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Three-dimensional observation of the fracture process zone in anisotropic granitic rock by X-ray CT scan

M.H.B. Nasseri, P.R.Young, B. Mohanty

Lassonde Institute, Department of Civil Engineering, University of Toronto, ON,

Canada, M5S 1A4

Contact

Dr. Farzine Nasseri (nasseri@ecf.utoronto.ca),

35 St. George St,

Lassonde Institute, Department of Civil Engineering,

University of Toronto, On,

M5S 1A4, Canada.

Three-dimensional observation of the fracture process zone in anisotropic granitic rock by X-ray CT scan

M.H.B. Nasseri, P.R.Young, B. Mohanty*

Lassonde Institute, Department of Civil Engineering, University of Toronto, ON,

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Fracture characteristics such as fracture toughness, fracture process zone (FPZ) and fracture surface roughness are critical components in characterization of both stable and unstable fractures with specific applications in rock mass stability and earthquake seismology.

A systematic laboratory study involving tensile loading of homogeneous granitic rocks (Mode I fracture) under standard test procedures (i.e. Cracked-Chevron-Notch-Brazilian-Disc, CCNBD) has been carried out with granitic rock samples involving pre-failure, real time and post-mortem studies. This consists of X-ray micro-CT scanning, acoustic emission, petrographic, scanning electron microscopy and fracture profilometry techniques.

Fracture toughness of the Barre granitic rock investigated has been shown to be strongly anisotropic and depends on the characteristic microstructural features of the rock. The microstructural characteristics such as grain size, micro-crack dimensions, lineament and their orientation have been correlated with fracture toughness along specific planes showing a clear correlation with the measured values. The anisotropy in toughness is directly linked to the anisotropy of dominant microstructural set, i.e. grain shape and micro-crack orientation with respect to fracture propagation direction. For example, fractures propagating at right angle to the major set of weakness plane yielded the highest fracture toughness value, (Nasseri and Mohanty, 2007).

Fracture toughness anisotropy appears to strongly control the dimensions and the nature of the fracture process zone (e.g. width of FPZ) within even the same rock type. The characteristics of FPZ have also been monitored in real time by its AE activity in a Lac du Bonnet granitic sample, (Nasseri et al. 2006). It is seen that the AE rate rapidly accelerates a few seconds prior to failure. Source locations suggest migration of the fracture plane occurring mainly in the triangular area defined by the notch. They also clearly show the evolution of FPZ around the main propagating crack issuing from the notch tip.

To further assess the role of pre-existing rock fabric on FPZ, high resolution micro-CT scanning system has been employed. This involved 3-D scanning of the entire cracked region ($35 \times 25 \times 10$ mm). About 1000 slices were prepared along three orthogonal planes in Barre granite to examine the role of micro-structure on the characteristics of FPZ along directions parallel and normal to dominant petrofabric orientations. The analysis shows that the width of FPZ is much larger in a direction that is perpendicular to the dominant petrofabric orientation. It also coincides (Fig 1a) with the larger fracture toughness (i.e. 1.9 MPa $m^{0.5}$). The same FPZ along a direction parallel to the preferred orientation is both narrower and more linear than the previous case (Fig 1b). It is also yields the lowest value of fracture toughness (i.e. 1.1 MPa $m^{0.5}$). The roughness of resulting fracture surfaces in the same rock was also analyzed by profilometry technique to compare the respective roughness of the fracture surface along these two directions. It was shown that the plane representing the highest K_{IC} (i.e. 1.9 MPa $m^{0.5}$) in Barre granite also shows the highest average fracture roughness value (i.e. 9.9), whereas the plane showing the lowest K_{IC} (1.1 MPa $m^{0.5}$) has a roughness value of 8.5 (Nasseri et al. 2007).

These results confirm the essential link among petrofabric anisotropy, fracture toughness, fracture surface morphology, and evolution and extent of FPZ along specific directions. The study also highlights the need for employment of advanced pre-failure, real-time and post-mortem diagnostic techniques in quantifying these inter-relationships.

Fig. 1a) Micro-CT image of fracture profile associated with the damage zone along XY plane characterized with maximum K_{IC}= 1.9 MPa.m$^{0.5}$along the direction perpendicular to that of preferred micro-fabric orientation in Barre granite. b) M-CT image of fracture profile along XY plane characterized by a minimum K_{IC}=1.1 MPa.m$^{0.5}$along a direction parallel to the preferred micro-fabric orientation in same rock. (The width of crack shown in fig.1b is an artefact of the process of slide preparations, and is not indicative of the true width of the crack)

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