Mechanics of Polymeric Porous Membranes Using Stabilized Extended B-Spline Material Point

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Polymeric porous membranes are crucial in water purification, filtering contaminants to ensure clean water. However, they often break under operational pressures due to a limited understanding of their mechanical behavior. These membranes feature macro-voids and a micro-porous structure, with these complex, hierarchically porous geometries significantly influencing their mechanics. When exposed to mechanical pressure, large strains develop near the pores, causing geometric instabilities like self-contacting creasing. Understanding the role of this multi-scale porous structure and the resulting instabilities under significant incompressible deformations presents major challenges. Additionally, developing predictive simulation tools that can accurately capture these deformations remains difficult.

The key focus of this presentation is to demonstrate an elegant computational framework for modeling polymeric membranes with double porosity using an implicit mixed B-spline Material Point Method (MPM). Double porosity is created by generating macroscopic voids and introducing micro-porosity through the selective removal of material points, and we verify our approach with examples compared against analytical homogenization constitutive equations. To mitigate volumetric locking due to material incompressibility, we propose an efficient subdivision-stabilization for the two-field **u**-p formulation [1], along with the corresponding Nitsche method for imposing essential boundary conditions. Additionally, using an extended B-spline framework, we address ill-conditioning caused by numerical cut-cell instability by interpolating mixed displacement and pressure fields from near boundaries to the interior degrees of freedom. Finally, to capture mechanical instabilities, we develop and showcase a stability analysis framework for MPM based on tracking the signature of the stiffness matrix. Through this comprehensive approach, we believe the proposed methodology provides a robust computational foundation to model and understand the behavior of hierarchically porous polymeric membranes, ultimately achieving better mechanical properties.

Keywords: Material Point Method, Subdivision Method, B-Spline, Nitsche method, Cut-cell instability, Mechanical instabilities, Porous membranes

[1] A. A. Madadi, B. Dortdivanlioglu, A subdivision-stabilized B-spline mixed material point method, Computer Methods in Applied Mechanics and Engineering 418 (2024) 116567. doi:10.1016/j.cma.2023.116567