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An experimental and numerical study of fracture coalescence in pre-cracked specimens under uniaxial compression

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ABSTRACT

This study presents crack initiation, propagation and coalescence at or near pre-existing open cracks or flaws in a specimen under uniaxial compression. The flaw geometry in the specimen was a combination of a horizontal flaw and an inclined flaw underneath. This flaw geometry is different from those reported in the previous studies, where a pair of parallel flaws was used. Three materials were used, PMMA (Poly Methyl MethAcrylate), Diastone (types of molded gypsum), and Hwangdeung granite. Crack initiation and propagation showed similar and different patterns depending on the material. In PMMA, tensile cracks initiated at the flaw tips and propagated to the tip of the other flaw in the bridge area. The cracks then coalesced at a point of the inclined flaw, which is affected by the flaw inclination angle. For Diastone and Hwangdeung granite, tensile cracks were observed followed by the initiation of shear cracks. Coalescence occurred mainly through the tensile cracks or tensile and shear cracks. Crack coalescence was classified according to the crack coalescence types of parallel flaws for overlapping flaw geometry in the past works. In addition, crack initiation and coalescence stresses in the double-flawed specimens were analyzed and compared with those in the single-flawed specimen. Numerical simulations using PFC^{2D} (Particle Flow Code in two dimensions) based on the DEM (Discrete Element Method) were carried out and showed a good agreement with the experimental results in the coalescence characteristics in Hwangdeung granite. These experimental and numerical results are expected to improve the understanding of the characteristics of cracking and crack coalescence and can be used to analyze the stability of rock and rock structures, such as the excavated underground openings or slopes, tunneling construction, where pre-existing cracks or fractures play a crucial role in the overall integrity of such structures.

1. Introduction

Rock contains a large number of discontinuities resulting from a variety of geological processes. Pre-existing discontinuities or cracks in rock play important roles in initiating new cracks. When a load is applied, new cracks start to grow at or near the tips of pre-existing cracks and propagate toward the direction of the major principal stress, sometimes coalescing with other cracks. A series of cracking processes eventually control the overall behavior of the rock, which have prompted extensive experimental studies of pre-cracked specimens of different materials, including rock-like brittle/semi-brittle materials and natural rocks: glass (Hoek and Bieniawski, 1965), Columbia Resin 39 (Bombolakis, 1968), Plaster of Paris (Lajtai, 1971, 1974), molded gypsum (Bobet, 2000; Park, 2001; Shen, 1995; Bobet and Einstein, 1998a,b; Reyes and Einstein, 1991; Sagong and Bobet, 2002; Wong and Einstein, 2008a,b), sandstone-like material (Mughieda and Alzo'ubi, 2004; Wong and Chau, 1998; Wong et al., 2001), granite (Miller and Einstein, 2008), marble (Park, 2001; Jiefan et al., 1990; Li et al., 2005; Wang et al., 1987), granodiorite (Ingraffea and Heuze, 1980; Wong et al., 2008), limestone (Ingraffea and Heuze, 1980), clay (Vallejo, 1987, 1988), etc. Although there are differences in the crack pattern, common characteristics have been observed: tensile cracks are initiated at the tips of the flaw and propagate in a curvilinear direction with increasing load and shear cracks grow at the tips of the flaw nearly coplanar to the flaw. In particular, Wong and Einstein (2009) reviewed previous studies and suggested that the terminology in the seven different types of the tensile and shear cracking (three types each for tensile and shear cracking and one type of mixed mode cracking) be standardized based on high-speed camera observations rather than by fractography.

Experimental research on a gypsum specimen with a pair of parallel flaws (the term 'flaw' denotes an artificially made pre-existing crack in a specimen) under compression has found a range of crack coalescence patterns according to the nature of crack initiation and coalescence. Shen (1995) reported that three different

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