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ANSYS® Customization: User Programmable Features

USERMAT: Implementation of an Anisotropic, Hyperelastic Material Law for Soft Biological Tissues

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Task

In ANSYS, the User Programmable Features (UPF) are a very powerful tool for customizing and extending the program behavior. Besides UserFunctions, UserElements and a lot more, the programming of own material models is the most popular application. As an example, the implementation of a model for soft biological tissues is shown on the right side.

Solution

Human soft tissues often show a fiber reinforced (hyper-) elastic behavior. The reinforcement is due to the wavy structure of collagen fibrils. Fiber directions can be obtained from histological sections. For arterial walls, Holzapfel [1] proposed an anisotropic strain energy function of the type

$$\Psi(\mathbf{C}, \mathbf{A}_{01}, \mathbf{A}_{02}, J) = \overline{\Psi}_{iso}(\bar{I}_1, \bar{I}_2) + \overline{\Psi}_{aniso}(\bar{I}_4, \bar{I}_6) + \Psi_{vol}(J)$$

introducing the structural tensors

$$\mathbf{A}_{01} = \mathbf{a}_{01} \otimes \mathbf{a}_{01} \quad , \quad \mathbf{A}_{02} = \mathbf{a}_{02} \otimes \mathbf{a}_{02}$$

and extending the invariant basis according to

$$\bar{I}_4\left(\overline{\mathbf{C}}, \mathbf{a}_{01}\right) = \overline{\mathbf{C}} \cdot \mathbf{A}_{01} \quad , \quad \bar{I}_6\left(\overline{\mathbf{C}}, \mathbf{a}_{02}\right) = \overline{\mathbf{C}} \cdot \mathbf{A}_{02}$$

A special form of the strain energy function $\overline{\Psi}_{aniso}$ is used to account for the exponential fiber behavior in tension:

$$\overline{\Psi}_{aniso}(\bar{I}_4, \bar{I}_6) = \frac{k_1}{2k_2} \sum_{i=4,6} \left\{ \exp\left[k_2\left(\bar{I}_i - 1\right)^2\right] - 1 \right\}$$

The constitutive law allows each arterial layer to be modeled as a fiber reinforced composite with two independent fiber directions. The implementation in ANSYS was done by the USERMAT-interface and is based on the deformation gradient **F**. By means of state variables, a detailed postprocessing is possible: matrix- and fiber stresses, fiber stretches et cetera.

Benefit for the customer

User defined materials allow a precise adaptation and a more realistic description of material behavior in numerical analysis. This is an attractive option if no standard material law can be applied.

[1] Holzapfel, G.A.; Gasser, T.C.; Ogden, R.W.: *A new constitutive framework for arterial wall mechanics and a comparative study of material models.*

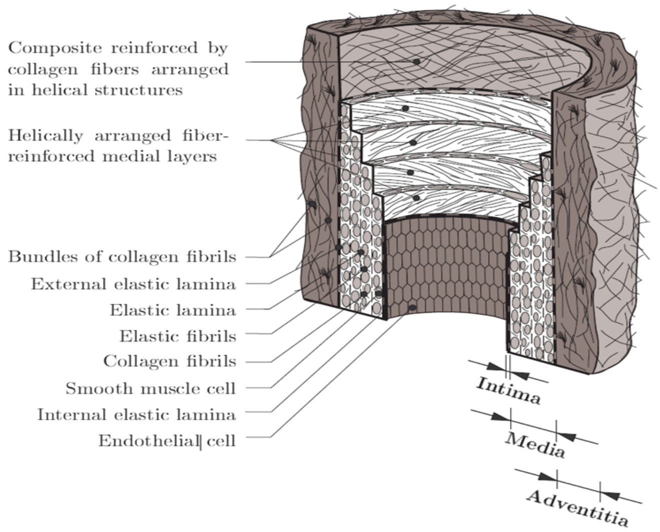

Fig. 1: Components of an elastic arterial wall: Intima, Media and Adventitia.

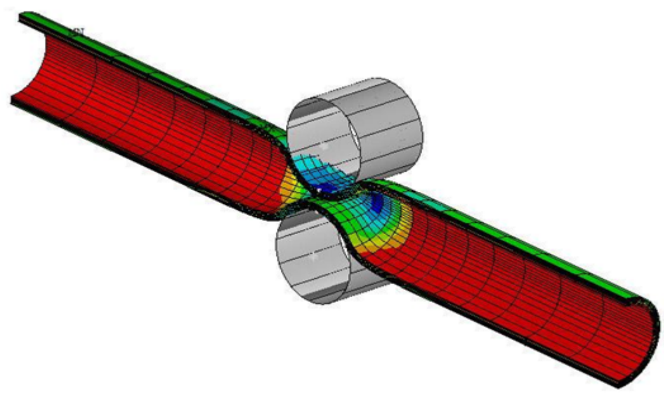

Fig. 2: Elastic Behavior of an artery during clamping.

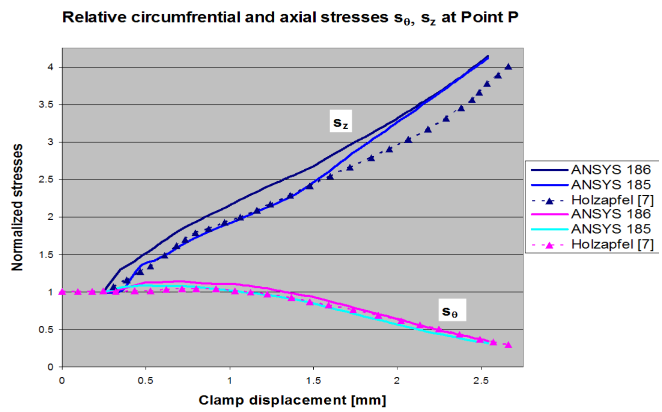

Fig. 3: Raise of factor in axial stresses