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Triaxial compression experiments on intact veined andesite

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ABSTRACT

A comprehensive experimental program was instigated to test intact veined andesite from the El Teniente Mine (Chile) under triaxial compression with confining pressure ranging from 2 to 60 MPa. The experimental program established that the veins acted as weak mechanical components in the specimens, promoting rock fracture under stress. The experimental results indicated that the stress thresholds identifying the onset of dilatancy and the transition from the stable to unstable fracturing were higher in intact veined rock than in intact rock. The observed behaviour illustrated a significant departure from intact rock where the onset of Acoustic Emissions (AE) correlates with the onset of specimen dilatancy. The experimental results from intact veined rock indicated that the onset of AE correlated with the crack damage stress. The departure from the behaviour of intact rock is attributed to the presence of veins.

1. Introduction

Since the early 1980s, cave mining technology has evolved considerably. Advances, improvements, and innovations made in the past thirty years are significant. However, challenges associated with mining harder rock at much greater depth and under high in-situ stress remain outside of past and current practices.[1] Geomechanical experience developed during caving of weak near-surface deposits of secondary ore has proven inadequate in mining of competent rock masses of primary ore. Caveability, fragmentation, seismicity, and ground support challenges have become prominent. Geomechanical aspects of caving have taken a crucial role in determining the success of a caving operation, especially the understanding of rock mass behaviour and its strength.

A rock mass is a collection of intact rock blocks bound by discontinuities. Given that discontinuities may not be abundant at depth and because in-situ stresses are high, our understanding of the rock mass behaviour, acquired mostly based on experience with relatively shallow ground conditions, is not transferable to deep deposits. This is further complicated in porphyry-type rock masses, host to major mining operations, as they are characterized by the presence of mineral-filled vein structures, known as *stockwork*. Our understanding of how the presence of mineral veins affects the strength of rock is currently limited. In the past, rock mechanics research into the behaviour of rock masses focused predominantly on the role of joints and their capacity to reduce the stiffness and strength of rock from measured intact to rock mass values. In this context the influence of veins on rock mass behaviour was overlooked.

Past research on the behaviour of veined rock[2,3] was of qualitative and observational nature. More recent work on intact veined rock involved laboratory experiments[4,5] and numerical simulations.[5,6].

In our recent experiments on intact veined rock,[4,5] cylindrical specimens of veined andesite from the El Teniente mine (Chile) were loaded triaxially under a stress path that was aimed to imitate loading of a passing caving front. The experiments demonstrated that veins controlled the fracturing process. The experiments were primarily focused on collection of data for numerical simulations,[5] providing a base for the design of a new set of experiments, which are discussed here.

In this paper we continue to explore the influence of mineral filled veins on the behaviour of intact veined rock through laboratory experimentation. Unlike in our previous work,[4,5] recent triaxial experiments were carried out using confining pressure between 2 and 60 MPa, allowing to explore the behaviour of intact veined rock under confinement of up to ½ of its unconfined compressive strength (UCS). Rather than focusing on peak strength, this paper explores how intact veined rock behaves throughout the experiment by interpreting various stages of its progressive failure, comparing the behaviour to the one of intact (without veins) rock. The paper presents and discusses the acoustic emission (AE) response that is unique to intact veined rock, which, to our knowledge, is the first documented work for intact veined rock.

A fundamental aspect of this work is the realisation of the contrasting behaviour of intact veined rock from the behaviour of intact rock. This has significant practical implications in mass mining.

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2. Description of specimens of intact veined andesite

2.1. Specimen origin and description

Two 150 mm diameter cores were extracted on the Teniente 7 level of the El Teniente Mine (Chile) from two orthogonal boreholes. One of the boreholes was drilled across the direction of the regional maximum principal stress (σ_1). The other was drilled subparallel to the direction of $\sigma_{1.}$ Detailed description of material origin is provided in Ref. 5.

Five 50 mm diameter 125 mm long specimens were tested. They were cored in the laboratory from the 150 mm diameter core section. The coring of the specimens was in the same direction as of the boreholes. Photographs of the prepared specimens are shown in Fig. 1. Specimens 1, 3, and 4 were cored normal to the direction of σ_1, and Specimens 2 and 5 were cored sub-parallel to the σ_1 direction.

The andesite specimens are representative of the El Teniente's mafic intrusive complex (CMET) lithology, which is the main host of primary copper ore at the mine.[3] The ore is usually characterized as massive, with very few open discontinuities. In laboratory experiments involving compression at high stresses the El Teniente's primary ore generally exhibits brittle behaviour. Table 1 summarizes the intact rock properties of CMET andesite.

P-wave velocity measurements (Table 2) showed that diametric velocities in Specimens 1, 3, and 4 were higher than axial velocities. These specimens were cored normal to the regional σ_1 direction. In Specimens 2 and 5, which were cored sub-parallel to the regional σ_1 direction, the opposite was observed; axial P-wave velocities were higher than diametric. This is indicative of the specimens containing pre-existing micro-cracks that oriented sub-parallel to the direction of the regional maximum principal stress. This phenomenon has been observed and discussed by[7].

Table 1
Intact rock parameters of CMET andesite (summarised from[5, 6, 42, 44–46]).

Parameter	*Value*
Density (kg/m^3)	2800
Young modulus (GPa)	25–60
Poisson's ratio	0.16–0.30
Unconfined compressive strength (MPa)	115–130
Tensile strength (MPa)	14
Hoek-Brown constant m_i	9.1

Table 2
Results of P-wave velocity measurements for the specimens.

Specimen	*Specimen coring direction with respect to regional σ_1*	*P-wave velocity (m/s)*		*Diam. vel./ axial vel. ratio*
		Diametric	*Axial*	
S1	⊥	4690	4104	1.14
S2	‖	4789	5020	0.95
S3	⊥	4230	3889	1.09
S4	⊥	4303	4004	1.07
S5	‖	4990	5243	0.95

2.2. Mineral veins

Each tested specimen contained a dense network of mineral veins that varied in thickness and in orientation within each specimen. A discrete vein network (DVN) was constructed for each specimen (Fig. 2) and each vein was catalogued including its dip angle with respect to the diametric plane, average thickness, and vein volumetric mineralogical composition.

Among the specimens, veins varied between 0.2 and 16.6 mm in thickness. The thickest vein (16.6 mm) was recorded in Specimen 5. Specimen averages of vein thickness ranged between 0.9 and 2.8 mm.

Analyses of vein angles demonstrated that vein orientations varied in the specimens from being parallel to normal with respect to the short axis. In many specimens, the angles followed nearly uniform distributions. All specimens contained veins inclined 50–70° with respect to the short axis, being preferentially-oriented for the development of a shear-type failure in triaxial compression experiments.

Vein mineralogical analysis demonstrated that anhydrite and

Fig. 1. 2 Photographs of the 5 specimens of intact veined andesite. Each specimen is 125 mm long and 50 mm in diameter. Marked vertical grid spacing between horizontal lines is 25 mm. Marked circumferential angular grid spacing is 15°.