Effect of Specimen Geometry and Testing Method on Mixed Mode I–II Fracture Toughness of a Limestone Rock from Saudi Arabia

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Summary

The effect of testing method and specimen geometry such as diameter, thickness, and crack length and type on measured fracture toughness was investigated using specimens collected from a limestone rock formation outcropping in the Central Province of Saudi Arabia. Straight Edge Cracked Round Bar Bend (SECRBB), semicircular disk specimens under three point bending, and Brazilian disk specimens under diametrical compression were used in this investigation. SECRBB specimens were used for the Mode-I study, and notched Brazilian disk and semicircular specimens were used for the mixed Mode I–II study. The results show that specimen diameter and crack type have a substantial influence on the measured fracture toughness; however, loading rate, crack size, and specimen thickness seem to have a negligible effect on the fracture toughness. Mode-I fracture toughness is significantly influenced by specimen diameter and crack type, while their effects on Mode-II fracture toughness are generally negligible. The different specimens (SECRBB, Brazilian disk, and semicircular) can give comparable results only when the proper span to diameter ratio is used. The Brazilian disk with a straight notch was found to be the most convenient geometry to use for fracture toughness determination. A simple method of making a precise notch inside the disk is presented, using the combination of a drilling machine and a wire saw.

1. Introduction

When a notched rock specimen is subjected to externally applied load, stress concentrates in the vicinity of the crack tip. As this concentrated stress reaches a critical value, failure occurs due to the propagation of the preexisting crack. The fracture toughness is then calculated in terms of stress intensity factor (SIF) using the failure load, notch size, and other geometrical parameters of the specimen. Based on the loading type, there are three basic crack propagation modes in a fracture process, namely: Mode-I (tension, opening), Mode-II (shear, sliding), and
Mode-III (tearing). Any combination of these modes can occur as a mixed-mode. This study focuses on Mode-I, Mode-II, and Mixed Mode I–II.

For a valid fracture toughness determination, it is necessary to use specimen geometry and a testing method for which the fracture toughness value is not dependent on either. Three testing methods were considered, namely: Straight Edge Cracked Round Bar Bend (SECRBB), Fig. 1, semicircular disk specimens under three point bending, Fig. 2, and Brazilian disk specimens under diametrical compression, Fig. 3. The specimen geometry requirement for a valid and representative fracture toughness value of a rock material has been a matter of controversy among researchers. The criterion of the specimen size requirement for rock material has been adopted from that proposed initially for metals and introduced by Schmidt (1976) in the form of the following mathematical expression for the notched Brazilian disk specimen:

\[
\frac{a}{W - a} \geq 2.5 \left( \frac{K_{IC}}{\sigma_t} \right)^2,
\]

where,
- \(a\) = crack length (half of the crack length for the Brazilian disk);
- \(W\) = diameter of the specimen;
- \(D\) = radius of the specimen;
- \(\sigma_t\) = tensile strength of the rock; and,
- \(K_{IC}\) = pure Mode-I stress intensity factor.

Barton (1982) introduced a requirement for a minimum specimen thickness as follows:

\[
B \geq r_{mc} = 0.269 \left( \frac{K_{IC}}{\sigma_t} \right)^2,
\]

where,
- \(B\) = thickness of the specimen;
- \(r_{mc}\) = critical radius of the fracture process zone (FPZ), radial distance measured from the notch tip.

More recent studies on fracture toughness have confirmed that the above-mentioned criterion of minimum crack length varies from case to case, and is not strictly valid for all rocks and test methods (Lim et al., 1994b). It has been proven by a number of researchers that factor 2.5 in Eq. (1) for the minimum crack length is somewhat conservative and a factor less than that has been reported for most rocks. A summary of minimum crack length studies provided by Whittaker et al. (1992) suggested that the multiplication factor in Eq. (1) could range between 1.5 and 2. A more recent study of minimum crack length for valid fracture toughness value was conducted by Lim et al. (1994a). They documented a comprehensive list of minimum crack lengths required for valid fracture toughness testing for differ-