On Flow and Failure – Pattern Formation from Instabilities in Complex Fluids

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The invasion of one fluid into another of higher viscosity is unstable in a quasi-two dimensional geometry. In isotropic systems, this viscous-fingering instability typically produces complex patterns that are characterized by repeated branching of the evolving structure, which leads to the common morphologies of fractal or dense-branching growth. In anisotropic systems, in contrast, the growth morphology changes to a highly ordered dendritic growth characterized by stable needle-like structures. We investigate such morphology transitions between dendritic growth and dense-branching growth in an intrinsically anisotropic liquid; a lyotropic chromonic liquid crystal in the nematic phase. We show that the transition is remarkably sensitive to the interface velocity and the viscosity ratio between the less-viscous inner fluid and the more-viscous outer liquid crystal. We discuss the importance of a stable shear alignment of the liquid crystal in governing the morphology transition to dendritic growth.

Expanding our work to more complex fluids, dense suspensions that exhibit both shear-thickening and shear-jamming behavior as a response to an applied stress allows us to probe transitions from flow instabilities to fracture instabilities. Displacing a cornstarch suspension by a pressure-controlled injection of air, we observe a variety of patterns: smooth fingering in the fluid regime and different modes of fracture, ranging from slow branched cracks to single fast fractures. We show how both the rheological state of the suspension and the confinement induce a transition to fracture, and discuss strategies to predict and control these different failure modes in dense suspensions.