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Numerical investigations of the failure mechanism evolution of rock-like disc specimens containing unfilled or filled flaws

Key words: Smoothed particle hydrodynamics (SPH); Mixed-mode failure model; Failure mechanism evolution; Crack coalescence; Filling distribution

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Hohai University, China

Methodology

➢ Basics of SPH method

- Governing equations

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho\nabla\cdot\boldsymbol{v}, \qquad \frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = \frac{1}{\rho}\nabla\cdot\boldsymbol{\sigma} + \boldsymbol{b},$$

- SPH approximation

$$\langle\nabla\cdot f(\boldsymbol{x}_i)\rangle = \sum_{j=1}^{N}\frac{m_j}{\rho_j}\left(f(\boldsymbol{x}_j) - f(\boldsymbol{x}_i)\right)\cdot\nabla W(\boldsymbol{x}_i - \boldsymbol{x}_j, h).$$

- Techniques adopted to avoid tensile instability

➢ Constitutive model for rock-like materials

- Drucker-Prager (D-P) model is employed for describing the elastoplastic behaviors of rock-like materials, as well as the damage activated by shear.

- The damage behavior induced by tensile failure is determined by the tensile damage model.

SPH model validation

- The proposed SPH algorithm is verified by implementing the mixed-mode failure model through simulations of the Brazilian disc test with double unfilled (or filled) flaws;
- The results indicate the applicability of the SPH simulation.

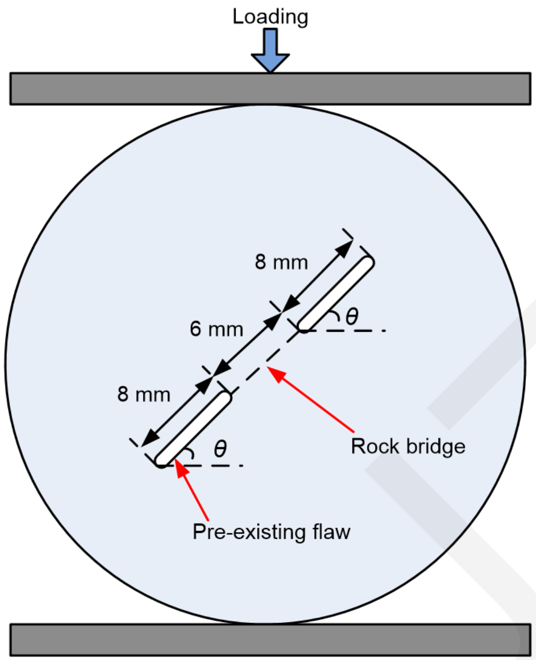


Fig. 1 Schematic diagram of the disc with double flaws. (θ is the flaw inclination angle)

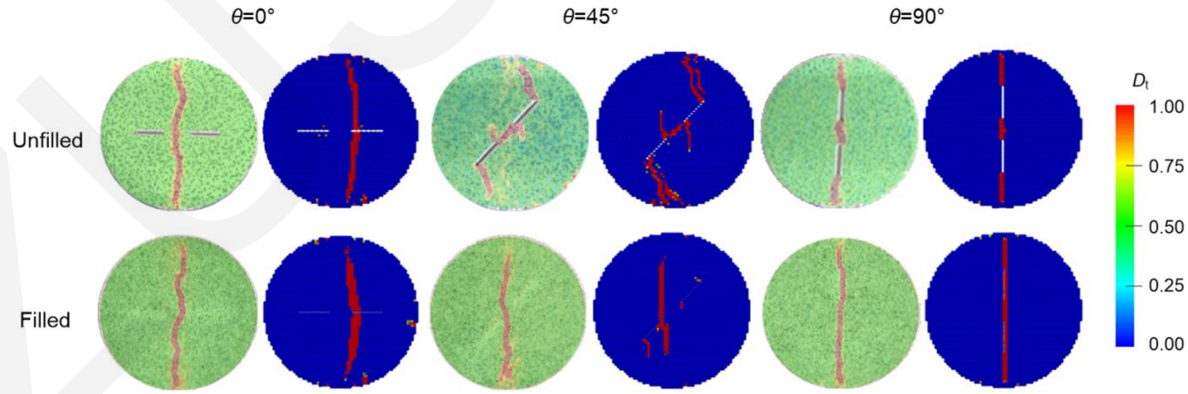
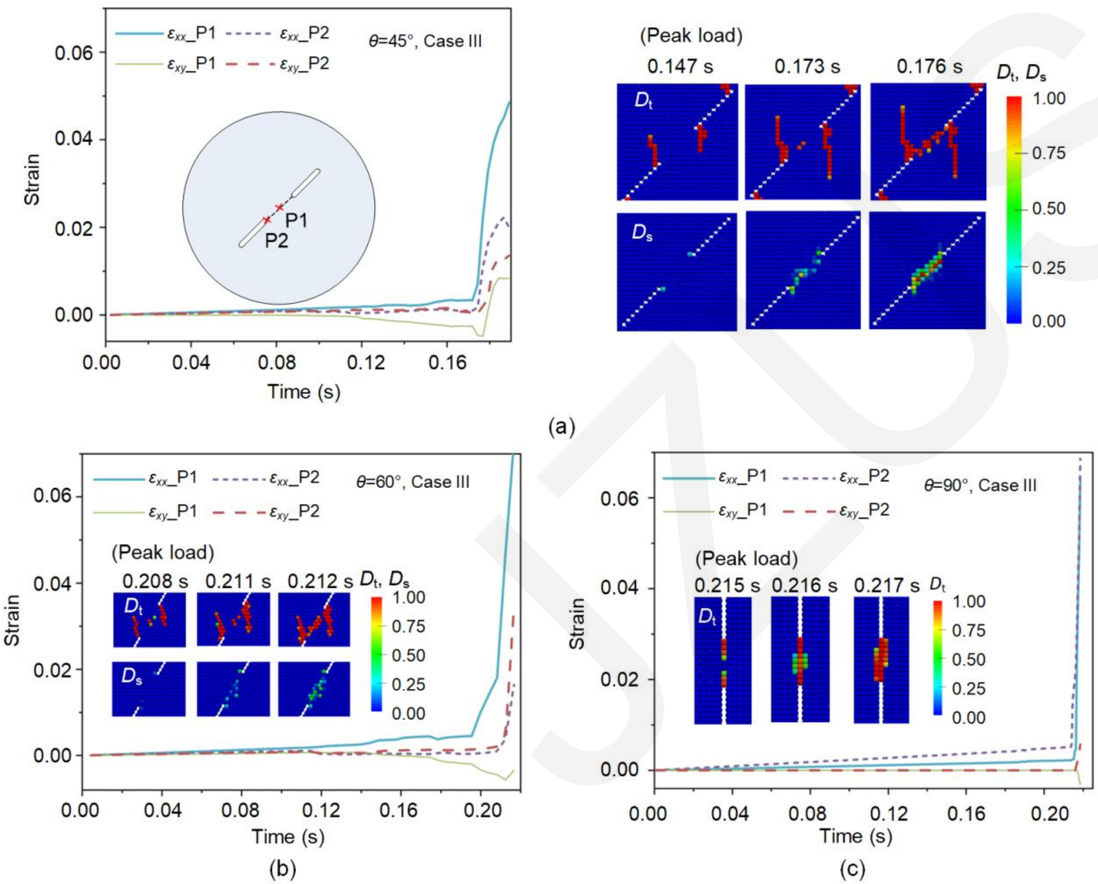


Fig. 2 Tensile failure diagrams of disc specimens with unfilled or filled flaws (discs in green: experimental results; discs in blue: SPH simulation results).

Case studies of fracture mechanism evolutions

- For flawed disc cases, the strains of two representative points (P1 and P2) in the bridge area are analyzed.
- Results proves that the fracture mechanism evolutions determine the crack coalescence type of the disc specimen.



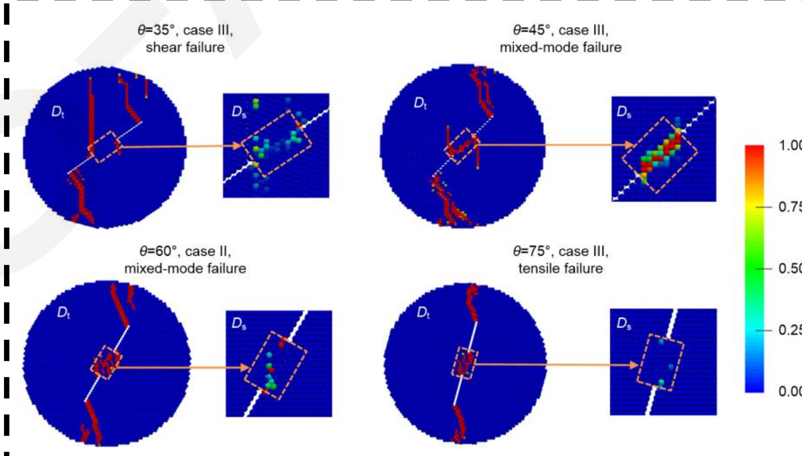


Fig. 4 Characteristic post-failure diagrams of disc specimens with different crack coalescence modes.

Fig. 3 Diagrams of tensile strain ε_{xx}, and shear strain ε_{xy}, histories at characteristic points of three typical disc specimens in the SPH simulations, and the corresponding crack coalescence processes in the rock bridge area of the disc specimens.

Case studies of fracture mechanism evolutions

- The failure mechanisms of the disc specimens are statistically analyzed to quantitatively evaluate the failure process for flaw-filled disc specimens.

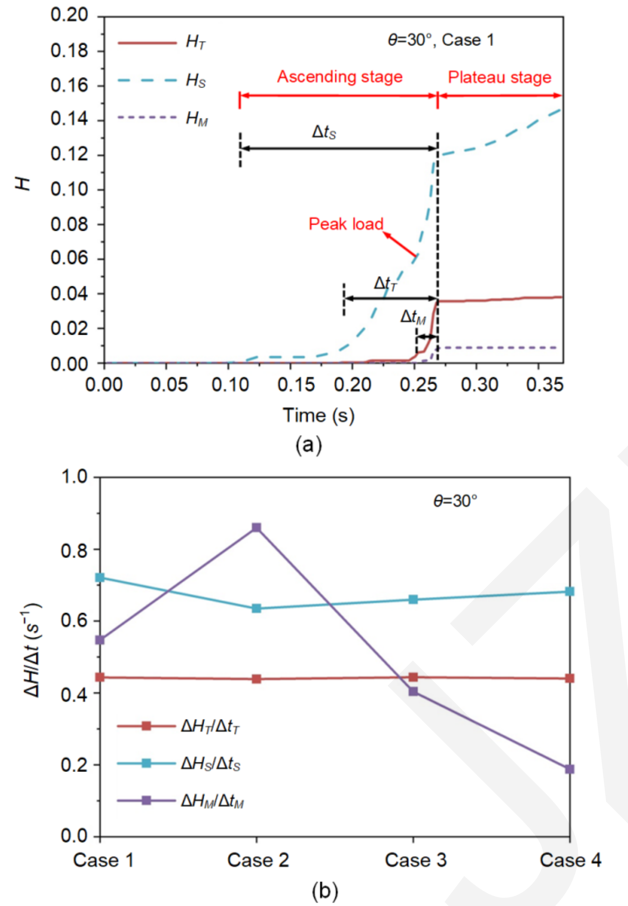


Fig. 5 Evolutions of damage ratios H of the disc specimen (θ=30°, Case 1) (a) and incremental rates of damage ratio for disc specimens (θ=30°) (b) under different types of fillings

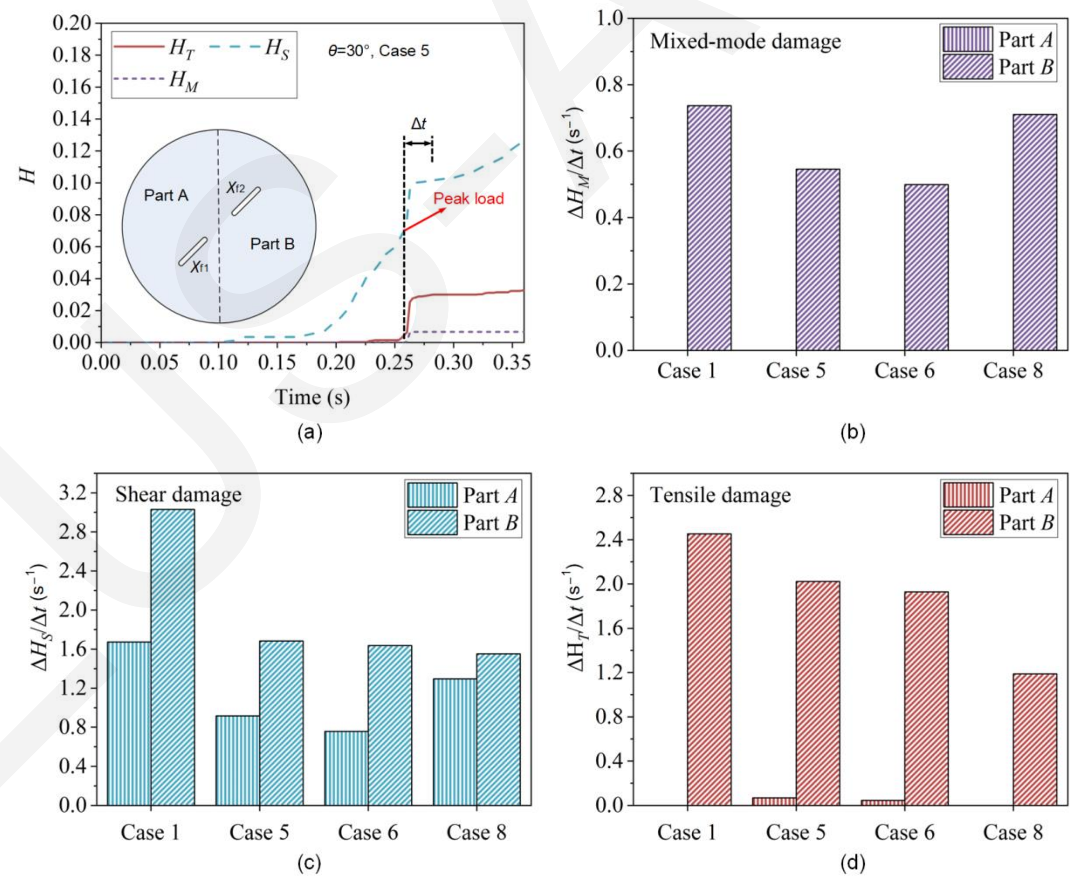


Fig. 6 Evolutions of damage ratios H of the disc specimen (θ=30°, Case 5) and a schematic diagram of the disc divided into two parts (a), and comparisons of damage ratio incremental rates of the disc specimens on the left and right side: (b) mixed-mode damage; (c) shear damage; (d) tensile damage

Conclusions

- In this study, the SPH method has been used to simulate the mixed-mode fracture of rock-like disc specimens.
- With the decrease of the flaw inclination angle, the crack coalescence mechanism in the rock bridge area will transform from tensile failure dominant to shear failure dominant.
- Considering disc specimens with filled flaws, the incremental rate of tensile damage grows more rapidly when the disc and filling material have a closer ratio of tensile strength to cohesion, which makes the entire specimen response greater brittleness.
- With the increasing non-uniformity of filling distribution, the incremental rate of tensile-activated damage decreases and the disc specimen performs more ductile. Besides, the influence of the fillings is greater when the flaw inclination angle is approaching 45° .