Experimental Investigation on the Effect of the Specimen Thickness on the Mode II Fracture Resistance of Rocks

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Extended Abstract

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Introduction

Rock masses have an enormous geometrical discontinuities such as void, notch, crack and flaw. These geometrical discontinuities which play as stress concentrator, cause to reduce the load bearing capacity of rock masses. In rock masses, the crack is the most important geometrical discontinuity assessed frequently by civil, mechanical and mining engineers and researcher. The fracture mechanics which is a branch of mechanical engineering science, has been often used for investigating the cracked rock samples. The fracture toughness is one of the important parameters in the fracture mechanics which describes the resistance of materials against the crack growth. On the other hand, since orientation of cracks relative to the loading directions can be arbitrary, brittle fracture in rocks may happen due to a combination of two major fracture modes, i.e. crack opening mode (mode I) and crack sliding mode without any opening or closing the crack flanks (mode II). In order to obtain the fracture toughness of rocks, several test configurations under pure mode I have been proposed. One of the parameters that has the influence on the fracture toughness of rocks and other materials is the thickness of test sample. Previous experimental results showed that the fracture toughness of rocks increases by increasing the specimen thickness until a specific thickness. After that, the fracture toughness decreases for thicker samples until plane strain condition occurs. Then, the fracture toughness becomes a fixed value when the thickness of sample varies.

The all preceding studies have been dealt with considering the effect of specimen thickness on fracture toughness focusing only the mode I fracture toughness and there is few research concerning the thickness effect on the mode II fracture toughness of rocks. Therefore, the aim of this paper is to investigate experimentally the effect of specimen thickness on the mode II fracture toughness.

Material and methods

To investigate the thickness effect on the mode II fracture toughness of rocks, several fracture tests were conducted on the semi-circular bend (SCB) specimens. The SCB specimen is a semi-disk of radius *R* and thickness *t* including an edge crack of length *a* loaded under three-point bending. When the crack is along the applied load and the bottom supports are symmetric relative to vertical crack, the SCB sample is under pure mode I loading. One of the methods for achieving the mixed mode loading in SCB sample is the asymmetry distances of bottom supports from the vertical crack located at the middle of bottom edge (see Figure 1). The pure mode II in this type of SCB sample is attained at a specific distances, i.e. at specific values of S_1 and S_2. These values of supporting distance can be obtained from finite element analysis.

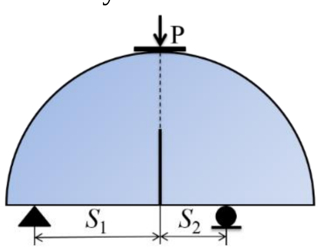

Figure 1. The schematic of SCB sample.

The fracture tests were done both on pure mode I and pure mode II, for the sake of comprehensiveness. Therefore, 32 SCB samples with 4 different thicknesses and 4 repetition for each specimen size were tested for both pure mode I and pure mode II. The specimens were cut from Ghorveh marble sheets with different thicknesses by water jet machine. Then, the specimens were cracked artificially by a high speed rotary diamond saw blade. The specimen dimensions and loading conditions are presented in

Table 1. Finally, the cracked SCB samples were tested by using a 300 kN ball-screw universal test machine. Table 1 also gives the average of four fracture loads (P_f) obtained for each thickness of specimen.

Table 1. The specimen dimensions and loading conditions.

R (mm)	t (mm)	a (mm)	S_1 (mm)	S_2 (mm)	P_f (N)	$S.D.$ (N)	
95	15	28.5	57	57	3220	150	Pure mode I
			57	11	4726	350	Pure mode II
95	25	28.5	57	57	6711	360	Pure mode I
			57	11	9445	882	Pure mode II
95	50	28.5	57	57	20285	1450	Pure mode I
			57	11	25441	4179	Pure mode II
95	80	28.5	57	57	31810	4672	Pure mode I
			57	11	36848	4686	Pure mode II

Results and discussion

The mode I and mode II fracture toughness (K_{Ic} and K_{IIc}) can be calculated for SCB samples from following equations:

$$K_{Ic} = \frac{P_f}{Rt}\sqrt{2\pi R}\, K_I^* \quad (1)$$

$$K_{IIc} = \frac{P_f}{Rt}\sqrt{2\pi R}\, K_{II}^* \quad (2)$$

where P_f is fracture load, R and t are the radius and thickness of SCB sample, respectively K_I^* and K_{II}^* are geometry factors which depend on geometrical ratios a/R, S_1/R and S_2/R and independent of specimen dimensions and magnitude of applied load. These dimensionless parameters are often obtained from finite element analysis. For tested SCB samples, the values of K_I^* and K_{II}^* were extracted from previous studies as shown in Table 2. Substituting the fracture loads and specimen dimensions from Table 1 and the values of K_I^* and K_{II}^* given in Table 2 into Eqs. (1) and (2), the mode I and mode II fracture toughness were calculated as listed in Table 2. Figure 2 also shows the variations of mode I and mode II fracture toughness with respect to specimen thickness. As seen from this figure, the fracture toughness for both pure modes increases for thicker samples until a specific thickness. After that, the values of K_{Ic} and K_{IIc} decrease by increasing the specimen thickness. For plane strain condition in which the thickness of specimen is relatively large, the values of K_{Ic} and K_{IIc} are nearly constant.

Table 2. The dimensionless parameters K_I^* and K_{II}^* for tested SCB samples and their corresponding fracture toughness.

R	t	K_I^*	K_{II}^*	K_{Ic} (MPa.√m)	K_{IIc} (MPa.√m)	
95	15	0.644	0.0	1.125	0.0	Pure mode I
		0.0	0.35	0.0	0.897	Pure mode II
95	25	0.644	0.0	1.411	0.0	Pure mode I
		0.0	0.35	0.0	1.075	Pure mode II
95	50	0.644	0.0	2.126	0.0	Pure mode I
		0.0	0.35	0.0	1.448	Pure mode II
95	80	0.644	0.0	2.083	0.0	Pure mode I
		0.0	0.35	0.0	1.311	Pure mode II

The other point assessed in the present study is the dependency of fracture path on specimen thickness in mode II loading. It was shown that the fracture trajectory becomes more curvilinearly when the thickness of specimen increases.

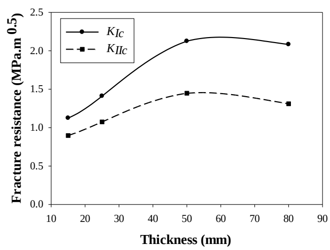

Figure 2. The variations of K_{Ic} and K_{IIc} versus the specimen thickness.

Conclusion

The effect of specimen thickness on the mode I and mode II fracture toughness of rock was investigated experimentally using the SCB specimens. The experimental results showed that the fracture toughness for both pure modes increases when the thickness of specimen increases until a specific thickness. After that, the values of K_{Ic} and K_{IIc} decrease by increasing the specimen thickness. For plane strain condition in which the thickness of specimen is relatively large, the values of K_{Ic} and K_{IIc} are nearly constant. Also, it is shown the crack grows more curvilinearly for thicker SCB samples.

Keywords: fracture toughness, rock, specimen thickness, fracture path, pure mode I and mode II loading.

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