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Three-dimensional numerical evaluation of the progressive fracture mechanism of cracked chevron notched semi-circular bend rock specimens

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ABSTRACT

The cracked chevron notched semi-circular bending (CCNSCB) method for Mode-I fracture toughness measurement has adopted the straight-through crack propagation assumption but never being fully verified. In this study, three-dimensional progressive fracture processes of CCNSCB specimens are numerically evaluated for the first time considering different supporting spans and heterogeneities. Results show that the crack front of the CCNSCB specimen is not straight-through but considerably curved, which inevitably induces errors for fracture toughness measurement; and the damaged/fractured zone can be prominently confined in the chevron notched ligament for a CCNSCB specimen with a large supporting span.

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1. Introduction

Rock fracture mechanics has been widely adopted in many engineering applications related to rock breakage or failure such as rockbursts, rock mass slope stability, rock cutting, hydraulic fracturing, tunneling, underground excavation, oil exploration and deep burial of nuclear waste. As an intrinsic property of rocks to resist fracture, the fracture toughness is of great significance in the research of rock fracture mechanics. Among the three basic fracture modes (i.e. Mode-I, the tensile mode; Mode-II, the shear mode; Mode-III, the tear mode), Mode-I (opening mode) fracture is the most frequently encountered failure mode of rocks against fracture; and thus the Mode-I fracture toughness has been mostly studied and an accurate determination of the Mode-I fracture toughness has attracted broad interests in rock fracture mechanics community.

Myriads of methods with varying sample configurations have been adopted in rock fracture toughness measurements including Brazilian disc (BD) method [1], notched semi-circular bend (NSCB) method [2] and [3], cracked chevron notched semi-circular bend (CCNSCB) method [4–6], cracked straight through Brazilian disc (CSTBD) method [7–11], cracked chevron notched Brazilian disc (CCNBD) method [12–16], diametric compression (DC) test [17], double edge cracked Brazilian disc (DECBD) method [18], edge crack triangular test [19], flattened Brazilian disc (FBD) method [20], hollow center cracked disc (HCCD) method [21], holed-cracked flattened Brazilian disc (HCFBD) method [22], holed-flattened Brazilian disc (HFBD) method [23], modified ring (MR) test [24], radial cracked ring [25] and [26], straight edge cracked round bar bend (SECRBB)

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Nomenclature

a	crack length
a_0	initial crack length
a_1	final crack length
a_m	critical crack length
AE	acoustic emissions
B	specimen thickness
BD	Brazilian disc
CB	chevron bending
CCNBD	cracked chevron notched Brazilian disc
CCNSCB	cracked chevron notched semi-circular bend
CSTBD	cracked straight through Brazilian disc
D	damage variable
DC	diametric compression
DECBD	double edge cracked Brazilian disc
E	elastic modulus of the damaged element
E_0	elastic modulus of the undamaged element
f'_c, f'_t	compressive and tensile failure strength of the element, respectively
FBD	flattened Brazilian disc
HCCD	hollow center cracked disc
HCFBD	holed-cracked flattened Brazilian disc
HFBD	holed-flattened Brazilian disc method
ISRM	International Society of Rock Mechanics
k	current calculation steps
K_I	Mode I stress intensity factor
K_{IC}	Mode I fracture toughness
m	heterogeneity index
MR	modified ring
N	total number of all elements in the model
n_i	number of damaged elements in the *i*th step
NSCB	notched semi-circular bend
P	load
P_{max}	maximum load
R	radius of the disc
RFPA	Rock Failure Process Analysis
RQD	rock quality designation
R_s	radius of rotary saw
S	span of the two support rollers
SECRBB	straight edge cracked round bar bend
SHPB	split Hopkinson pressure bar
SIF	stress intensity factor
SNDB	straight notched disk bending
SR	short rod
$W(x)$	Weibull distribution
Y^*	dimensionless stress intensity factor
Y^*_{min}	minimum dimensionless stress intensity factor
α_0	dimensionless initial crack length
α_1	dimensionless final crack length
α_B	dimensionless thickness
α_m	dimensionless critical crack length
α_s	dimensionless radius of rotary saw
β	the ratio of span to diameter
σ'_1, σ'_3	major and minor principal stress, respectively
σ_{c0}, σ_{t0}	uniaxial compressive and tensile strength, respectively
σ_{rc}, σ_{rt}	elemental residual compressive and tensile strength, respectively
ε	strain
$\bar{\varepsilon}$	equivalent strain
ε_{t0}	threshold strain at the elastic limit
ε_{ut}	ultimate tensile strain
λ	residual strength coefficient
φ'	angle of friction

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