Simulation of the interaction between seismic slip and melt layer considering temperature dependent viscosity and moving boundary

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1.Introduction

In terms of the energy balance, earthquake is a process that the accumulated strain energy is consumed as radiated seismic wave energy and dissipated energy at the fault zone. Dissipated energy is partitioned to the fracture energy and frictional heat. Some researchers have mentioned the possibility that the frictional heat causes abrupt rise of the pore pressure or the melting of the fault gauge, and finally large stress drop and seismic slip. However, the interaction between such effects and seismic slip has not been studied quantitatively. In this study, we aim to evaluate the effect of frictional melting on the seismic slip quantitatively. We simulate the fault response with melt layer introducing temperature dependent viscosity of melt and allowing the boundary of the phases to move.

2. Constatnt Loading Velocity

At first, we check the frictional response of the melt layer to constant loading velocity. We assume a laminar flow within the melt layer, no density change throughout both phases, and a sharp boundary between the solid and melt phases. From this assumption, the temperature distribution is calculated from thermal diffusion equation. We express a function of viscosity as A*exp[B/(T+C)] (T: Temperature; A,B,C: constants). Physical parameters are chosen referring to the study of Huppert and Sparks (1988), and Otsuki et al. (2003). In the melt layer, viscosity determines heat generation rate at each point. To simulate moving phase boundary problem, we use a front tracking method of Murray and Landis (1959). As the boundary conditions, we set no heat flow at the center of melt layer, and fix the temperature at the boundary of the phases (Tm: temperature of melt point), and the temperature at sufficiently large distance from the fault (T0). For the initial conditions, we give the thickness of melt layer (h0), uniform initial temperature of the melt layer as Tm, and uniform solid phase temperature as T0.

We calculate the response varying Ve (external loading velocity) and h0. At first stage, the thermal gradient in the melt layer is immediately formed with concentrated velocity gradient at the center of the melt layer, and shear stress drops with this temperature rise. Then, shear stress modestly changes and the thickness of the melt increases. When Ve = 1m/s, the characteristic time of the stress drop is the 0.1s for h0=1mm, and 0.001s for h0=0.001s for h0=0.1mm, and 10.0s for h0=10mm. On the contrary, the external loading velocity has little effect to the stress drop time. These results show the characteristic time of stress drop corresponds to the time of the thermal response of the system.

3. Interaction between the faulting and melting process

To evaluate effect on the seismic slip, we model the interaction using a formulation of the 1D seismic radiation damping (Rice, 1993). In this formulation, seismic waves are radiated only as outgoing S-wave. If stress drop does not change after the initiation of slip, slip rate exponentially decays in this model. However, when the secondary stress drop occurred (e.g. melting), the slip rate decreases more slowly, and for an abrupt stress drop slip rate may increase.

The solid and dotted lines in the figure are examples of our simulation in the case of constant Ve and seismic radiation damping model, respectively. In this case, the reduction of shear stress drastically increases slip velocity for the elastic response of several hundred meters crack, which has characteristic time of 0.1s of exponential decay without the interaction of melt layer. The relation between two characteristic times (fault response and formation of the thermal structure) may determine the stress drop behavior.

References:

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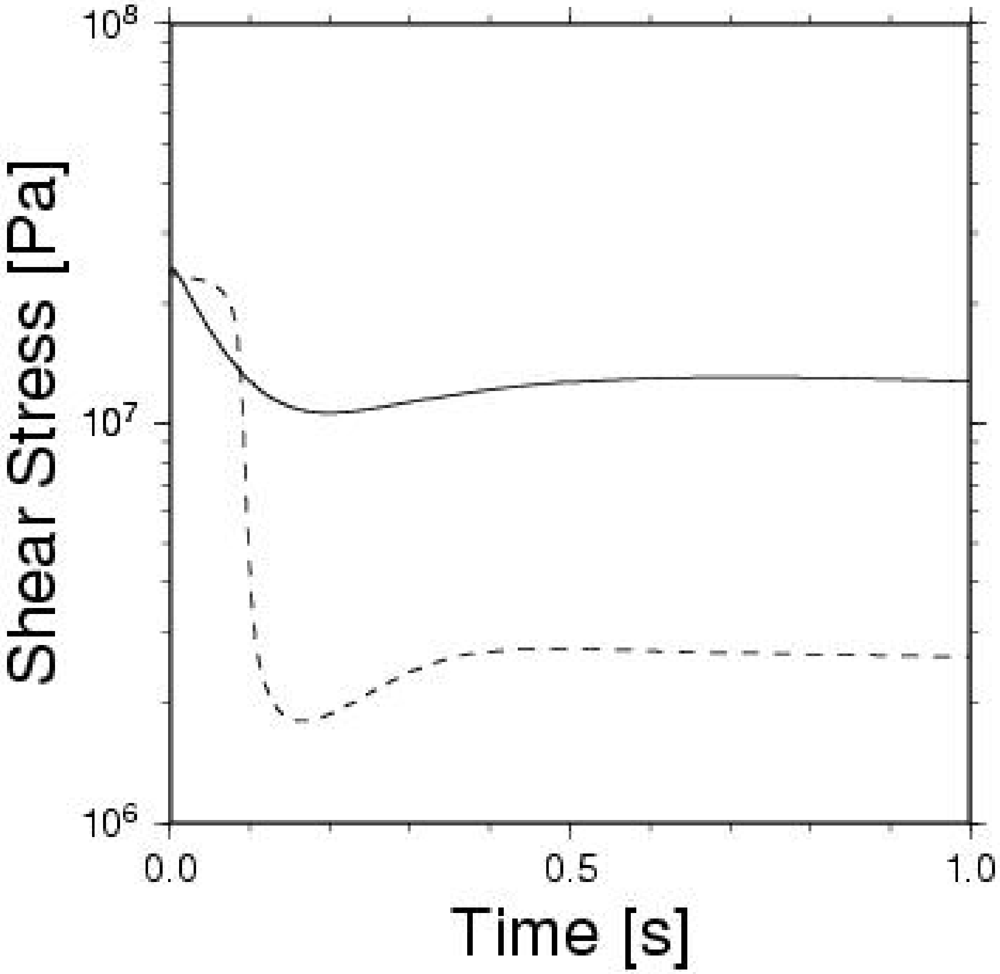
Shear Stress [Pa]
10^8
10^7
10^6
0.0
0.5
1.0
Time [s]