On the mutual coupling of viscoelasticity and the Mullins effect

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Abstract

It is generally accepted that soft biological tissue shows inelastic material behavior, such as viscoelasticity and loss of stiffness after primary loading, akin to the Mullins effect in rubber. Recently, there has been experimental evidence suggesting a coupling of these rate-dependent and damage-related effects in porcine thoracic aorta (1). Two observations in favor of this hypothesis are (i) rate-dependent equilibrium relations and (ii) considerable differences in viscous dissipation between loading to unloading.
With respect to continuum-mechanical modeling, thermodynamically-consistent formulations of anisotropic viscoelasticity at finite strains can be achieved with and without a multiplicative split of the deformation gradient, cf. (2) and (3), respectively. However, by definition, these approaches do not include damage-related effects. Regarding the latter, a wide-spread description for the Mullins effect has been proposed by (4) and popularized by (5). Here, the rate of deformation does in turn not influence the magnitude of damage, since the initial material response is taken to be purely elastic. As is often the case when modeling different sources of dissipation, one can superpose these two inelastic effects without truly coupling the phenomena, e.g., cf. (6). Consequently, the material response might allow for both viscous and damage-related dissipation, but rate-dependent equilibrium hystereses remain nonetheless impossible.

We attempt to address these deficiencies by extending the damage model of (4) to initially viscoelastic materials. This leads to a set of simple expressions which can straightforwardly be brought into line with the dissipation inequality, while still allowing for a wide range of possible material behaviors. We then discuss the consequences of this mutual coupling both from a purely theoretical point of view and with respect to experimental data from aortic and gastric porcine tissue.

References:

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