Investigation of crack propagation in multi-layered media using an adaptively refined phase-field approach

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Fracture propagation in layered subsurface media is actively studied by engineers, and geoscientists. In various geo-engineered systems, such as, unconventional hydrocarbon reservoirs, enhanced geothermal systems, tunnels, and mines, fracture patterns in the subsurface play a critical role. Predictive numerical simulations are an essential tool to facilitate well-designed subsurface systems. However, despite significant advances in recent years, numerically predicting fracture propagation in the subsurface remains an outstanding challenge for the computational mechanics community [1]. This is partly because the subsurface is highly heterogeneous and contains several layers with distinct mechanical properties. The presence of these heterogeneities significantly affects the propagation of fractures in the subsurface. Depending on prevailing conditions of contrasts in elastic moduli, fracture toughness, layer thickness and in-situ stress of surrounding layers, cracks may either arrest, penetrate, or branch at the material interface [2]. Furthermore, the interface strength also plays a crucial role in the eventual crack topology in the subsurface.

In this study, we used an adaptively refined phase-field framework of Muixì et al. [3], originally developed for homogeneous materials, to investigate various failure mechanisms in layered materials. Firstly, we simulated three layered models without pre-existing flaws and with mismatch in mechanical properties (such as elastic stiffness mismatch and fracture toughness mismatch) under tensile loading. Through these models, we study the effect of heterogeneous mechanical properties on the competition between crack penetration and branching at the layer interface. Secondly, we vary the thickness of the sandwiched layer to examine its effect on the crack patterns in the middle layer. Thirdly, we studied the combined effect of confining pressure and material mismatch on crack nucleation and delamination along the layer interface. Finally, we examine the effect of weak interfaces on crack deflection and penetration at layer boundaries. We incorporate interface weakening in our model by adding interface energy term to the bulk elastic and fracture energy contributions following Kuhn and Muller [4]. The outcomes of this numerical study provide valuable insight into the various failure mechanism in multi-layered systems.

References

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