Potential-Based Dynamic Fracture Simulation with Adaptive Topological Operators

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Research Objectives

- Develop the potential-based constitutive model for mixed-mode cohesive zone modeling
- Employ the extrinsic cohesive zone model for dynamic fracture and branching problems
- Develop systematic adaptive mesh refinement and coarsening (AMR+C) schemes for dynamic cohesive fracture simulation
- Employ adaptive topological operators such as nodal perturbation, edge-swap, edge-split and vertex removal

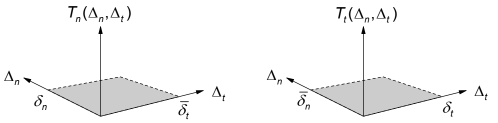
PPR: Potential-Based Cohesive Model

$$\psi = \min(\phi_n,\phi_t) + \left[\Gamma_n\left(1-\frac{\Delta_n}{\delta_n}\right)^{\alpha} + \langle \phi_n-\phi_t\rangle\right]\left[\Gamma_t\left(1-\frac{|\Delta_t|}{\delta_t}\right)^{\beta} + \langle \phi_t-\phi_n\rangle\right]$$

$$T_n(\Delta_n,\Delta_t) = -\alpha\frac{\Gamma_n}{\delta_n}\left(1-\frac{\Delta_n}{\delta_n}\right)^{\alpha-1}\left[\Gamma_t\left(1-\frac{|\Delta_t|}{\delta_t}\right) + \langle \phi_t-\phi_n\rangle\right]$$

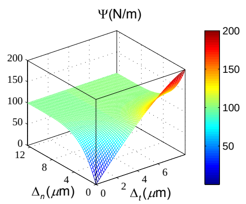
$$T_t(\Delta_n,\Delta_t) = -\beta\frac{\Gamma_t}{\delta_t}\left(1-\frac{|\Delta_t|}{\delta_t}\right)^{\beta-1}\left[\Gamma_n\left(1-\frac{\Delta_n}{\delta_n}\right) + \langle \phi_n-\phi_t\rangle\right]\frac{\Delta_t}{|\Delta_t|}$$

- **Fracture Parameters**
  - Fracture energy: ϕ_n, ϕ_t
  - Cohesive Strength: σ_{max}, τ_{max}
  - Shape parameters: α, β
- **Softening Region**



$$\delta_n = \frac{\alpha\phi_n}{\sigma_{max}} \quad \bar{\delta}_t = \delta_t - \delta_t\left(\frac{\langle\phi_t-\phi_n\rangle}{\phi_t}\right)^{1/\beta} \qquad \bar{\delta}_n = \delta_n - \delta_n\left(\frac{\langle\phi_n-\phi_t\rangle}{\phi_n}\right)^{1/\alpha} \quad \delta_t = \frac{\beta\phi_t}{\tau_{max}}$$

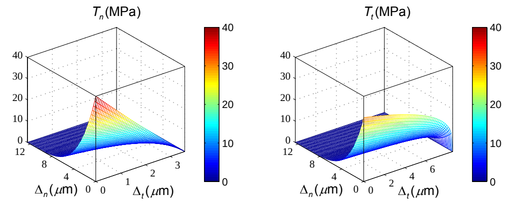
- **Constitutive Relationship**



$\phi_n = 100$N/m, $\phi_t = 200$N/m

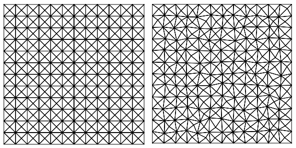
$\sigma_{max} = 40$MPa, $\tau_{max} = 30$MPa

$\alpha = 5$, $\beta = 1.3$

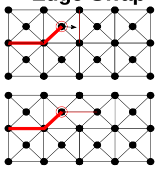


Adaptive Topological Operators

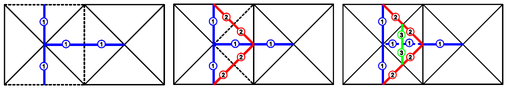
- **Nodal Perturbation**



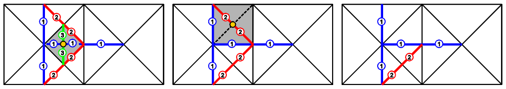
- **Edge-Swap**



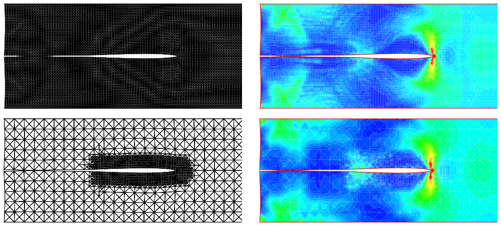
- **Edge-Split**

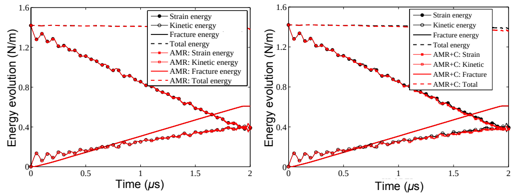


- **Vertex-Removal (or Edge-collapse)**

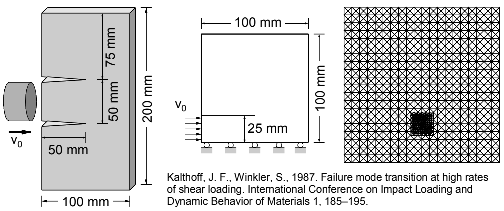


Mode I Predefined Crack





Mixed-Mode Crack Propagation



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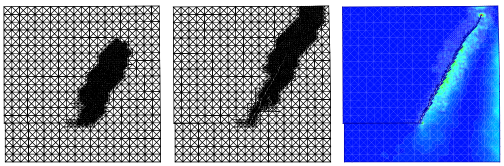
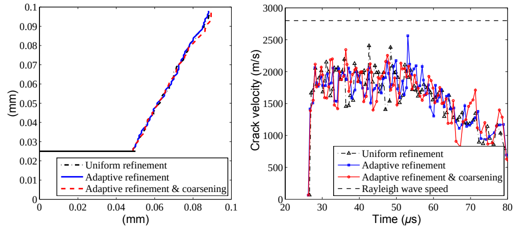
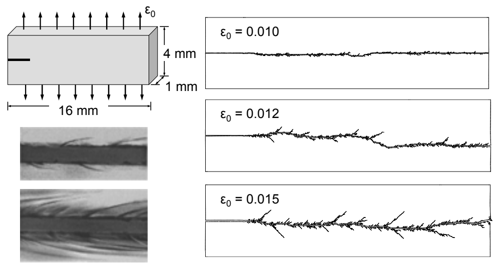


Mixed-Mode Crack Propagation (cont.)



Micro-Branching Instability



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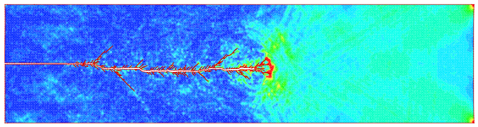

Conclusions

- The potential-based constitutive model with adaptive operators (nodal perturbation, edge-swap, edge-split, and vertex-removal) leads to an effective and efficient computational framework to simulate physical phenomena associated with fracture.
- The computational results of the adaptive mesh refinement and coarsening is consistent with the results of the uniform mesh refinement.

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