The thermomechanical behavior of glassy polymers: applications to modeling shape memory behavior and 3D-printed polymers

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Vicky Nguyen
Johns Hopkins University

Glassy polymers are amorphous polymers that have been driven out of equilibrium by cooling to below the glass transition temperature and thus experience a wide range of time-dependent and temperature-dependent mechanical behavior. In the nonequilibrium state, the polymer chains continue to slowly rearrange towards a lower entropy state. This process causes physical properties, such as the viscosity, yield strength, and enthalpy, to change with time in a process commonly referred to as physical aging or structural relaxation. Physical aging can be reversed by plastic deformation, which moves the material further away from equilibrium. This mechanical rejuvenation process is also responsible for post-yield dynamic softening observed in the stress-strain behavior glassy polymers, the extent of which determines the toughness and failure response of the material. Though structural relaxation and viscoplasticity are interdependent phenomenon, they have been treated as separate processes and described by different theoretical approaches. I will present a new theory that strongly couples both viscoplasticity and structural relaxation through an effective temperature thermodynamic framework. Using this framework, we developed a new unifying thermomechanical theory for amorphous polymers that describes a wide range of nonequilibrium phenomena, including the glass transition, viscoplasticity, physical aging, mechanical rejuvenation, and orientation hardening, using a common set of physically measurable parameters. I will also present applications of the theory to two problems that require this unified thermomechanical description: predicting the shape memory behavior of amorphous polymers for morphing and deployable structures and modeling the mechanical behavior of polymers printed by fused deposition modeling.

Thao (Vicky) Nguyen received her S.B. from MIT in 1998, and M.S. and Ph.D. from Stanford in 2004, all in mechanical engineering. She was a research scientist at Sandia National Laboratories in Livermore from 2004-2007, before joining the Mechanical Engineering Department at The Johns Hopkins University, where she is currently a tenured associate professor and the Marlin U. Zimmerman Faculty Scholar. Dr. Nguyen's research encompasses the biomechanics of soft tissues and the mechanics of active polymers and biomaterials. Dr. Nguyen has received the 2008 Presidential Early Career Award for Scientists and Engineers (PECASE) and the NNSA Office of Defense Programs Early Career Scientists and Engineer Awards for her work on modeling the thermomechanical behavior of shape memory polymers. She received the 2013 NSF CAREER award and 2016 JHU Catalyst Award to study the micromechanisms of growth and remodeling of collagenous tissues. She was also awarded the inaugural Eshelby Mechanics Award for Young Faculty, the ASME Sia Nemat-Nasser Early Career Award both in 2013, and the ASME Applied Mechanics Division T.J.R. Hughes Young Investigator Award in 2015.

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