Hypervelocity impact and fragmentation of brittle materials

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Introduction

- Material is said to be under extreme environment if it undergoes large pressure and temperature changes over a short period of time.
- High velocity impact is a typical example of extreme environment where shock waves are generated in the material.
- Extreme environments are found in planetary collisions, micrometeorite impact on satellites, ballistic impact, and even day to day environments like crashes and collisions.
- We study shock wave propagation brittle materials.

EOS and evolution laws

- The equation of state or the constitutive law comprises of a bulk part, a shear part and a thermal part.
  \[ \varepsilon(B, I, E, J) = \frac{2}{3} \left( \eta^2 - 1 \right)^2 + C_0 T_0 \theta(\eta) (\varepsilon^2 - 1) + 2 b_2(\eta) e \]
  where \( \eta \) and \( e \) are functions of invariants of strain.
- The evolution of damage is prescribed by a Grady-Kipp evolution law, \( F_d = \sqrt{1 - D} \left[ I_3 \right] \), where \( \frac{d\varepsilon}{dt} = (m + 3)\alpha_2 \frac{e}{\varepsilon^{m/3}} \).
- The inelastic deformations are governed by a plastic evolution law
  \[ L_p = \lambda_p \text{ dev} \Sigma / ||\text{dev} \Sigma|| \]
  where \( \lambda_p = \lambda_0 \exp \left( \frac{1}{\gamma} \left( \frac{\rho_0}{\rho} \frac{F(T)}{F(0)} - 1 \right) \right) \)
- The yield strength and shear modulus of the material is influenced by the pressure in the material.
- The moduli, \( \alpha_2 \) and \( b_2(\eta) \) degrade with damage in the system.

Brittle materials

- Geological materials: rocks, ice, etc.
- Infrastructural materials like concrete and glass.
- General progression of damage:
  - Void and microcrack nucleation
  - Growth and propagation of microcracks under mode I loading
  - Coalescence of microcracks to form bigger cracks.
- Under shock loading, the progression of damage is violent and catastrophic.
- This is called dynamic fragmentation.

Continuum Damage Mechanics

- We use the ideas of Continuum Damage Mechanics (CDM) to model damage within the system.
- Here the damage is introduced as an auxiliary configuration along with damage tensor \( F_d \).
- \( F_d \) degrades the moduli of the material in its equation of state \( \varepsilon = \varepsilon \left( B_u, a(B_u) \right) \), \( B_d = F_d F_d^T \)

Results

- Impact of an Aluminum sphere on Basalt sphere.
- Aluminum is purely elastic while Basalt has high plastic yield strength with Grady Kipp fragmentation model.

References


Future Work

- Degradable yield strength \( Y_p = (1 - D) Y_i + D Y_d \), where \( Y_i \) and \( Y_d \)
  denote yield strength of intact and damaged material.
- \( Y_i = Y_i + \mu p / (1 + (\mu p/\gamma_d) - Y_d) \) and \( Y_d = \mu p \)
- Combined tensile and shear damage \( D_t = D_s + D_d \)
- \( D_t \) is governed by Grady-Kipp law and \( D_s \) depend on plastic strain evolution in the material.
- Stochastic anisotropic damage laws (DFH)
  \[ \frac{dn_{i-1}}{dt^{n-1}} + 1 \frac{dD_i}{dt} = \lambda_i \left( \frac{\rho_0}{\rho} \frac{F(T)}{F(0)} - 1 \right) \]
- Gradient damage for regularization and avoiding damage localization
  \[ E_{\text{new}} = E + \frac{70}{12} \left( |V| - |D| \right)^2 \]
- Viscoelasticity and phase transitions: \( F_i = F_i F_i \) where \( F_i \) is inelastic deformation tensor associated with viscoelasticity and phase transitions.
- Shock induced phase transitions and long time effects such as viscoelastic behavior will be included.

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