Society of Engineering Science 51st Annual Technical Meeting

1–3 October 2014

Purdue University, West Lafayette, Indiana, USA

Coupled Eulerian–Lagrangian extended finite element approach to simulating the mechanics and growth of biofilm, cells, and tissues

Duddu, Ravindra; Aryal, Anup, Vanderbilt University, United States; Foucard, Louis; Vernerey, Franck, University of Colorado, Boulder, United States

ABSTRACT

Simulating the mechanics and growth of soft biological and biomimetic materials (e.g., hydrogels, fibroblast-ECM system, biofilm evolution, cell protrusion, spreading of a cell nucleus) requires coupling large deformation solid mechanics with fluid mechanics, advective-diffusive transport, growth, and the evolution of embedded phase/material interfaces. The standard Lagrangian finite element approach suffers from numerical issues due to excessive mesh distortion and mesh-moving/remeshing algorithms can be cumbersome; therefore, there is a need for more robust and efficient numerical approaches. An Eulerian finite element approach that allows the material to move against the numerical mesh does not suffer from mesh distortion issues; so, it may be advantageous; however, specialized techniques are required for capturing the evolution of the phase interfaces or domain boundaries.

In this presentation, we first present a Lagrangian solid mechanics formulation for studying the mechanics of a linear elastic biofilm to motivate the need for the proposed Eulerian approach. Next, we briefly describe the coupled Eulerian–Lagrangian extended finite element method (XFEM) for modeling the moving interface problem associated with finite deformation of isotropic hyperelastic materials. This formulation is based on the Eulerian description of motion and on the updated Lagrangian description for the transport of the isochoric part of the deformation gradient and of the Jacobian determinant, separately. The XFEM is used to discretize the equilibrium and transport equations in a two-phase medium. A mixed interpolation scheme (biquadratic for velocity and bilinear for Jacobian determinant and the isochoric part of the deformation gradient) is adopted to improve the stability and accuracy of the numerical formulation. A variational multiscale residual-based approach is employed to stabilize the formulation for flow problems. The two-phase interface is represented by the level set function and is evolved using the grid based particle method. The performance of the scheme is explored in two dimensions in the compressible and nearly incompressible regime. Our numerical results for benchmark examples involving: (i) uniaxial tension and simple shear flow are in agreement with theoretical results; and (ii) indentation of a rectangular block is in agreement with those from a Lagrangian finite element implementation in Abaqus. We believe the method can be used to better characterize biological materials and to explain physical mechanisms in conjunction with experiments.