

Mechanical Engineering Doctoral Defense

Effects of Phase Transformations and Dynamic Material Strength on Hydrodynamic Instability Evolution In Metals

School for Engineering of Matter, Transport and Energy

Saul Opie

Advisor: Pedro Peralta

abstract

Hydrodynamic phenomena such as the Rayleigh-Taylor (RT) and Richtmyer-Meshkov (RM) instabilities can be described by exponential/linear growth of surface perturbations at a bimaterial interface when subjected to constant/impulsive acceleration. A challenge in designing systems to mitigate or exploit these effects is the lack of accurate material models at the large dynamic strain rates that often occur during the instability evolution. In particular, little stress-strain constitutive information at large strain rates and pressures is available for transient material phases formed at high pressures, and the continuum effect the phase transformation process has on the instability evolution. In this work, a phase-aware isotropic strength model is developed and partially validated with a novel RM-based instability experiment in addition to existing experimental data from the literature. With the validated material model additional simulations are performed to provide insight into the role that robust material constitutive behavior (e.g., pressure, temperature, rate dependence) has on RM instability and how RM instability experiments can be used to characterize and validated expected material behavior. For phase aware materials, particularly iron in this work, the simulations predict a strong dependence on the Atwood number that single phase materials do not have. At Atwood numbers close to unity the high pressure phase dominates the RM evolution provided the pressure is well into the high pressure stability region. However, at the opposite spectrum of Atwood numbers, close to negative one, the RM evolution is only weakly affected by the high-pressure phase even for shocks well above the phase transformation threshold. In addition to RM evolution we also look at the closely related shock front perturbation evolution. Existing analytical models for isentropic processes in gases and liquids are modified for metal equation of states and plastic behavior for the first time. It is found that the presence of a volume collapsing phase transformation with increased pressure causes shock front perturbations to decay sooner, while plastic strength has the opposite effect which is significantly different from the effect viscosity has. These results suggest additional experimental setups to validate material models, or relevant material parameters that can be optimized for system design objectives, e.g., minimize feed through perturbations in inertial confinement fusion capsules.

May 31, 2017; 1:00PM; ERC 593