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Frictional sliding modes along an interface between identical elastic plates subject to shear impact loading

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Abstract

Frictional sliding along an interface between two identical isotropic elastic plates under impact shear loading is investigated experimentally and numerically. The plates are held together by a compressive stress and one plate is subject to edge impact near the interface. The experiments exhibit both a crack-like and a pulse-like mode of sliding. Plane stress finite element calculations modeling the experimental configuration are carried out, with the interface characterized by a rate and state dependent frictional law. A variety of sliding modes are obtained in the calculations depending on the impact velocity, the initial compressive stress and the values of interface variables. For low values of the initial compressive stress and impact velocity, sliding occurs in a crack-like mode. For higher values of the initial compressive stress and/or impact velocity, sliding takes place in a pulse-like mode. One pulse-like mode involves well-separated pulses with the pulse amplitude increasing with propagation distance. Another pulse-like mode involves a pulse train of essentially constant amplitude. The propagation speed of the leading pulse (or of the tip of the crack-like sliding region) is near the longitudinal wave speed and never less than $\sqrt{2}$ times the shear wave speed. Supersonic

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trailing pulses are seen both experimentally and computationally. The trends in the calculations are compared with those seen in the experiments.

Keywords: Dynamic sliding; Rate and state friction; Crack-like; Pulse-like

1. Introduction

Frictional sliding along an interface between two rapidly deforming solids is a basic problem of mechanics that arises in a variety of contexts including moving machinery surface interaction (both macro and micro machines), material processing (e.g. cutting), the failure of fiber reinforced composites (e.g. fiber pullout) and earthquake dynamics (fault rupture). However, a framework for quantifying the wide range of observed dynamic frictional phenomena is only beginning to emerge. The classical Amontons–Coulomb description of friction states that the shear stress at an interface is proportional to the normal stress, with the coefficient of proportionality being the coefficient of friction. Two coefficients of friction are identified; a static coefficient of friction that governs the onset of sliding and a dynamic coefficient of friction that characterizes the behavior during sliding.

At the microscale, an evolving population of deforming and fracturing contacts, possible phase transitions and the presence of various lubricants play an important role in setting the static and dynamic coefficients of friction as well as in governing the transition between them. Rate and state models of friction aim at incorporating the effects of these microscale processes through appropriately chosen state variables, e.g. Dieterich (1979), Ruina (1983), Rice and Ruina (1983), Linker and Dieterich (1992), Prakash and Clifton (1993), and Prakash (1998).

Rate and state models of friction have come to the fore because they substantially influence the predicted mode and stability of sliding. Of particular interest is whether sliding occurs in a crack-like mode in which the surfaces behind the leading edge of sliding continuously slide or in a pulse-like mode, first proposed by Heaton (1990), in which sliding occurs over a relatively small propagating region. One significance of the sliding mode is that the calculated frictional dissipation in the pulse-like mode is significantly less than in the crack-like mode and is consistent with some values of heat generation inferred from geophysical field measurements (Heaton, 1990).

The classical Amontons–Coulomb description of friction is inadequate for addressing fundamental issues of sliding along interfaces between elastic solids because with Amontons–Coulomb friction sliding along such an interface is unstable to periodic perturbations for a wide range of friction coefficients and material properties, with a growth rate proportional to the wave number (Renardy, 1992; Adams, 1995). When generalized Rayleigh waves exist, Ranjith and Rice (2001) found that there are unstable modes for all values of the friction coefficient. Mathematically, instability of periodic perturbations renders the response of a material interface with Amontons–Coulomb friction ill-posed. Physically, it implies that during sliding energy is transferred to shorter wave lengths, leading to pulse