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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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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.

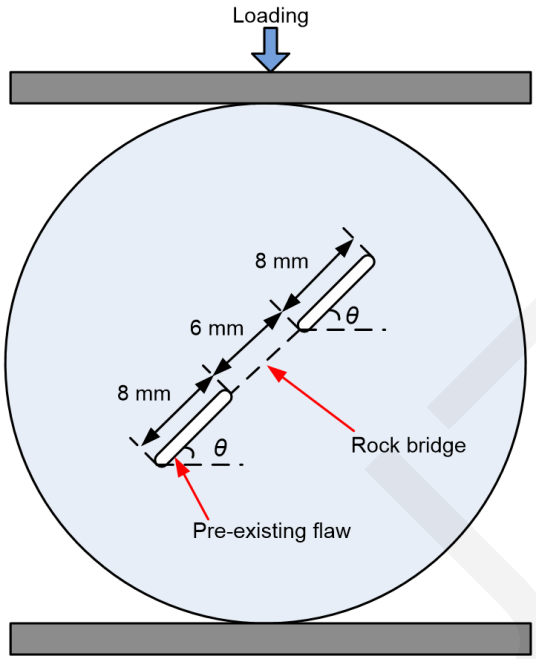


Fig. 1 Schematic diagram of the disc with double flaws. (θ is the flaw inclination angle)

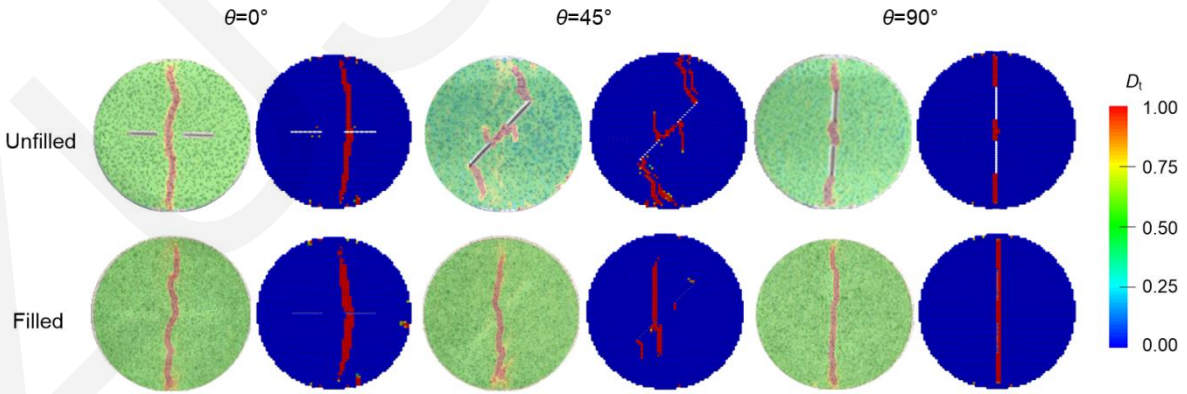


Fig. 2 Tensile failure diagrams of disc specimens with unfilled or filled flaws (discs in green: experimental results; discs in blue: SPH simulation results).

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.

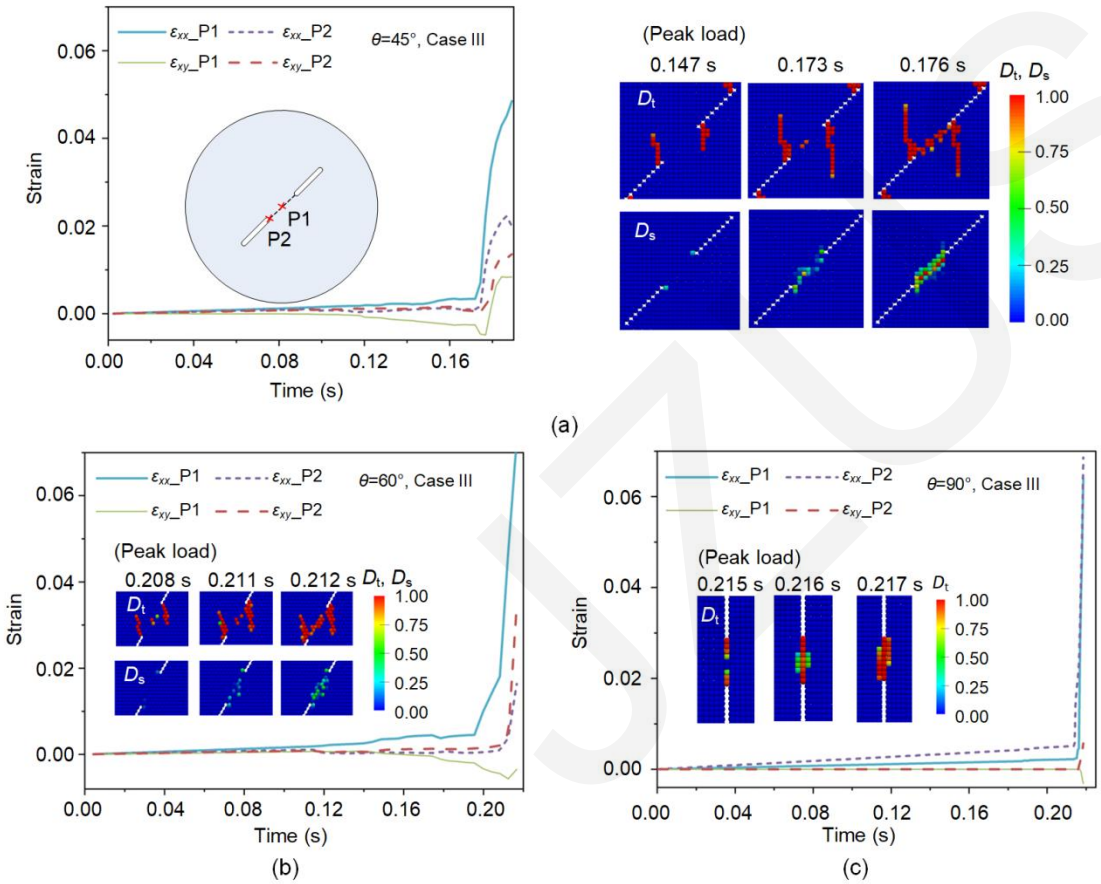


Fig. 3 Diagrams of tensile strain ε_{xx}, and shear strain ε_{xy}, histories at characteristic points of three typical disc specimens in the SPH simulations, and the corresponding crack coalescence processes in the rock bridge area of the disc specimens.

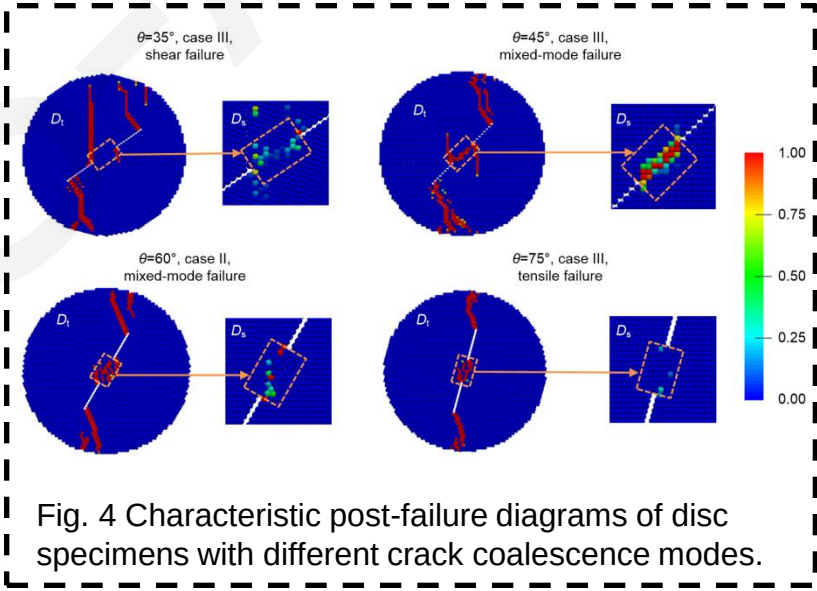


Fig. 4 Characteristic post-failure diagrams of disc specimens with different crack coalescence modes.

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.

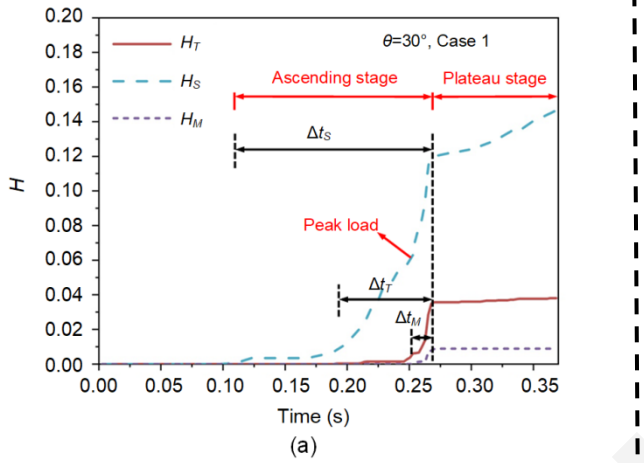


Fig. 5 Evolutions of damage ratios *H* of the disc specimen (*θ*=30° , Case 1) (a) and incremental rates of damage ratio for disc specimens (*θ*=30°) (b) under different types of fillings

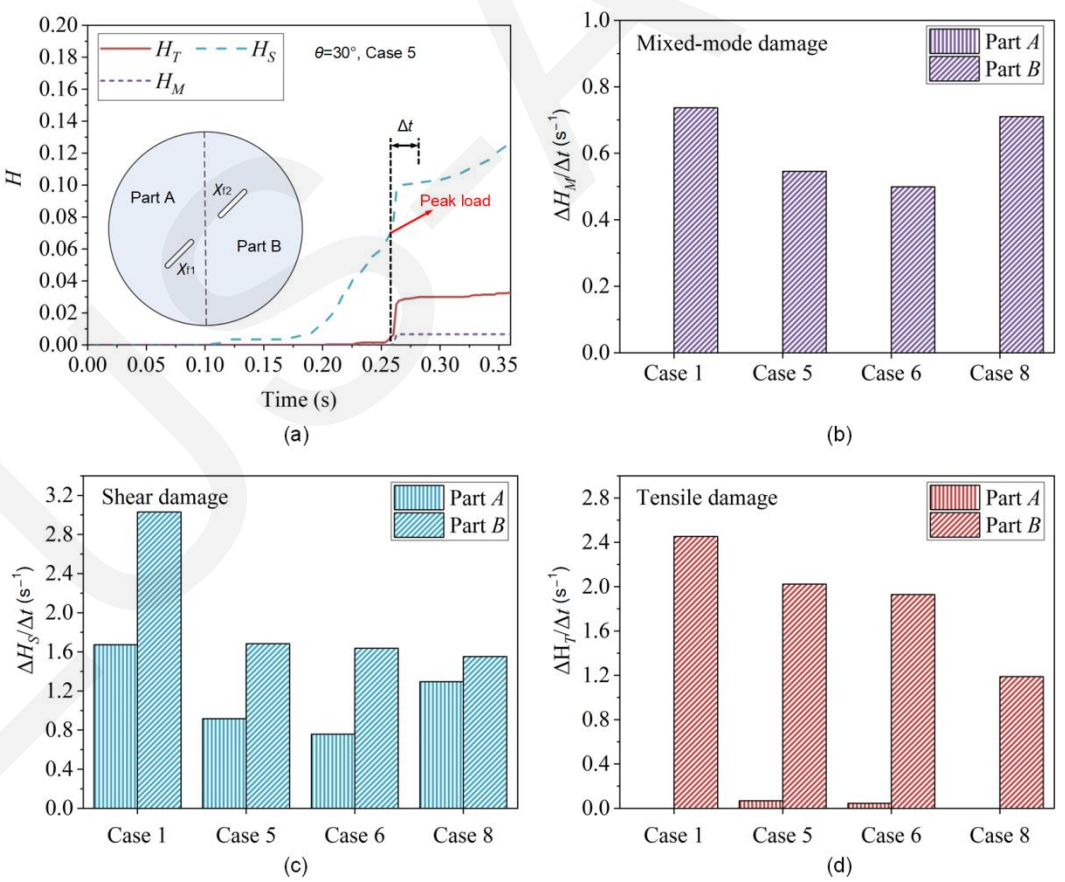


Fig. 6 Evolutions of damage ratios *H* of the disc specimen (*θ*=30° , Case 5) and a schematic diagram of the disc divided into two parts (a), and comparisons of damage ratio incremental rates of the disc specimens on the left and right side: (b) mixed-mode damage; (c) shear damage; (d) tensile damage

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°.