High-Velocity Friction Experiments for Samples of Various Size: Scale Effect in the Critical Slip Rate for Dynamic Weakening

○Hiroyuki NODA・Kiyokazu OOHASHI

Introduction

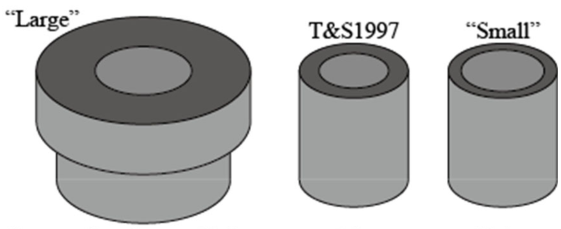
There is a large difference in length scale between laboratory and natural large events. Then it is crucial to study the scale effect in friction and evaluate applicability of lab-experiments. It is known that friction decreases dramatically at coseismic slip rate due to frictional heating and various associated physico-chemical effects (e.g., Tsutsumi and Shimamoto, 1997 (TS97); Di Toro et al., 2011). High-velocity friction experiments for centimeter-scale samples showed the dynamic weakening at slip rates V of the order of 0.1 m/s. On the other hand, recent experiments by Yamashita et al. (2015) (Y+15) demonstrated that a large sample with 1.5 m-long and 0.1 m-wide frictional surface showed the dynamic weakening at V of the order of 0.01 m/s, arguing existence of the scale effect on the weakening slip rate V_w.

Noda (2023) pointed out that it can be explained by concentration of frictional power due to thermoelastic instability (e.g., Dow and Burton, 1972). Heterogeneous normal stress causes heterogeneous thermal expansion of wall rocks, which may positively feeds back to enhance the heterogeneity. If there is not enough time for thermal conduction to smears out the perturbation field, or at high enough slip rate $V>V_{cr}$, the thermoelastic effect causes unlimited growth of the heterogeneity. V_{cr} is the critical slip rate derived from the linearized theory for an infinite medium, being proportional to the wavenumber of the heterogeneity. If the thermoelastic instability occurs, frictional power density should concentrate to hot spots on the sliding surface, where the dynamic weakening locally takes place. Because a larger sample hosts heterogeneity of a smaller wavenumber, it should weaken at a lower slip rate. In this case, V_w is expected to be inversely proportional to the sample size.

Here, we present our preliminary results of high-velocity friction experiments for samples of various size conducted in order to confirm the scale effect and the hypothesis of the thermoelastic instability.

Methodology

We used gabbro of sub-millimeter grain size, “Zimbabwe black” which is comparable to experiments by TS97 and by Y+15. Because thermal properties of the apparatus matters (Yao et al., 2016), we used the same apparatus that TS97 used, which is now at Yamaguchi University. Width of the frictional surface W is 4.5 mm in TS97, 0.1 m and 11.5 mm in Y+15. So far, we conducted experiments with W of 3 mm and 13.5 mm (Figure 1). The experimental conditions are similar to TS97; the normal stress was kept at 1.5 MPa and successive positive velocity steps of a factor of about 1.5 were applied every about 50 m of slip.



	“Large”	T&S1997	“Small”
Inner diameter [mm]	22.2	16	19.1
Outer diameter [mm]	49.2	25	25.0
Fault width W [mm]	13.5	4.5	2.9

Fig1. Samples of different widths of frictional surface used in this study.

Results and discussion

The sample with W=3 mm weakened at V=0.4 m/s, while that with W=13.5 mm did at V=0.25 m/s. When plotted together with TS97 and Y+15 (Figure 2 left), V_w sizes ranges for about 2 orders of magnitude with inversely correlation with W. Normalization of the slip rate by V_{cr}, which is inversely proportional to W, reduces this variation to about 1 order of magnitude (Figure 2 right). It is likely that the dynamic weakening occurs at about V=10V_{cr}. This factor of 10 may be from nonlinear effects such as partial opening of the frictional surface and reduction in the friction coefficient due to temperature rise (e.g., Noda 2008), or from the end effect of the experimental configuration. Evaluation of this point deserves further study. In any event, the comparison in this study indicates the existence of the scale effect, reconfirming the discovery by Y+15 and inferring significance of thermoelastic instability although more data may be needed.

It should be mentioned that the direct applicability of the thermoelastic instability remains to be investigated. The natural fault has wear material (fault gouge) between wall rocks, and the approximation as a simple rock-on-rock configuration may be inappropriate. In addition, not only thermal, but also hydraulic effects (e.g., Lachenbruch, 1980; Segall and Rice, 1995) affect the fault behavior significantly. Investigation of the dominant mechanism during coseismic slip rate on natural faults is an important future study,

Summary

Frictional experiments for samples with different fault size using the same apparatus show that a large sample weakens at a low slip rate. The observed correlation is consistent with the consequence of thermoelastic instability and resulting local activation of dynamic weakening. The dynamic weakening occurs at about V=10V_{cr}.

References

Di Toro, G., et al. (2011), *Nature*.
Dow, Th. A., & Burton, R. A. (1972). *Wear*.
Lachenbruch, A. (1980). *JGR*.
Segall, P., & Rice, J. R. (1995). *JGR*.
Tsutsumi, A. & Shimamoto, T. (1997). *GRL*.
Noda, H. (2008). *JGR*.
Noda, H. (2023). *EPS*.
Yamashita, F., et al. (2015). *Nature*.
Yao, L. (2016), *GRL*.

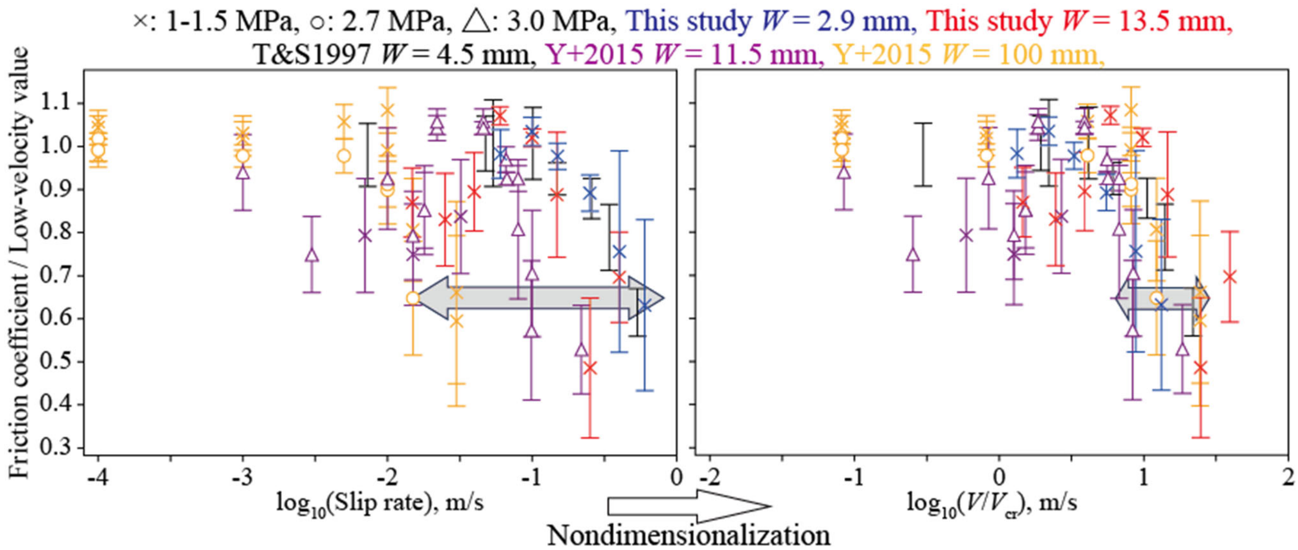


Fig 2. Normalized friction coefficients by low-velocity values for experiments in this study (x), TS97 (only errorbars), and Y+15 (other symbols) plotted against V (left) and V/V_{cr} (right). The dynamic weakening occurs at around V=10V_{cr}.