

Available online at www.sciencedirect.com



JOURNAL OF THE MECHANICS AND PHYSICS OF SOLIDS

Journal of the Mechanics and Physics of Solids 56 (2008) 25-50

www.elsevier.com/locate/jmps

Transition of mode II cracks from sub-Rayleigh to intersonic speeds in the presence of favorable heterogeneity

Yi Liu^a, Nadia Lapusta^{b,*}

^aDivision of Engineering and Applied Science, California Institute of Technology, Pasadena, CA 91125, USA

^bDivision of Engineering and Applied Science and Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA

Received 22 January 2007; received in revised form 8 June 2007; accepted 11 June 2007

Abstract

Understanding sub-Rayleigh-to-intersonic transition of mode II cracks is a fundamental problem in fracture mechanics with important practical implications for earthquake dynamics and seismic radiation. In the Burridge-Andrews mechanism, an intersonic daughter crack nucleates, for sufficiently high prestress, at the shear stress peak traveling with the shear wave speed in front of the main crack. We find that sub-Rayleigh-to-intersonic transition and sustained intersonic propagation occurs in a number of other models that subject developing cracks to intersonic loading fields. We consider a spontaneously expanding sub-Rayleigh crack (or main crack) which advances, along a planar interface with linear slipweakening friction, towards a place of favorable heterogeneity, such as a preexisting subcritical crack or a small patch of higher prestress (similar behavior is expected for a small patch of lower static strength). For a range of model parameters, a secondary dynamic crack nucleates at the heterogeneity and acquires intersonic speeds due to the intersonic stress field propagating in front of the main crack. Transition to intersonic speeds occurs directly at the tip of the secondary crack, with the tip accelerating rapidly to values numerically equal to the Rayleigh wave speed and then abruptly jumping to an intersonic speed. Models with favorable heterogeneity achieve intersonic transition and propagation for much lower prestress levels than the ones implied by the Burridge-Andrews mechanism and have transition distances that depend on the position of heterogeneity. We investigate the dependence of intersonic transition and subsequent crack propagation on model parameters and discuss implications for earthquake dynamics. © 2007 Elsevier Ltd. All rights reserved.

Keywords: Dynamic fracture; Supershear transition of earthquakes; Crack mechanics; Elastic material; Boundary integral equations

1. Introduction

Understanding sub-Rayleigh-to-intersonic transition of mode II cracks is a fundamental problem in fracture mechanics with important practical implications for earthquake dynamics and seismic radiation. In this work, the word "intersonic" refers to speeds between the shear wave speed c_s and the dilatational wave speed c_p , the range which is often called "supershear" in the geophysical literature. Large strike-slip

^{*}Corresponding author. Tel.: +1 626 395 2277; fax: +1 626 583 4963.

E-mail address: lapusta@caltech.edu (N. Lapusta).

^{0022-5096/} $\ensuremath{\$}$ - see front matter $\ensuremath{\textcircled{}}$ 2007 Elsevier Ltd. All rights reserved. doi:10.1016/j.jmps.2007.06.005

earthquakes are dominated by in-plane sliding and some of their dynamics can be understood by considering them as mode II cracks. Although average rupture speeds for earthquakes are sub-Rayleigh in general, seismic data for several earthquakes points to intersonic propagation. Examples are 1979 Imperial Valley earthquake (Archuleta, 1984; Spudich and Cranswick, 1984), 1992 Landers earthquake (Olsen et al., 1997), 1999 Izmit earthquake (Bouchon et al., 2001), 2001 Kunlun earthquake (Bouchon and Vallée, 2003), and 2002 Denali earthquake (Ellsworth et al., 2004). While this evidence is indirect, as it is obtained through analysis of seismic data, it presents a compelling case that intersonic propagation and hence sub-Rayleigh-to-intersonic rupture transition may occur during earthquakes.

Direct evidence for the possibility of spontaneous intersonic transition and propagation has been obtained in the laboratory. Intersonic crack propagation of mode II cracks was observed on weak interfaces under impact loading conditions (Rosakis et al., 1999; Rosakis, 2002). Needleman and Rosakis (1999) numerically modeled those experiments and qualitatively reproduced their crack speed histories. Xia et al. (2004) reported experimental observations of spontaneous sub-Rayleigh-to-intersonic transition of mode II cracks propagating along a frictionally held homogeneous interface. Xia et al. (2005) experimentally observed a change in rupture speed from sub-Rayleigh to intersonic along a bi-material interface.

Studies of sub-Rayleigh-to-intersonic transition have important practical implications. On the one hand, understanding which parameters and conditions do, and do not, lead to intersonic rupture propagation in models can help constrain properties and stress conditions on those faults where rupture speeds of large earthquakes have been inferred. On the other hand, it is important to know which conditions can lead to intersonic propagation on faults and how likely are intersonic ruptures to occur. This is because intersonic ruptures can cause much stronger shaking far from the fault than subsonic ruptures can, as Mach fronts generated by intersonic ruptures carry large stresses and particle velocities far from the fault (Bernard and Baumont, 2005; Dunham and Archuleta, 2005; Bhat et al., 2007).

Theoretical and numerical studies of sub-Rayleigh-to-intersonic transition date back to Burridge (1973) and Andrews (1976). Burridge (1973) considered a self-similar mode II crack and found that a shear stress peak propagates with the shear wave speed c_s in front of the crack. Andrews (1976) performed numerical simulations of spontaneous crack propagation on a uniformly prestressed interface governed by a linear slipweakening law (Fig. 1a) in which friction linearly decreases from static friction strength τ^s to constant dynamic friction strength τ^d over a characteristic slip d_0 . This law implies a finite fracture energy given by $\frac{1}{2}(\tau^s - \tau^d)d_0$. Andrews (1976) started with shear stress and slip distributions appropriate for a critical static crack under a uniform far-field shear loading τ^o and initiated a dynamic crack by slightly increasing shear stress along the critical crack profile. The half length of the critical crack is given by (Andrews, 1976):





Fig. 1. (a) Linear slip-weakening friction law. Γ is the shear strength of the interface and δ is slip (or relative displacement in shear) across the interface. (b) A prescribed crack interface is embedded in an infinite, elastic, and homogeneous space. The main crack is initiated from a region around x = 0. This work considers interaction of the main crack with a region of heterogeneity that exists in front of the main crack and may initiate a secondary crack. Depending on the model, the heterogeneity is a preexisting subcritical crack, a patch with higher prestress, or a patch with lower static friction strength. When discussing crack tips and their speeds for both main and secondary cracks, we always refer to crack tips that propagate in the direction of increasing x, or to the right in all figures, unless specified otherwise.

Download English Version:

https://daneshyari.com/en/article/797029

Download Persian Version:

https://daneshyari.com/article/797029

Daneshyari.com