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Technical Note

The shape effect on the morphology of the fracture surface induced by the Brazilian test

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1. Introduction

Fractures are one of the most important features affecting the mechanical behaviour of rock masses. The degree of fracturing in a rock mass can be influenced by several factors: in situ stress, boundary conditions and geological history. Fractures are the main factor that must be taken into consideration in the control of thermo-hydro-mechanical behaviour. Two important physical characteristics of fracture that are used in rock mass classification systems are: the aperture and the roughness. Many studies have been conducted on these two components to show their relation with the mechanical behaviour.[1–3] In applied rock mechanics, the shear strength of discontinuities is the most important parameter for stability analyses. To estimate the shear strength, the surface roughness can be taken into account to model the shear behaviour of fractures.[4,5]

Fracture roughness has been quantitatively characterized based on morphological approaches, such as empirical,[6] statistical[7,8] and fractal approach.[9–11] Each of these approaches uses parameters that quantify the fracture topography. Among them, empirical approaches are the most commonly used in rock mechanics. The Joint Roughness Coefficient (*JRC*) – as an empirical approach – is a widely used roughness parameter.[12] Since *JRC* is a subjective parameter that is estimated by comparing the roughness profile with ten standard roughness profiles,[13] relationships have been proposed between the *JRC* value and various roughness parameters used in statistical approaches. These relations quantitatively express the roughness parameters.[8,14–19]

Brady and Brown[20] showed that fractures occur in three conditions or modes: shear, tensile or a combination of both. Mode I defines the fracture created in tension, while Mode II and III are the fractures induced by both tensile and shear stresses (Mode II as in-plane shear and Mode III as out of plane tear). These fracture modes can be created in laboratory using direct or indirect tensile, uniaxial and triaxial compression tests. The fracture surface induced by an indirect tension test (Brazilian test) is created in Mode I. Fig. 1 shows the roughness variation of these fracture modes on Gabbro samples. There are many experimental and numerical studies for the stress and strain distribution in the samples split by Brazilian tests.[13,21–27] More recently, several investigations have been conducted on the cracking patterns of foliated and pre-notched samples with different arrays.[28–33] Stirling et al.[34] performed Brazilian tests based on ASTM, ISRM and Flattened loading methods and identified the location of crack initiation and fracture patterns. They showed that the onset location of cracking is clearly at the center; however, the crack propagation could not be captured by Digital Image Correlation (DIC) in these tests.

Apart from the ultimate stress applied on samples submitted to Brazilian tests of different L/D ratio, the strain variation along the loading direction was also investigated by Stirling et al.[34] Accordingly, the degree of the deformation perpendicular to the loading axis increases across the diameter as L/D ratio decreases. This may be due to the confinement induced by the length of the specimen. The results of this study showed that the effect of the strain distribution in terms of the L/D ratio is more tangible on the fracture surface along the loading direction.

To date however, little work has been done on the relationship between the fracture roughness and loading modes. Seredin et al.[35]

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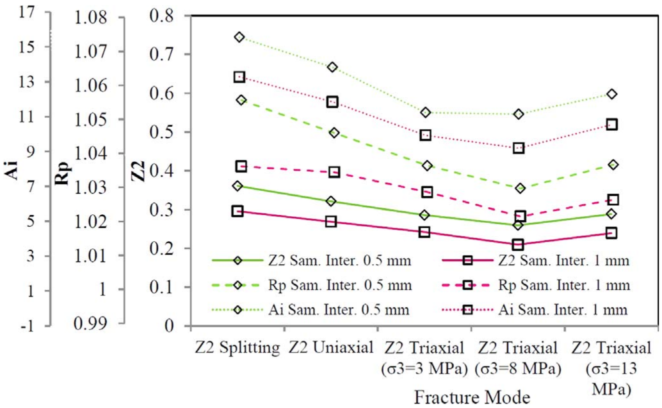

Fig. 1. Roughness of the fracture obtained from different loading modes[36].

also conducted laboratory tests on rocklike material to create fractures in different modes. The results of this study showed a variation of roughness in fractures created by different loading modes. This investigation indicated that the roughness of the fracture created using uniaxial tension is higher than those created using other loading modes. They also concluded that the roughness decreases when the confining pressure (in triaxial mode) increases.

Khosravi et al.[36] and Khosravi [37] also investigated the influence of the fracture modes on the roughness by conducting splitting, uniaxial and triaxial compression tests. The observed results for gabbro were in good agreement with the results obtained by Seredin et al.[35] However, in this case, the roughness obtained using splitting test was higher than those obtained from other loading modes. Fig. 1 shows the schematic view of the splitting test and the results obtained using different loading modes for gabbro samples.

Feng et al.[38] carried out an investigation on the fracture surface morphology obtained from Brazilian tests on granite samples with a L/D ratio of 0.4. Three fracture roughness profiles were selected parallel to the loading axis. The results showed that the three segments along the profiles - even with 60% overlap do not have identical roughness parameters.

A similar study was conducted by Khosravi and Simon[39] on tensile induced fractures in gabbro samples. Different roughness profiles parallel to the loading axis were selected. The results indicated that the roughness parameters calculated for three non-overlapping segments were not similar. Khosravi and Simon[39] also investigated the roughness profile of the fractures created using Brazilian tests on Gabbro samples with different L/D ratio. The results showed that the roughness of the profiles parallel to the loading axis decreases when the L/D ratio increases.

In this paper, the roughness parameter (*JRC*) of the tensile fracture surfaces induced by Brazilian test was studied considering the loading direction and the size and rock type of the samples. The variation of roughness parameters along the roughness profiles parallel and perpendicular to the loading axis was investigated for different rock types. The results illustrate how the shape and loading direction of the samples can affect the fracture roughness. The roughness variation of three rock types with different grain sizes is also compared.

2. Methodology and experimental procedure

This study comprised of four steps including: (1) Samples with different L/D ratios were subjected to Brazilian tests. A total of five samples were tested for each L/D ratio; (2) At least 2–3 non-damaged fracture surfaces were scanned using a 3D laser scanner to evaluate the roughness profiles in the direction parallel and perpendicular to the loading axis.; (3) The root mean square (RMS) of the first derivative of the roughness profiles was calculated using the approach proposed by Myers[40]; and (4) The variation of the roughness parameter was studied for each induced fracture surface with respect to the loading direction and the size of the specimens.

2.1. Specimen type and size

This study was carried out on three rock types, gabbro, microgabbro and basalt. The gabbro tested was a coarse grained rock with a grain size ranging from 1 to 5 mm. Half of the gabbro samples mainly contained pyroxene (mainly clinopyroxene) and olivine as dark-coloured minerals and the other half of the samples contained grey-coloured plagioclase feldspar (up to 90%) in the form of rectangular crystals. Less than 5% of the gabbro was composed of quartz. The microgabbro tested was a plutonic intrusive igneous rock with intermediate sized grains ranging between 0.5 and 1.0 mm. The crystals in the microgabbro were smaller than those of the gabbro and were formed in an environment in which the magma cooled faster. It was composed of plagioclase crystals (≈60%), clinopyroxene (≈30%) and olivine (≈10%). The basalt tested was a fine-grained igneous (volcanic) rock mainly containing olivine, plagioclase and pyroxene with grain sizes ranging from approximately 0.3 to 0.5 mm. Olivine was a significant constituent in this basalt, which made the color greenish. Some other secondary minerals were found, such as calcite, quartz and chlorite. In summary, the gabbro, microgabbro and basalt samples were relatively similar in chemical composition but differed in grain size.

For this study, Brazilian tests were conducted on cylindrical NQ rock samples and different length (i.e., 23.75, 35.6, 47.5, 59.4 and 71.25 mm). A total of eighty-nine specimens were prepared for Brazilian tests.

2.2. Brazilian tests

To study the effect of sample shape on the roughness parameters, Brazilian tests were conducted on eighty-nine NQ sized specimens (47.5 mm diameter) using a Tinius Olsen testing machine with a capacity of 400,000 lbs at the Rock Mechanics Laboratory, at the University of École Polytechnique of Montreal. In this study, all tests were carried out based on ASTM[21] method by applying a line load induced by two flat platens and two cardboard cushions between the sample and platens. At least five samples were loaded for each L/D ratio using a loading rate of 0.3 MPa/s. It should be noted that only forty-one samples with undamaged surface were obtained after the Brazilian tests. Therefore, the L/D ratios of microgabbro samples were limited to 0.5, 0.75, and 1.0 due to sample availability and damaged samples.

2.3. Equipment

In this study, a laser profilometer (Kreon Zephyr© 25) was used to obtain 3D coordinates of the fracture surfaces. The best vertical resolution of this profilometer is 3 µm (in the z axis). Keron Zephyr is able to scan 30,000 points/s. The fracture surfaces were scanned after each Brazilian test. A high data density can be obtained using the profilometer in the form of a cloud of points. In this study, about 10,000,000 points for each sample were scanned and reduced by gridding to obtain the roughness parameters. The sampling interval of 0.1 mm (distance a data-point to the adjacent point) was taken into account in gridding the cloud of points.

2.4. Roughness characterization

This part of the study focused on the roughness characterization of the induced tensile fractures created in Brazilian tests. In most of the split samples, one half of the split sample was affected by a secondary fracture in the compression zone at the loading area(s). The other half was usually undamaged. Based on the cracking pattern and the degree