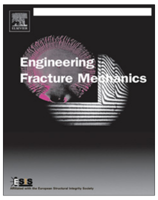
ARTICLE IN PRESS

Engineering Fracture Mechanics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech



Effects of loading rate and bedding on the dynamic fracture toughness of coal: Laboratory experiments

Yixin Zhao [a,b,c,*], Shuang Gong [b,c], Xianjie Hao [b,c], Yan Peng [d], Yaodong Jiang [a]

[a] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology, Beijing 100083, China
[b] College of Resources and Safety Engineering, China University of Mining and Technology, Beijing 100083, China
[c] Beijing Key Laboratory for Precise Mining of Intergrown Energy and Resources, China University of Mining and Technology, Beijing 100083, China
[d] State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing, 102249, China

ARTICLE INFO

Article history:
Received 12 June 2016
Received in revised form 7 March 2017
Accepted 9 March 2017
Available online xxxx

Keywords:
Coal
Fracture toughness
Bedding angle
SHPB
Notched semi-circular bend

ABSTRACT

In order to study the influence of bedding angle and loading rate on the initiation fracture toughness (IFT) of coal, notched semi-circular bending (NSCB) specimens were made by using a split Hopkinson pressure bar (SHPB) system. The dynamic IFT of NSCB coal specimens with various bedding angles and crack lengths under different loading rates were analyzed and discussed. A high-speed high-resolution digital camera was used to record the processes of cracking initiation and propagation in coal specimens. The experimental results indicate that the effects of bedding plane on the cracking pattern decreases with the increase of both loading rate and crack length in the specimens. The impact velocity dominates the evolution of the dynamic IFT of coal, and the anisotropy caused by bedding planes in the specimens plays a more critical role in the evolution of dynamic IFT than the crack length. The effects of bedding angles on the dynamic IFT decrease with the increase of impact velocity. The growth behavior of dynamic IFT of coal distinctly changes after the loading rate exceeds a critical value. In addition, a model of rate dependency was established to describe the dynamic IFT of coal.

1. Introduction

Dynamic fracture toughness of coal is the resistance of coal against fracture under high-rate loading [1,2], which is important for the selection of blasting parameters, stability analysis of coal mass under dynamic impact loading, and the prevention of coal bumps or bursts. So far, great efforts have been made to investigate the dynamic fracture toughness of rock/rock-like materials, such as Laurentian granite [3–6], Barre granite [7], marble [8–14], Fangshan gabbro [8–10], Huanglong limestone [15], asphalt mixtures [16], sandstone [17–20], shale [19], concrete [20], ceramic [21] and glass [22] using the split Hopkinson pressure bar (SHPB) or Kolsky bar. Compared with other rocks, coal is a well-known complex anisotropic and rate dependence rock [23]. The complex networks of bedding planes in coal and the different loading velocity associated with the transient nature of loading may result in difficulties to characterize the dynamic fracture features of coal. Therefore, there are just a few academic articles about investigations on the dynamic fracture toughness of coal. For example, the fracture toughness of Canadian coal under both quasi-static and dynamic loading conditions was determined by Klepaczko et al. [24], the mixed-mode fracture toughness of coal under dynamic loading conditions was investigated by Zipf and Bieniawski [25] and

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* Corresponding author at: College of Resources and Safety Engineering, China University of Mining and Technology, Beijing 100083, China.
E-mail address: zhaoyx@cumtb.edu.cn (Y. Zhao).

http://dx.doi.org/10.1016/j.engfracmech.2017.03.011
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Please cite this article in press as: Zhao Y et al. Effects of loading rate and bedding on the dynamic fracture toughness of coal: Laboratory experiments. Engng Fract Mech (2017), http://dx.doi.org/10.1016/j.engfracmech.2017.03.011

Nomenclature

a	crack length (mm)
A_B	cross-sectional area of the incident/transmitted bar (mm^2)
B_s	thickness of the specimen (mm)
c	cohesion of the specimen (MPa)
C_r	Rayleigh wave velocity (m/s)
D	diameter of the specimen (mm)
e	crack width (mm)
E_B	Young's modulus of the incident/transmitted bar (GPa)
K_{IC}	mode I initiation fracture toughness (MPa $\sqrt{\mathrm{m}}$)
K_{Id}	dynamic initiation fracture toughness (MPa $\sqrt{\mathrm{m}}$)
$K_I(t)$	dynamic stress intensity factor (MPa $\sqrt{\mathrm{m}}$)
$\dot{K}_{\mathrm{I}}$	loading rate of fracture toughness(GPa $\sqrt{\mathrm{m}}$/s)
$P(t)$	applied dynamic load (N)
P_1	force at incident bar-specimen interface (N)
P_2	force at transmitted bar-specimen interface (N)
R	radius of the specimen (mm)
R_0	vitrinite reflectance (%)
S	span of bending (mm)
t	time recorded by high speed camera (μs)
t_f	time to fracture
v	impact velocity (m/s)
$Y(\alpha_a)$	geometric correction function (–)

Greek symbols

α_a	dimensionless crack length (mm/mm)
α_s	dimensionless supporting span (mm/mm)
σ_t	tensile strength (MPa)
$\varepsilon_I(t)$	incident strain (mm/mm)
$\varepsilon_R(t)$	reflected strain (mm/mm)
$\varepsilon_T(t)$	transmitted strain (mm/mm)
θ	bedding angle of the specimen (°)
ν	Poisson's ratio of the sample material (–)
ρ	density of the specimen ($\mathrm{kg/m}^3$)
σ_c	uniaxial compressive strength (MPa)
φ	friction angle of the specimen (°)

Abbreviations

BD	Brazilian disc
CB	chevron bend
CCNBD	cracked chevron notched Brazilian disc
CT	compact tension
CV	coefficient of variation
IFT	initiation fracture toughness
ISRM	International Society for Rock Mechanics
NSCB	notched semi-circular bending
SHPB	split Hopkinson pressure bar
SIF	stress intensity factor
SR	short rod

the mode-I fracturing of coal under impact loading conditions [23] was also analyzed based on the results of experiments and numerical simulation.

Unlike quasi-static fracture toughness tests, the dynamic fracture test has not had a uniform set of testing standards until now [26]. The methods to determine the dynamic fracture toughness of rocks are mostly extended from quasi-static ones, which can be approximately categorized into three groups, i.e. BD-type methods [3,9,12,14,21], bending-type methods [4,27–29] and compact-tension (CT)-type methods [7,17]. Moreover, the core-based sample configurations suggested by International Society for Rock Mechanics (ISRM) in the above testing methods involve the chevron bend (CB) and short rod (SR) specimens [30], the cracked chevron notched Brazilian disc (CCNBD) specimen [31] and the notched semi-circular bend (NSCB) specimen [32]. Among them, the NSCB specimen in the split Hopkinson pressure bar (SHPB) system

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