Frictional Contact in an Eulerian Phase-Field Framework

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Abstract

Traditional approaches to contact modeling – and solid mechanics in general – primarily rely on Lagrangian frameworks. While effective for systems with fixed domains, these methods encounter significant challenges when addressing dynamic or evolving surfaces, such as growing biofilms, emerging crystal precipitates, or other multiphysical problems where changes in geometry induce contact and mechanical loading. Eulerian frameworks have re-emerged as a promising alternative, offering a unified description of interface dynamics and the mechanical problem.

In this work, we incorporate friction in an Eulerian framework. We use a diffuse phase-field representation of solids, the reference-map technique for modeling elasticity, and apply penalty-based body forces for both normal and tangential traction components. Each solid is represented by its own set of field variables, enabling straightforward detection of overlapping regions. Frictional interactions are captured through the local slip rate, derived from velocity differences between the two solids, and used to implement a frictional contact law. Besides the known advantages of a Eulerian description, this framework avoids the need for explicit contact tracking, making it particularly well-suited for problems involving complex and evolving geometries.

We demonstrate the implementation using a simple Coulomb friction law and validate it by a comparison with the analytical Cattaneo-Mindlin solution. The results show the framework's ability to accurately capture the tangential traction profile, distinguish between stick and slip regions, and reproduce history-dependent energy dissipation via hysteresis loops. We include additional examples involving large sliding scenarios and frictional interactions under significant deformations, highlighting the robustness and versatility of the method.

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In conclusion, this Eulerian phase-field framework provides a streamlined, adaptable solution for modeling interfacial interactions that are coupled with multiphysical phenomena such as growth. By leveraging the inherent strengths of the Eulerian description – including simplified contact detection and compatibility with evolving interfaces – we broaden the applicability of computational contact mechanics to holistically model an array of new systems. This work lays a foundation for further exploration of frictional contact phenomena in multiphysical settings, with potential applications in the study of biological growth patterns or corrosive damage in concrete.