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Experimental investigation on strength and failure behavior of pre-cracked marble under conventional triaxial compression

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ABSTRACT

Fractures in natural rocks have an important effect on the strength and failure behavior of rock mass, which are often evaluated in rock engineering practice. The theoretical evaluation of mechanical behavior of fractured rock mass has no satisfactory answer due to the role of confining pressure and crack geometry. Therefore, in this paper, conventional triaxial compression experiments were carried out to study the strength and failure behavior of marble samples with two pre-existing closed cracks in non-overlapping geometry. Based on the experimental results of a number of triaxial compression tests, the effect of crack coalescence on the axial supporting capacity and deformation property were investigated with different confining pressures. The results show that intact samples and flawed samples (marble with pre-existing cracks) have different deformation properties after peak stress, which change from brittleness to plasticity and ductility with the increase of confining pressure. The peak strength and failure mode are found depending not only on the geometry of flaw, but also on the confining pressure. The strength of flawed samples shows distinct non-linear behavior, which is in a better agreement with non-linear Hoek–Brown criterion than linear Mohr–Coulomb criterion. For a kind of rock that has been evaluated as a Hoek–Brown material, a new evaluation criterion is put forward by adopting optimal approximation polynomial theory, which can be used to confirm more precisely the strength parameters (cohesion and internal friction angle) of flawed samples. For intact samples, the marble leads to typical shear failure mode with a single fracture surface under different confining pressures, while for flawed samples, under uniaxial compression and a lower confining pressure (σ_3 = 10 MPa), tests for coarse and medium marble (the coarse and medium refer to the grain size) exhibit three basic failure modes, i.e., tensile mode, shear mode, and mixed mode (tensile and shear). Shear mode is associated with lower strength behavior. However, under higher confining pressures (σ_3 = 30 MPa), for coarse marble, the axial supporting capacity is not related to the geometry of flaw. The friction among crystal grains determines the strength behavior of coarse marble. For medium marble, the failure mode and deformation behavior are dependent on the crack coalescence in the sample. The present research provides increased understanding of the fundamental nature of rock failure under conventional triaxial compression.

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1. Introduction

Rock is a kind of complex geological media, containing many flaws such as the joints, fissures, cracks, weak surfaces and faults, etc. Failure in a rock mass can often take place along pre-existing joints and partly through the intervening intact rock. The experimental, theoretical, and numerical investigations on the mechanical behaviors of fractured rock were greatly improved due to intermittent structural characteristics of many rock engineering. In order to understand and explore the fracture mechanism of various rock engineering, such as dam-base rock engineering, jointed rock slope project, nuclear waste disposition project, etc., extensive studies (Nemat-Nasser and Horii, 1982; Bobet, 1997, 2000; Shen, 1993, 1995; Zhu et al., 1998; Wong et al., 2001) have been investigated for the mechanical behaviors of pre-cracked materials (artificial material and real rock material). The results have showed that the geometries of flaws (such as flaw length, flaw angle, and ligament length, etc.) in the rocks have an important influence on the strength, deformation and failure behaviors. Up to now, the main experimental methods of previous studies on mechanical behaviors of pre-cracked material have included the following three kinds.

- Physical tests on model materials (rock-like materials) under uniaxial and biaxial compression.
- Numerical tests on model samples by some numerical software (such as RFPA^{2D}, FROCK, etc.) in uniaxial compression (2D model).
- Physical tests on real rock material in uniaxial compression.

The above first experimental method is widespread because model sample is easy to fabricate. Model sample is fabricated by a mixture of gypsum, cement, barite, and water with a different mass ratio to simulate and reflect the mechanical behavior of real rock material. By inserting mica, paper or thin steel disc, etc., the open or closed flaws (the term flaw will be used from now on for pre-existing cracks) are pre-fabricated to investigate the initiation, propagation, and coalescence behavior of cracks in model materials in 2D conditions. Nemat-Nasser and Horii (1982) investigated the mechanisms of crack interactions and failure modes in flaw plates (model material) under uniaxial and biaxial compression, which showed that flaw length is one of the parameters controlling the failure mode of sample. Bobet (1997, 2000), Bobet and Einstein (1998), Zhu et al. (1998), Wong and Chau (1998), Vasarhelyi and Bobet (2000) have investigated the 2D cracks propagation and coalescence on rock-like materials containing two inclined open or closed flaws. Fig. 1 showed typical three main modes of 2D crack coalescence in two flawed samples under uniaxial compression by Wong and Chau (1998). Under uniaxial and biaxial conditions, the experimental investigation of coalescence of two non-overlapping flaws has confirmed the well-established behavior. It has also revealed many important new physical phenomena (Bobet and Einstein, 1998). Wing cracks occurred at flaw tips as was well known. But these wing cracks shifted toward the middle of the flaws and did not occur as confining stresses increased. Wong et al. (2001) investigated experimentally crack coalescence and peak strength of model materials containing three parallel fractional flaws. The results showed that the mechanisms of 2D cracks coalescence depended on the flaw arrangement and the frictional coefficient on the flaw surface. Prudencio and Van Sint Jan (2007) presented the results of biaxial tests on physical models of rock with non-persistent joints. Tests showed three basic failure modes: failure through a planar surface, stepped failure, and failure by rotation of new blocks. Planar failure and stepped failure were associated with high strength, and small failure strains, whereas rotational failure was associated with a very low strength, ductile behavior, and large deformation. In reality, pre-existing flaws are usually three-dimensional (3D) in nature. Therefore the growth mechanisms of 3D crack is nearer to rock engineering practice, but the mechanism of 3D crack growth is more complicated (Germanovich and Dyskin, 2000) than that of 2D crack growth. Huang and Wong (2007) performed a series of uniaxial compressive tests on the frozen PMMA (polymethyl methacrylate) with pre-existing 3D cracks. Based on the test results, the mechanisms of crack propagation and coalescence in brittle materials were investigated. It was found that for 3D surface cracks, the interactions of cracks affected crack growth and extension in two aspects, i.e., the interaction either prompting crack extension or restraining it. The mechanism of crack interaction depends mainly on the location of cracks in

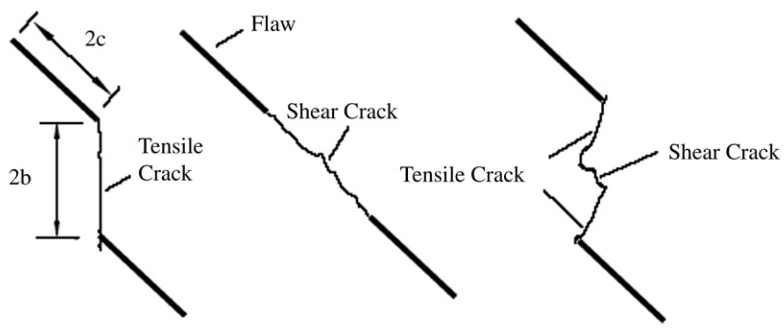

Fig. 1. Three main modes of 2D crack coalescence in two flaw samples under uniaxial compression (Wong and Chau, 1998).