Numerical simulations of the effect of frictional melting on seismic slip and rupture process

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1. Introduction

We numerically simulate an interaction between seismic slip and frictional melting in 1-dimensional (1D) and 2-dimensional (2D) elastic medium. The effect of frictional melting on the seismic slip has not been estimated quantitatively. If viscosity of frictional melt is very low, large stress drop may appear (Jeffreys, 1942). However, the rock experiments about frictional melt under high speed shearing show large frictional stress at the onset of the melting (Hirose and Shimamoto, 2005). Thus, such high frictional stress may prevent further seismic slip in the faulting process (Fialko, 2004). To evaluate these interactions, we construct a model of frictional behavior from the onset of seismic slip to frictional melting, and simulate the behaviors of seismic slip with this model.

2. Model of friction

We introduce a model with three friction regimes; the constant friction without melt patches, the transitional friction to complete melting, and the viscous friction after melt covers fault surface. During the viscous friction, we assume that the viscosity decreases with temperature, and the development of thickness of viscous melt layer is described by the balance of heat conduction. This fault model reproduces the rise of shear stress at the transitional friction regime and the peak frictional stress at the onset of complete melting as seen in the experiments.

3. Result

For a typical case of 1D elastic medium in our study (1 m/s of initial slip velocity, 1 s of characteristic time of slip, 20 MPa of frictional stress, and 2 mm thickness of inelastic layer), slip velocity drops from the case of no interaction at 0.1 s by high viscous friction (viscous braking). Though heating rate is reduced by the decrease of slip velocity, sustained slip continues to supply energy into fault zone. Consequently, frictional melting occurs and large stress drop arises (melt lubrication) at 0.5 s. Our simulations for various parameters show not only heating rate but adiabatic situation is important to cause melt lubrication.

We introduce the above frictional system into 2D anti-plane problem, where the rupture starts spontaneously at the time that the shear stress exceeds peak strength at the point. As well as the 1D cases, viscous braking and subsequent melt lubrication occur at each point of fault plane, for example in the case of 5 MPa of stress drop, 1 s of characteristic time of slip, 20 MPa of frictional stress, and 2 mm thickness of inelastic layer. Assuming 20 km size of asperity, we simulate the interaction for various parameters, and evaluate the influences on the seismic slip of asperity. Within our parameter sets, following changes of parameters have an effect to promote melt lubrication; high frictional stress, large stress drop, thick inelastic layer, low thermal conductivity, and low viscosity. Moreover, frictional melting process also affects rupture velocity. Though viscous braking decelerates the rupture velocity, rupture process and melt lubrications are accelerated by the large stress drop after melt lubrication starts.

4. Discussion

Though our results show the large scale distributions of frictional melting is likely to occur for realistic parameters, such large distribution of pseudotachylyte is rare. This may suggest the inelastic zone is wider than our assumption, or another physical process (e.g. thermal pressurization) may prevent the fault zone from such high heating. Comparison with geological and experimental observations will enable us to construct more realistic model of the source process in earthquakes.

References

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