Dynamic fracture along bimaterial and heterogeneous interfaces

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Dynamic fracture, Friction, Bimaterial interfaces, Heterogeneities, Intersonic crack, Boundary integral method

1 INTRODUCTION

Intersonic debonding, for which the speed of the debonding front exceeds the shear wave speed of the more compliant material, has received increasing attention over the past decade. In particular, the case of bimaterial problems characterized by high material mismatch shows that contact plays a key role in the failure process. Rosakis and co-workers (1995, 1998, 2003) performed different experiments of dynamic debonding along planar interfaces between a quasi-rigid medium made of Steel or Aluminum, and a compliant medium, PMMA or Homalite. By recording the fringe patterns in the vicinity of the propagating debonding front, they provided a better description of the subsonic/intersonic transition and the behavior of contact behind the crack tip.

We investigate numerically the dynamic in-plane debonding along bimaterial planar interfaces using a spectral formulation of the elastodynamic boundary integral equations. This boundary integral method, developed by Geubelle and Rice (1995) and extended to bimaterial problems by Breitenfeld and Geubelle (1997, 1998), allows for the very efficient modeling of dynamic debonding using a discretization limited to the interface. It provides very fine level of refinement, unattainable with more conventional methods such as the finite element and finite difference schemes. The focus of this study is put on the role of friction along bimaterial interfaces in the transition from subsonic to intersonic regimes of propagation.

2 PROBLEM DESCRIPTION

The problem geometry is described by two semi-infinite bodies bonded together along a planar interface. Each body is made of a linear isotropic elastic material characterized by the elastic modulus E, the Poisson's ratio ν, the shear wave speed c_s and the dilatational wave speed c_p. Friction resulting from post-fracture contact along the interface is modeled using a regularization of Coulomb friction law presented by Kammer *et al.* (2014).

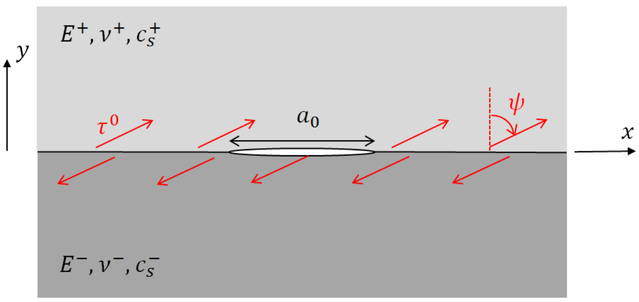

FIGURE 1 – Geometry of the bimaterial fracture problem.

The geometry of the problem is presented in Figure (1). A 1-D interface is pre-stressed with a load τ_0 applied in the $x - y$ plane with an angle ψ with respect to the y axis. At time $t = 0$, a crack of initial length a_0 is introduced and starts to propagate spontaneously along the interface.

3 ORIGIN OF CONTACT ZONES IN BIMATERIAL FRACTURE

We first study a failure event along an Aluminum-Homalite interface through space-time diagrams, the evolution of damage parameters at discrete positions in the path of the crack, energetic arguments, and the evolution of the speed of the leading and trailing edges of the cohesive and contact zones. Compared to the single-material system, the bimaterial set-up breaks the symmetry at the interface causing two effects. First, an inherent mode mixity participates in the failure even with purely tensile or shear far field loading conditions. Secondly, an asymmetric behavior is observed between crack propagation directions, i.e., in the same or the opposite direction of the shear displacements of the more compliant material. When the crack propagates in the same direction, the subsonic/transonic transition is sharp and the contact area appears directly after the cohesive zone. The oncoming crack propagation shows, however, a smooth subsonic/intersonic transition and a contact zone which detaches from the crack tip.

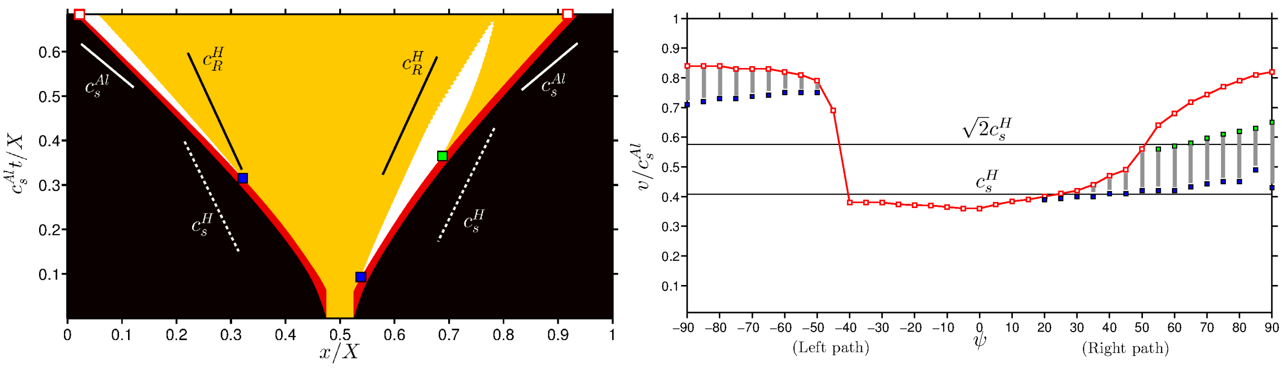

FIGURE 2 – (*Left*) Space-time diagram of a dynamic debonding between Aluminum and Homalite for $\psi = 75°$. The black regions correspond to intact portions of the interface, the red areas indicate the cohesive zones, the yellow regions are traction-free and the white regions correspond to the contact zones. (*Right*) Influence of ψ on the propagation speed v. As highlighted in the space-time diagram, white squares show the propagation velocities reached at the end of the simulation, blue squares the speeds when a contact area appears behind the crack tip and green squares the speeds when the contact zone detaches from the crack tip. The vertical gray bars highlight crack velocities where the contact zone is trailing the crack tip.

Figure (2) present the results with a particular attention given to the behavior and the role of frictional contact. At the left tip of cracks subjected to a shear-dominated loading, the material mismatch causes a normal compressive stress leading to a contact zone trailing the crack front. Another type of contact zones was observed as the front propagates with $c_s < v < \sqrt{2}c_s$ with respect to Homalite. Subsequent to face closure behind the crack tip, a Rayleigh disturbance propagating at the surface of the material causes a contact zone detached from the propagation front. We finally showed that if the contact behavior is entirely described by the more compliant material in the Aluminum-Homalite problem, a mixed behavior (governed by the top and bottom materials) is observed when the material mismatch is reduced.

4 ONGOING WORK

Despite a fundamental set-up (semi-infinite solids, periodic boundary conditions), the spectral scheme allows for the simulations and the descriptions of many different behaviors observed in bimaterial experiments (distinct natures of contact zones, unfavorable velocity range, asymmetric crack propagation). Using the same method, the current work is focusing on the effect of tougher heterogeneities along the interface. A centered crack propagating along a 1-D heterogeneous interface under mixed-mode loading is considered. The surrounding medium is only made of Homalite while interface heterogeneities correspond to regularly-spaced stripes of higher (five times) fracture energy. Figure (3) presents space-time diagram of the resulting fracture event.
Two regimes of propagation are observed during time. The first one is characterized by the existence of several crack tips ; a front tip breaking the weaker bonds while the tougher region traps the rear front.

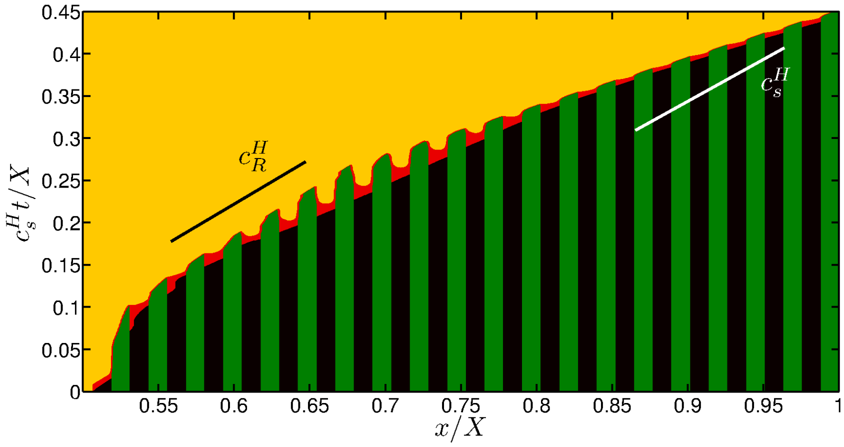

FIGURE 3 – Space-time diagram of a dynamic rupture along a heterogeneous Homalite-Homalite interface for $\psi = 45°$. A regime transition is observed around $c_s^H t/X = 0.33$. Green regions represent intact portions of the interface with five times higher fracture energy. Color code as in Figure (2).

The failure occurs by successive instabilities similar to a stick-slip crack propagation. As more energy is available at the interface (i.e. longer crack), a second regime is observed where failure happens at a single front propagating with a steady pattern. These behaviors are similar to *weak* and *strong pinning* regimes observed along 2-D heterogeneous fracture plane (Roux *et al.* 2003).

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