Computational Modeling of the Deformation and Failure of Soft Materials

Chad M. Landis, Professor, ASE/EM

Abstract: The goal of the proposed research is to develop constitutive models and computational methods for the analysis of soft materials for biomedical and biomaterials applications. These investigations will be focused on two areas of recent collaboration with colleagues, (a) computational modeling of magneto-active polymers and hydrogels for biological testing platforms, and (b) computational modeling of failure in soft reinforced materials with applications towards failure of collagenous tissues. Biological cells and tissues often have functionalities that are either dictated or affected by their mechanical environment. Alterations in the mechanical environment can lead to cell damage, and cell damage can lead to microstructural changes that manifest as changes in mechanical properties. Computational models of many biological processes, from tumor growth to healing of bones, require detailed constitutive models that have parameters that must be determined from experiments. Magneto-active polymers (MAPs) have been proposed as a testing platform that will allow for remote magneto-mechanical stimulation of biological tissues. The design of these stimuli-responsive MAPs is complicated by the combination of nonlinear mechanical behavior, rate dependence, the magnetic response, and solvent diffusion processes. To aid in the understanding of the magneto-mechanical behavior of these materials, their design and optimization, a general continuum framework to couple magnetics, solvent diffusion, and nonlinear mechanics will be developed. The computational framework will be used to guide the design and interpretation of cell-level mechanical experiments. The second area is to develop computational models to simulate the failure of fiber reinforced hydrogels, which are relevant to soft collagenous tissues. These models will vary in their treatment of the reinforcing fibers depending on the scale of interest. To gain an understanding of the mechanics of fiber failure, load transfer, and damage tolerance in soft materials, one model will represent fibers explicitly and simulate how fiber breaks can initiate damage in the surrounding matrix, transfer load to other fibers, and ultimately cause local damage to evolve in a small ensemble of fibers. At a larger scale to model macroscopic crack formation and propagation, the fiber reinforcement will be modeled as fiber families each with their own fiber structure tensors. A phase-field damage parameter will then represent damage in the fiber families that can also propagate and evolve in the gel matrix. This modeling approach will be applied to investigate the fracture and tearing of layered biomembrane structures, e.g. the fetal membrane.