1 Abstract

Observations suggest that shear bursts and sustained shear superposition may have occurred in a number of earthquakes (such as 1992 Landers, 1999 Srigi, and 2001 Kurnut), in which two mechanisms have been proposed to explain the sub-Rayleigh-to-supershear rupture transitions. However, it is still debatable whether it is a 2D or 3D process. It needs to accomplish two goals: (i) nucleate a crack and (ii) drive the crack fast enough. These two goals are inseparable in the Burgers-Andrews mechanisms, as they both initiate from the shear stress peak of the main crack propagating in a uniform prestress field. Our simulations show that goal (i) can be achieved in other ways. For example, we can advance Mode II rupture to a location susceptible to crack nucleation, such as a preexisting subcritical crack, a patch of lower static friction strength, or a patch of higher prestress. In these cases and under the right conditions, the secondary cracks nucleates before the shear stress peak arrives, and the stress field of the advancing main rupture is still able to drive the secondary crack to supershear speeds. Hence nucleating the daughter crack at the shear stress peak, as it is done in the Burgers-Andrews mechanism, is not essential for the subsequent supershear propagation. One can also use different means of driving the crack supersear, such as overstretching or a patch of an dynamic stress field.

We observe the following interesting features in our simulations, which we will present along with our preliminary analysis:

(1) Crack fronts can abruptly jump from the Rayleigh-wave speed to a supershear speed. We call this “direct” supershear transition. For example, consider a secondary crack nucleated by overstressing a fault for the case $\tau_l > \tau_s$. At the beginning of the simulation, the crack front is advancing at the Rayleigh-wave speed. Once the Rayleigh-wave speed is reached, the secondary crack jumps to a supershear speed instantaneously.

(2) The supershear transition mechanisms we have described work not only in 2D plane models, but also in 3D models under certain conditions.

(3) Once the transition takes place in our models, the supershear rupture propagation speed is independent of the prestress, and is driven by the Burgers-Andrews mechanisms. This shows that the level of prestress implied by the prestress on the crack edge (Nc or $\tau_l$) is enough to trigger the Burgers-Andrews mechanism.

2 Supersear transition in our model

In the following, we will present supershear rupture propagation speeds and smaller cell size $\Delta x$. Hence, in the limit of $\Delta x \to 0$, the daughter crack should be inseparable from the crack propagating at Rayleigh-wave speed. At $\tau_l > \tau_s$, a daughter-like crack initiates the main cell ahead of the preexisting crack front, and propagates with supershear speeds immediately. This process is the same as that observed under the advancing stress field of the main rupture. The right figure shows the rupture time on the interface of the simulation for the case $\tau_l > \tau_s$. At the beginning of the simulation, the crack front is advancing at the Rayleigh-wave speed. At $\tau_l > \tau_s$, a daughter-like crack initiates at cell ahead of the preexisting crack front, and propagates with supershear speeds immediately. This process is the same as that observed under the advancing stress field of the main rupture.

3 A crack under over-stressing condition

Supershear transition can induced by overstressing a crack. Consider the case with prestress $\tau_l > \tau_s$. At the beginning of the simulation, the stress inside the patch drops from $\tau_l$ to $\tau_s$ instantaneously, and supershear propagation starts. The right figure shows the initial stress distribution in front of a main rupture.

4 Advanced main rupture toward a patch of higher prestress

Instead of having a preexisting crack, we introduce a patch of higher prestress. The fault outside the patch has stress low compared to the Burgers-Andrews mechanism, with $S < \tau_s/Lc$. The small patch of higher prestress completely changes the rupture behavior. Without the patch, the main rupture propagates with sub-Rayleigh speeds. However, the patch (with the length $Lc$ in the simulation) induces the rupture to transition to supershear, and the rupture remains supersear afterward. This shows that the level of prestress implied by the Burgers-Andrews mechanism is not needed to maintain the supershear propagation. Hence, supershear propagation on real faults can occur under prestress that are much lower than the values implied by the Burgers-Andrews mechanism.

5 Discussion

The described abrupt supersear transition mechanisms work in 3D fault models as well. We simulate the rupture propagation on a strike-slip fault interface, where a crack crack is initiated by shear stress in the 3D plane models. This process is the same as that observed under the advancing stress field of the main rupture.