

Peer-reviewed Conference Contribution

A sequentially coupled chemical-mechanical damage constitutive model for carbonate rocks

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Modelling the constitutive relations of chemically corroded carbonate rocks is important for the design and stability evaluation of engineering constructions in karst areas (e.g., mines, tunnels and dams, etc.) [1-4]. This paper presents a sequentially coupled chemical-mechanical (C-M) damage constitutive model for engineering rocks in karst areas. First, the chemical damage caused by carbonate dissolution and the mechanical damage caused by external loads are investigated based on experimental results. After that, the chemical damage is expressed by the degradation ratio of Young's modulus under the effect of the chemically induced secondary pores compaction. The chemically induced secondary pore is quantified by reactive transport behavior considering the geochemical procedure of free-face dissolution and precipitation under different H^+ concentrations, temperature and corrosion periods [5]. The mechanical damage is formulated based on a statistical theory [6,7], which underlines the strength of the mesoscopic element and considers the damage initiation threshold. To capture the nonlinear strength responses of the mesoscopic element at various chemical damage and confining pressures, a modified Mohr-Coulomb (M-C) criterion is introduced, in which the instantaneous friction angle and cohesion are expressed as functions of the confining pressure and chemical damage. The proposed model is validated and shows good agreement with experimental data.

Result of this research shows that: (1) the porosity increases with increasing corrosion period and the increase rate (i.e., the slope of the porosity curve) is steep initially and then decreases gradually (see Fig. 1 (a)). (2) As shown in Fig. 1 (b), Young's modulus decrease with porosity growth. (3) The C-M coupled damage evolution curve is S-shaped and consists of four stages (see Fig. 1(c)), i.e., a linear elastic stage, a stable damage stage, a damage acceleration stage and a post-peak stage. In damage stage 1, stress is lower than the mechanical damage initiation threshold and the stress-strain curve is in a linear elastic state. At this stage, mechanical damage doesn't initiate (i.e., $D_m = 0$). Therefore, the total damage (D_{cm}) evolution curve is horizontal and only contains chemical damage ($D_c=0.165$) caused by carbonate dissolution. Once the axial strain exceeds the mechanical damage initiation threshold, the damage enters stage 2. In this stage, total damage (D_{cm}) begins to slightly rise and steadily increases with the increasing load. In damage stage 3, the damage-strain curve rises concave upward. After the peak strength point, damage development comes to stage 4, i.e., the post-peak stage.

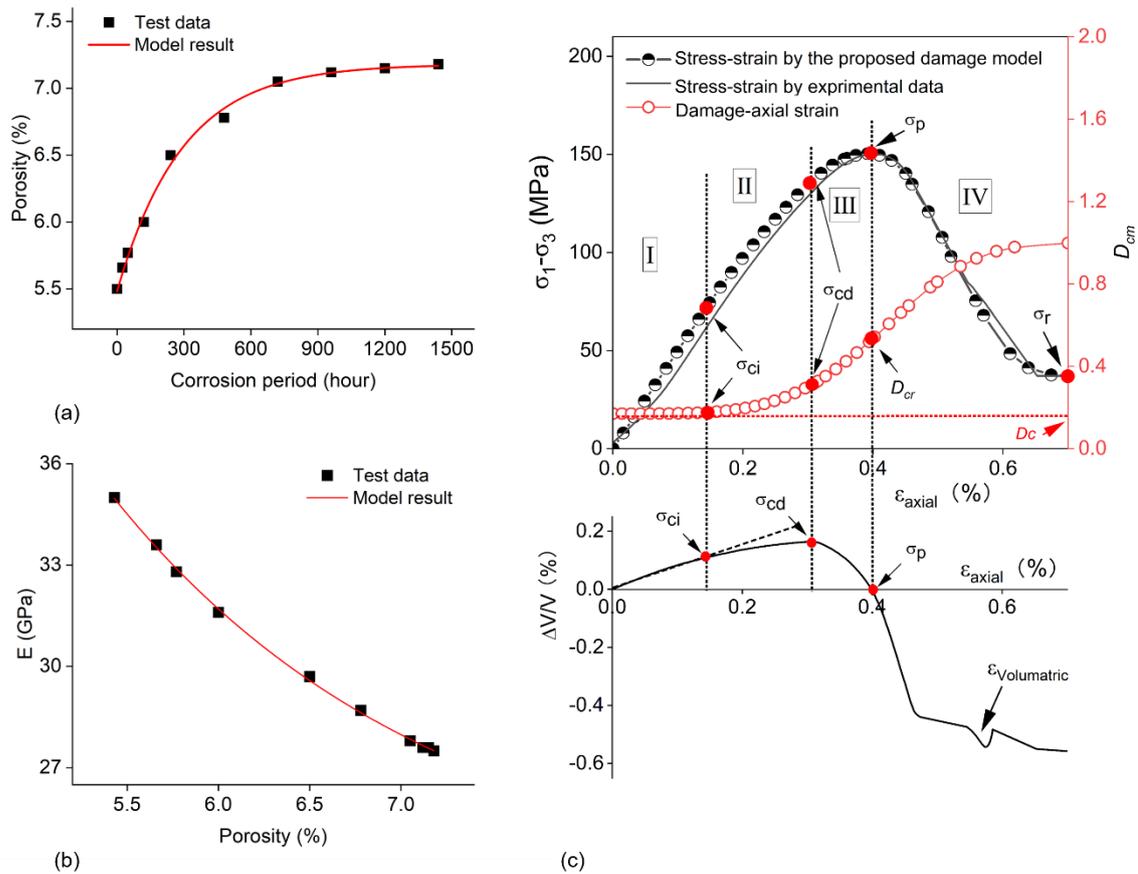


Figure 1: (a) Porosity versus chemical corrosion period of the samples in pH3 solution. (b) Young's modulus (E) versus porosity of the samples in pH3 solution. (c) Stress-strain and damage-strain curves of limestone sample calculated by the proposed C-M damage model. I, II, III and IV denote linear elastic stage, stable damage stage, damage acceleration stage and post-peak stage, respectively. σ_{ci} , ϵ_{ci} , σ_{cd} , ϵ_{cd} , σ_p and ϵ_p denote the stress and strain at the thresholds of the damage stages. D_c denotes chemical damage caused by carbonate dissolution and D_{cm} denotes the C-M coupled damage.

Contributor statement

Hao Li: Methodology, Writing. **Leo Pel:** Editing, Supervision. **David Smeulders:** Editing, Supervision. **Ruizhi Zhong:** Editing. **Zhenjiang You:** Editing.

Acknowledgments

The authors wish to thank Dr. Xiaohong Zhu for useful suggestions and discussion. Special thanks to Prof. Liangqi Zhang and Prof. Keshui Ge for their help, passion and enthusiasm devoted to this scientific investigation.

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