Viscoelastic soft elasticity of nematic liquid crystal elastomers in tension and compression

Leila Rezaei[1], Sahar Riazi[1], Giulia Scalet[2], Michaël Peigney[3], and Aurélie Azoug[*†1]

[1]Oklahoma State University [Stillwater] – United States
[2]Università degli Studi di Pavia = University of Pavia – Italy
[3]Laboratoire Navier – Université Paris-Est, Ecole des Ponts ParisTech, IFSTTAR – France

Abstract

Liquid Crystal Elastomers (LCEs) are a class of smart elastomers where the polymer chains forming the network include mesogenic molecules, *i.e.* the liquid crystals, attached as side groups or included in the backbone. Their mechanical response then combines the elasticity of the polymer network with the orientation and disorientation of the mesogens. As a result, LCEs are effective actuators, exhibiting an isochoric, reversible contraction strain of up to 180 % when triggered by a stimulus, for example heat or light, due to the mesogens disorienting from the nematic (ordered) to the isotropic (disordered) phase. In the nematic phase, LCEs exhibit soft elasticity, meaning they show an increase in strain at constant stress as the mesogens reorient themselves in the direction of the mechanical stretch. In compression, mesogens orient planarly rather than uniaxially, which is not necessarily associated with soft elasticity. Additionally, LCEs dissipate more energy than equivalent traditional elastomers. These nonlinear behaviors indicate a strong coupling between the movements of the polymer chains and the tendency of the mesogenic parts to form intermolecular ordered structures.

We focus on the viscoelasticity of LCEs during the soft elasticity phenomenon, leading to coupled time-dependent relaxation mechanisms and significant damping. We measured the rotation of the mesogens during stretching via polarized Raman spectroscopy and Nuclear Magnetic Resonance. We developed a finite strain phenomenological constitutive model of the viscoelastic soft elasticity of LCEs, inspired by the Souza-Aurrichio plasticity model dedicated to the superelasticity of shape memory alloys. Material parameters are fitted to dynamic mechanical analysis master curves as well as uniaxial tensile and compression experiments at multiple strain rates.

Experimental results show the increase in order parameter during stretching at different strain rates. The model predicts the change in modulus before, during, and after the soft elasticity region in tension and the change in modulus in compression. We investigate the coupling between relaxation mechanisms and soft elasticity, showing that the long-time mechanisms are coupled to the soft elasticity while the short-time mechanisms are decoupled. The threshold stress determining the onset of the soft elasticity is time-dependent but the viscosity of the mesogen rotation is negligible.

---

[*]Speaker

[†]Corresponding author: azoug@okstate.edu