Modeling the Transition from Fracture to Granular flow

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Technical Approach

• Relate stresses, crack growth and fragment distributions to strain rate
• Calibration for boron carbide
• Develop discrete particle-based model of brittle solids that can treat control elastic response and mode of failure
• Use results to calibrate and validate continuum models
• Advantages of particle based model:
  - Unrestricted geometry of crack growth
  - Damaged regions fully elastically coupled
  - Arbitrary loading stresses and rates
  - Arbitrary initial defect distribution

Materials-by-Design Process

Mechanism-based Approach

Key Accomplishments

• Demonstrated control of elastic and plastic material properties
• Characterized model material properties, for $k = 0$:
  - Ratio of bulk to shear modulus $\sim 0.33$
  - Velocity of crack growth $\sim 0.37$ Rayleigh speed
  - $K_{IC}/K_{IC} \sim 1.3$
• Generated wing crack growth in response to uniaxial loading in the limit of weak mode 1 fracture toughness
• Found preliminary results for rate dependent fragmentation in granular flow

Advantages of particle based model:

- Add angular springs, tune stiffness
- Create network of breakable, attractive bonds representing coarse grained spatial regions
- Evolve grain size distribution and particle size evolution calibrate and test continuum model of granular flow (Cil, Graham-Brady)
- Studies of rate-dependent particle size evolution calibrate and test continuum model of granular flow
- Comparing simulations of cement sample with known structure to experimentally measured fracture and stress distributions to determine mechanisms (Hurley)

Major Results

- Evolution of grain size distribution can be fully tracked as a function of strain
- Fracture pattern after 100% strain can identify strain-rate dependent length scale in resulting granular fragment size
- Can control elastic response to match properties of boron carbide
- Uniaxial compression of pre-cracked system – vary $k$ to transition from shear crack growth to wing cracking

Transitions to ARL, within CMRG and to other CMRGs

• Microstructural data of boron carbide samples from ARL allowed us to start from real defect distributions
• Simulations of 3D wing crack growth and realistic defects provide input for continuum models of fragmentation based on damage measures and crack interactions (Bhattacharjee, Graham-Brady)
• Studies of rate-dependent particle size evolution calibrate and test continuum model of granular flow
• Comparing simulations of cement sample with known structure to experimentally measured fracture and stress distributions to determine mechanisms (Hurley)

Impact

• Transition between fracture and fragmentation and granular flow is of great importance in characterizing the ultimate performance of brittle materials in extreme environments, including Army specific application of boron carbide impact tests
• Better understanding of physical processes, such as 3D wing crack growth or the dynamics of comminution, helps to motivate a more physically realistic integrative model
• The ability to model a generic, brittle material with adjustable fracture toughness and elastic response has broader applications to ceramics

Key Goals

- Develop discrete particle-based model of brittle solids that can treat the transition from a defected solid to a fractured system undergoing granular flow with realistic geometrical complexity
- Calibrate model for boron carbide
- Relate stresses, crack growth and fragment distributions to strain rate and initial defect distribution and compare to experiment (Sun, Cil)
- Use results to calibrate and validate continuum model (Bhattacharjee, Cil) that feed into the integrated model (Zheng)