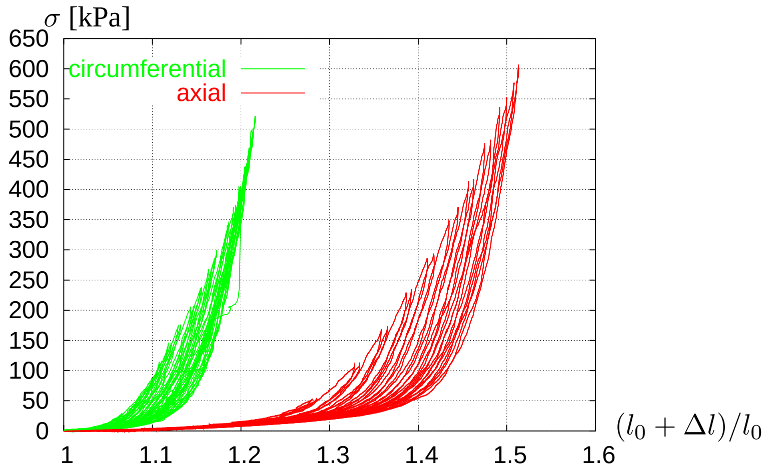

Figure 1: Cauchy stress σ in kPa vs. stretch λ for cyclic uniaxial tension of a media in circumferential (green) and axial direction (red).

In this contribution we extend the constitutive model in [2] to the ability to reflect the typical hysteresis observed in cyclic tension tests. For the representation of the physiological range of deformation we apply an anisotropic polyconvex strain-energy function, cf. [3], [4], in order to ensure the existence of minimizers and to satisfy the Legendre-Hadamard condition automatically. To account for the anisotropy the concept of structural tensors and representation theorems for anisotropic tensor functions are used, and the energy is formulated in terms of the basic and mixed invariants of the deformation and structural tensor. For the description of the anisotropic damage we assume that the softening occurs mainly in the fiber direction. Hence, we consider an additively decomposed structure of the strain-energy function, i.e. an isotropic energy for the (undamaged) non-collagenous groundmatrix and a transversely isotropic energy for the embedded collagen fiber families in which the damage model is considered. For each fiber family we use a scalar-valued damage variable and consider a saturation function which accounts for converging stress-strain curves in cyclic tension tests at fixed load levels. For the description of such saturating damage hysteresis see reference [6]. As a numerical example we consider the circumferential overstretch of an atherosclerotic artery, cf. Fig. 2.

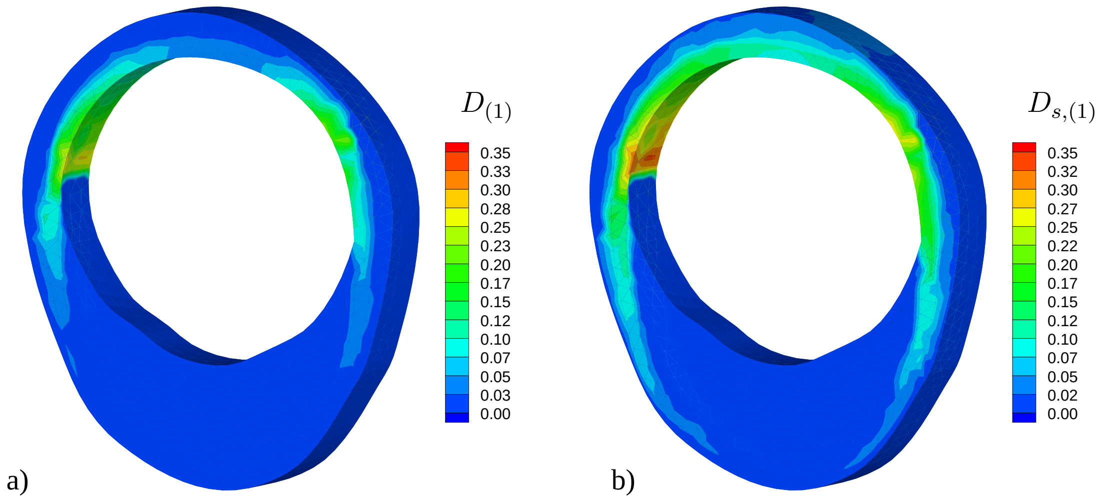

Figure 2: Deformed artery under internal pressure $p = 2760.0$ mmHg; distribution of a) damage variable $D_{(1)}$ and b) saturation variable $D_{s,(1)}$.

REFERENCES

[1] D. Balzani, J. Schröder, and D. Gross. “A Simple Model for Anisotropic Damage with Applications to Soft Tissues”. *Proceedings in Applied Mathematics and Mechanics*, Vol. **4**, 236–237, 2004.

[2] D. Balzani. “Polyconvex Anisotropic Energies and Modeling of Damage Applied to Arterial Walls”, PhD Thesis, ISBN 3-7739-6019-0, 2006.

[3] D. Balzani, P. Neff, J. Schröder, and G.A. Holzapfel. “A Polyconvex Framework for Soft Biological Tissues. Adjustment to Experimental Data”, *International Journal of Solids and Structures*, Vol. **43(20)**, 6052–6070, 2006.

[4] G.A. Holzapfel, T.C. Gasser, and R.W. Ogden. “A New Constitutive Framework for Arterial Wall Mechanics and a Comparative Study of Material Models”. *Journal of Elasticity*, Vol. **61**, 1–48, 2000.

[5] G.A. Holzapfel, A.J. Schulze-Bauer, and M. Stadler. “Mechanics of Angioplasty: Wall, Balloon and Stent”. *Mechanics in Biology*, AMD-Vol. **242**, BED-Vol. **46**, 141–156, 2000.

[6] C. Miehe and J. Keck. “Superimposed Finite Elastic-Viscoelastic-Plastoelastic Stress Response with Damage in Filled Rubbery Polymers. Experiments, Modeling and Algorithmic Implementation”. *Journal of Mechanics and Physics of Solids*, Vol. **48**, 323–365, 2000.