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Cohesionless crack at peak load in a quasi-brittle material

Ali Fakhimi [a,*], Ali Tarokh [b], Joseph F. Labuz [b]

[a] Department of Mineral Engineering, New Mexico Institute of Mining and Technology, Socorro, NM 87801, USA
[b] Department of Civil, Environmental, and Geo-Engineering, University of Minnesota, Minneapolis, MN 55455, USA

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ABSTRACT

A three point bending fracture test was performed on a typical quasi-brittle material (Berea sandstone). The loading was continued into the post-peak region where crack growth was visible along the center line of the beam. Subsequent inspection of a portion of the specimen showed that part of the fracture offered no resistance to loading – a cohesionless crack existed. Digital image correlation was used to study the nature of the displacement discontinuity associated with the cohesionless (traction free) crack. The pattern identified in the post-peak region was used as a guide to study the displacement discontinuity at peak load. Two possibilities are offered: (1) The critical opening was developed at peak load. (2) A cohesionless crack, a few millimeters in length, existed at peak load, an observation that is not consistent with linear fracture mechanics. Some justification for cohesionless crack extension at peak load is discussed.

1. Introduction

Fracture of a quasi-brittle material does not completely follow the rules dictated by the linear elastic fracture mechanics (LEFM). The reason is the existence of a microcracked region surrounding the crack tip that behaves nonlinearly [1–3]. This nonlinear region called the fracture process zone (FPZ) influences the load-deformation characteristics and stability of the structure, and in many situations (particularly for small specimens), its existence cannot be ignored.

One approach to approximately consider the influence of the FPZ is to use the equivalent crack model in which the process zone is replaced by a crack and then this extended crack is considered in order to obtain a better estimate for the fracture toughness of the material. On the other hand, to capture the entire load-deformation process of a structure, the fracture energy is assumed to increase with the increase of the equivalent crack length (or with the increase of the FPZ size with loading); an *R*-curve is suggested to predict the complete fracture process of the quasi-brittle material.

In this study, a three point bending fracture test was conducted on a rock specimen and the induced displacement field was investigated using digital image correlation (DIC), a relatively simple technique to obtain the displacement field. DIC can be considered as a particle tracking method to identify the 2D displacement field from digital images [4]. The best match of subsets from current and reference images is acquired by minimizing the correlation coefficient of intensity values [5,6]. It is shown that for the particular rock and specimen size, a cohesionless crack was developed at peak load. This is an observation that is not normally accepted for fracture of a specimen with a positive geometry, where the stress intensity factor increases with extension of the crack. The justification for a cohesionless crack at peak load is discussed.

* Corresponding author.
E-mail address: ali.fakhimi@nmt.edu (A. Fakhimi).

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Nomenclature

G_f	fracture energy

Abbreviations

CMOD	crack mouth opening displacement
DIC	digital image correlation
FPZ	fracture process zone
LEFM	linear elastic fracture mechanics

2. Test results

Berea sandstone was used in this study. The rock has a Young's modulus of 10 GPa and a *P*-wave velocity of 2380 m/s. The sandstone specimen was prepared with length = 276 mm (span = 254 mm), height = 99.9 mm, and thickness = 24 mm. A notch at the center of the beam was cut to a length = 15 mm and width = 1.7 mm. Three point bending was applied by controlling the crack (notch) mouth opening displacement (CMOD) rate = 0.1 μm per second. DIC was used to study the displacement field in an area 20 × 30 mm surrounding the notch tip.

The load-CMOD response is shown in Fig. 1; note the substantial nonlinear response indicative of a large process zone. The peak load, 1537 N, occurred at the CMOD = 137 μm. The loading of the beam was continued up to 50% of peak load in the post peak regime and then it was unloaded. The displacement fields at 50% post-peak and the peak load were obtained from the DIC technique and are reported in Fig. 2. Notice the sharp clustering of displacement contours both at the peak load and in the post-peak region suggesting intensive damage along the centerline of the beam.

The unloaded beam was inspected and a crack of about 25 mm in length above the notch tip was observed with an unaided eye (Fig. 3). To measure the loading resistance of portions of the induced crack, the specimen was secured with metal bands to prevent it from falling apart after cutting. The specimen was carefully cut along the beam length to the tip of the visible crack. Subsequently, the metal bands were cut to inspect the specimen. The two rock pieces were separated along the induced crack without applying any force, suggesting that the induced crack (or at least the visible part of it) was cohesionless or traction free. The cohesionless crack and DIC measurements provided an opportunity to study the displacement field in the specimen around the crack.

Fig. 4 shows the total horizontal displacement profiles along horizontal lines for different *y*-values; *y* = 0 is the notch tip location. The loading interval is from zero to 50% in the post-peak. Note that there is a displacement discontinuity once the center line of the beam is crossed. This displacement discontinuity, as expected, is reduced as the observation line is moved from the notch tip to the positions of greater *y* values. Further, the displacement profiles show some asymmetry with respect to the beam center line due to the tortuous crack path and some small rigid body motion in the horizontal direction.

It is interesting to note that on both sides of the displacement discontinuity, there is a small segment in Fig. 4 with a zero and then a negative slope. Assuming that this region is still behaving elastically, we can conclude that this region is either carrying no axial load (in the horizontal direction) or it is under compression. The compressive load could be due to contact forces developed along the faces of the induced tortuous crack (Fig. 5).

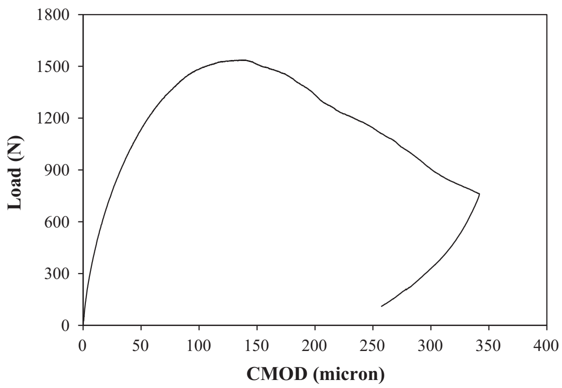

Fig. 1. Load vs CMOD for the sandstone specimen under three point bending.