LMS Seminar

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Constitutive Modeling of Strain Rate Sensitive Polymeric Gels and Biological Tissues

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ABSTRACT

A comprehensive experimental and analytical modeling effort is carried out to capture the visco-hyperelastic response of soft materials. The commonly used thermodynamic dissipation-based models utilize strain energy density and dynamic viscous dissipation potentials, and have been studied to describe short-time memory responses of soft materials for over two decades. In this study, it is demonstrated that the existing forms of viscous dissipation potential in the literature do not capture strain rate dependence of elastic moduli and Poisson's ratio, a phenomenon which has been experimentally observed in many soft tissues and polymeric gels. To capture the overall response of these materials, the current work is carried out in two phases: First, a generalized thermodynamic stability criterion for isotropic finite elastic solids is derived using the fundamental balance laws and field equations of continuum mechanics, which is then used to formulate constitutive inequalities for the polynomial forms of hyperelastic constitutive equations. It is shown that the model constants of a hyperelastic constitutive model should fall within a domain called the Region of Stability (ROS) for all three primary deformation modes, i.e., uniaxial compression, uniaxial tension and shear. It is then shown that experimental data from only a particular deformation mode of deformation may not capture the complex behavior of a material under multiaxial state of stress for hyperelastic materials and hence data must be captured from all three deformation modes to obtain a realistic constitutive behavior. Second, a novel generalized viscous dissipation potential form is proposed, which not only captures strain rate sensitivity, but also consists of physically-based model parameters that relate to the material's strain rate sensitivity behavior. The proposed viscous dissipation potential is combined with standard polynomial-based hyperelastic strain energy density function to define visco-hyperelastic constitutive equation, which is then used to model quasi-static to high strain rate response of soft materials such as hydrogel, ballistic gelatin, human patellar tendon, porcine brain tissue. Finally, challenges of conducting simple shear experiments on hyperelatic materials are highlighted. The robustness of constitutive model for capturing deformations under complex loads such as wedge-indentation and high velocity long-rod impact on a rigid surface are demonstrated.

BIOGRAPHY

Professor Ghatu Subhash obtained his PhD from University of California San Diego in 1991 and conducted his post-doctoral research at California Institute of Technology. He is Newton C Ebaugh Professor in Mechanical and Aerospace Engineering at University of Florida. His research focuses on multiaxial behavior of advanced ceramics, metals, composites, gels and biological materials. In 2024, he received the Murray Medal from the Society of Experimental Mechanics and the James I. Mueller Memorial Award from the American Ceramic Society. Prof. Subhash is the Editor-in-Chief of Mechanics of Materials and an Associate Editor of Journal of the American Ceramic Society.