A Microstretch Approach for Modeling the Large Deformation Thermoviscoelastic Behavior of Liquid Crystal Elastomers.

Thao (vicky) Nguyen*†[1]

[1]Johns Hopkins University – United States

Abstract

Liquid crystal elastomers (LCEs) exhibit complex thermomechanical behaviors that can be exploited for a wide variety of applications in soft robotics, biomedical devices, and impact and vibration protection. Monodomain nematic elastomers (MNEs) undergo orientational ordering when cooled below the nematic-isotropic transition temperature and in response to mechanical loading. For main-chain MNEs, where the mesogens are located in the polymer backbone, mesogen ordering produces a large anisotropic shape change and a semi-soft stress response to large deformation. Furthermore, the soft behavior of the mesogens provided nematic elastomers with enhanced viscoelastic dissipation, compared to conventional elastomers, over a wide range of frequencies, strain rates, and temperatures. Predictive modeling is needed to efficiently design and optimize LCE structures to achieve the desired performance to fully leverage the potential of nematic elastomers. This presentation will describe our recent efforts to develop a finite deformation viscoelastic microstretch model for MNEs. The nematic microstructure is represented in the model as an order tensor, characterized by a director orientation for the mean alignment direction of the mesogens, an order parameter for the degree of alignment along the director, and a biaxiality parameter to indicate a secondary alignment of mesogen in the plane perpendicular to the director. The director orientation can rotate, and order parameters and biaxiality parameters can stretch independently of the deformation gradient. We further assume that the stress couple tensor response to the director microrotation and microforce vectors response to the microstretch of the order parameter and biaxiality parameter can be decomposed additively into elastic and viscous parts. The stress response of the network can also be decomposed additively into equilibrium and nonequilibrium parts. Following the Coleman and Noll procedure, we developed thermodynamic restrictions for the constitutive relations for the stress, stress couple, and micro-stretch force vectors. The model reduces to the finite deformation viscoelastic micropolar model developed in prior work. Finally, we applied the model to study the time-dependent and rate-dependent effects of the spontaneous stretch behavior of the nematic-isotropic temperature transition and rate-dependent uniaxial tension behavior.

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*Speaker

†Corresponding author: vicky.nguyen@jhu.edu