Modeling Fracture Behavior of Brazilian Splitting Tests Using Micromechanics-based Variational Phase-field Method

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The Brazilian splitting test is an indirect method for measuring the tensile strength of brittle materials, assuming that failure occurs at the center of the disc, where stress is theoretically equal to the ultimate tensile strength. However, the difficulties in determining the crack initiation point in experimental setups has led to debate over the validity of the measured tensile strength [3]. Studies show that failure is not always modulated by mode I fracture energy in the Brazilian splitting test. Material properties (compressive over tensile strength ratio, inhomogeneity, friction angle) or boundary conditions can change the fracture mode from mode I (tensile) to mode II (shear) [2, 3]. This has been studied using the micromechanics-based phase-field model. Micromechanics-based phase-field modeling is an approach used to study the behavior of quasi-brittle materials like mortar and concrete. The aim of this model is to connect field variables at the macroscale with physical dissipative mechanisms at the microcrack level. The model distinguishes between close and open microcracks to capture different fracture modes naturally, without implementing heuristic energy decompositions [1]. This feature is used to simulate the fracture behavior of mortars in the Brazilian splitting test.

The viscoplastic regularization is introduced to the model in order to overcome numerical issues caused by stress concentration near applied loads. The response of a single volume element under homogeneous strain field is studied to explain the effect of confining pressure in the Brazilian splitting test and compared to the analytical solution. Different loading conditions were applied to the volume element to identify different failure modes, utilizing the model's main feature of distinguishing between fracture modes. Results indicated that under biaxial confining pressure and axial tension, the element may experience a tensile or shear fracture depending on the level of biaxial compression, which explains the reason for the observed mode II fracture in the simulation. Additionally, Brazilian splitting tests are conducted using Digital Image Correlation technique to capture the strain field and calibrate the numerical parameters of the model. The model is next validated using experimental data from the work of Deresse et el. [4] and calibrated parameters are used to predict the failure behavior of other samples with the same material but different geometry and boundary conditions. Results show that the numerical failure prediction is consistent with the experiment, confirming the validity and reliability of the simulation model and its ability to predict material behavior and fracture modes under specific loading conditions.

References

[1] J. Ulloa, J. Wambacq, R. Alessi, E. Samaniego, G. Degrande and S. François, A micromechanics-based variational phase-field model for fracture in geomaterials with brittle-tensile and compressive-ductile behavior, Journal of the Mechanics and Physics of Solids 159 (2022) 104684.

[2] H. Lin, W. Xiong, W. Zhong and C. Xia, Location of the crack initiation points in the Brazilian disc test, Geotechnical and Geological Engineering 32 (2014) 1339–1345.

[3] Y. Ma and H. Huang, DEM analysis of failure mechanisms in the intact Brazilian test, International Journal of Rock Mechanics and Mining Sciences 102 (2018) 109–119.

[4] N.E. Deresse, C. Van Steen, M. Sarem, S. François and E. Verstrynge, Acoustic Emission Analysis of Fracture and Size Effect in Cementitious Mortars, Applied Sciences 12 (2022) 3489.