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Fracture evolution around pre-existing cylindrical cavities in brittle rocks under uniaxial compression

Xing-dong ZHAO[1,2], Hong-xun ZHANG[1], Wan-cheng ZHU[1]

1. College of Resources and Civil Engineering, Northeastern University, Shenyang 110819, China;
2. State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Beijing 100083, China

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Abstract: The development of fracture around pre-existing cylindrical cavities in brittle rocks was examined using physical models and acoustic emission technique. The experimental results indicate that when granite blocks containing one pre-existing cylindrical cavity are loaded in uniaxial compression condition, the profiles of cracks around the cavity can be characterized by tensile cracking (splitting parallel to the axial compression direction) at the roof−floor, compressive crack at two side walls, and remote or secondary cracks at the perimeter of the cavity. Moreover, fracture around cavity is size-dependent. In granite blocks containing pre-existing half-length cylindrical cavities, compressive stress concentration is found to initiate at the two sidewalls and induce shear crack propagation and coalescence. In granite blocks containing multiple parallel cylindrical cavities, the adjacent cylindrical cavities can influence each other and the eventual failure mode is determined by the interaction of tensile, compressive and shear stresses. Experimental results show that both tensile and compressive stresses play an important role in fracture evolution process around cavities in brittle rocks.

Key words: cylindrical cavity; fracture evolution; uniaxial compression; acoustic emission event location; slabbing

1 Introduction

As underground excavations progress into deeper and more complex geological environments, the eventual and ultimate limitation in all mining is depth [1]. Excavation-induced macroscale fractures, such as roof fall, side wall slab and rock burst [2−5], can be often observed in the deep high-stressed hard-rock mines, occurring extensively in the side walls of underground working face. Understanding of the failure modes around cavities in brittle rocks under compressive loading conditions becomes more and more important in searching solutions to the problem that mining activity meets [6].

In laboratory loading uniaxial compressive stress conditions, the fracture patterns of rock specimens containing a circular cavity may involve three different failure processes: primary fracture at the tensile stress concentration, secondary fracture at positions inside the rock abutments, and side wall slabbing at the concentration of compressive stress [7,8]. HOEK and BROWN [2] used photoelastic film to demonstrate the presence of remote areas of tension about a circular opening. LAJTAI et al [9] used plaster models to demonstrate the combination fracture of slabbing−crushing and the shear fracture with the failure process in the compression zone causing the collapse of the cavity. LAJTAI et al [10] employed the physical method to study the development of fractures around cavities. MARTIN et al [11] carried out a similar test in Lac du Bonnet granite and found three types of fractures around a 60 mm diameter circular opening. The breakout occurred in the maximum shear stress region around the boundary of the circular opening, which, for plane-strain conditions, was given by JAEGER and COOK [12]. However, like other classic physical models, the fracture patterns in the rock samples were incapable of characterizing the entire fracture process, which involved the initiation, propagation, and coalescence of

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Corresponding author: Xing-dong ZHAO; Tel: +86-24-83691093; E-mail: zhaoxingdong@mail.neu.edu.cn
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micro-cracks through the formation of a full-scale macro-crack.

Some numerical solutions have been developed to illustrate the evolution process of fractures from the micro-cracks existing around openings. ZHU et al [13,14] and TANG et al [15] applied the rock failure process analysis (RFPA) code to model the progressive fracturing around a circular opening under uniaxial compression and the acoustic emission (AE) distributions, where fracturing patterns and the maximum shear stress distributions were presented. FAKHIMI et al [16] used the particle flow code (PFC) based on the distinct element method, to simulate the localization behavior of rock samples within a circular cavity and to reproduce the damage zone. These numerical results could be used with more confidence to examine the nature of damage and failure in rocks. However, these codes have rarely been reported to simulate the fracture evolution of rock samples with half-length cylindrical excavations or with three cylindrical cavities.

To enable good comparison between the previous studies, 15 granite specimens with cylindrical cavities of different diameters were examined to study crack initiation, propagation and coalescence of cylindrical cavities on the failure patterns of rock specimens. Two other groups of granite samples in the panel, containing a half-length cylindrical cavity or three cylindrical cavities, were also used to study their failure patterns. The aim of this study is to identify the evolution, interaction and development of fractures around cavities subjected to uniaxial compression and to interpret their failure patterns.

2 Experimental

2.1 Physical specimen model test

Twenty five medium-grained brittle hard granite blocks with dimensions 100 mm×100 mm×200 mm were cut and ground to accurate size based on the recommendation of the ISRM [17]. All the specimens have a height-to-width ratio of 2. Parallelism between top and bottom faces of each specimen is within an error of 0.02 mm. The fracture evolution in granite samples with pre-existing single cylindrical cavities was experimentally modeled to examine the influence of cavity diameter on crack evolution behavior. Fifteen blocks of granite, divided into 3 groups of 5 blocks each, were prepared with cylindrical cavities with diameters of 20, 28 and 38 mm. This was the uniform of the fifteen rock samples. The compressive strength averaged 112 MPa while the tensile strength averaged 12 MPa. All of the specimens with cylindrical cavities were loaded under uniaxial compression. Each cuboid granite specimen was equipped with four axial and lateral strain gauges attached on the surface of the specimens and positioned directly in direction of tensile/ compressive stress concentration areas (Fig. 1).

2.2 Testing apparatus

The uniaxial compression tests were carried out with a 3000 kN capacity testing machine (Fig. 2), which used displacement control featuring electromechanical controllers with three control channels. The loading system recorded the values of the load and displacement

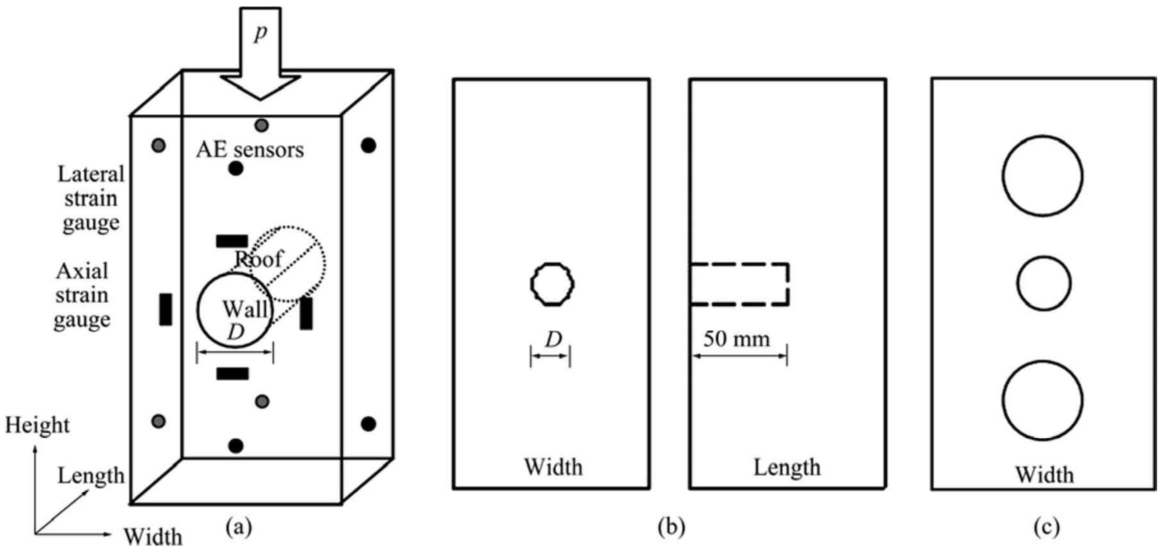

Fig. 1 Specimen with different cylindrical cavities in diameters of 20, 28 and 38 mm, strain gauges, acoustic emission monitoring system and loading conditions (a), cuboid granite samples consisting of half-length cylindrical cavity with 20 mm in diameter and 50 mm in length (b), and cuboid granite samples containing three cylindrical cavities with diameters of 28 mm (top and bottom) and 20 mm (center) (c)