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Scale dependency of rock friction strength revealed by large scale biaxial friction experiment

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In order to bridge a scale-gap between natural earthquakes (~10^3 m) and laboratory experiments (~10^{-2} m), we carried out biaxial friction experiments using meter-sized rock specimens. We used a pair of Indian gabbro, whose nominal contact area was 1.5×0.1 m^2. The experiments were conducted under conditions with loading velocities from 10^{-4} to 3×10^{-2} m/s and with normal stress of 1.3, 2.7 and 6.7 MPa. The normal and shear loads were measured with load cells. Hereafter, we refer the shear load divided by the normal load as the friction coefficient. It is well known that the rock friction has dependency on slip velocity at high slip velocity. We observed a similar tendency in the present experiments; the friction coefficient is almost constant (~0.75) at low loading velocities (10^{-4} to 10^{-3} m/s), whereas it falls suddenly at the loading velocity of 10^{-2} m/s approximately. This feature is consistent with the results using small rock specimens whose dimension is on the order of 10^{-2} m (e.g. Di Toro *et al*., 2011, Nature). It should be noted that the velocity weakening characteristics of rock friction is first confirmed on meter-sized rock. However, we found that the measured friction coefficients show weak dependency on normal stress, which suggests that the slip velocity is not a unique factor controlling the rock friction strength. On small sized rock specimens, dependency of the friction coefficient on work rate was reported; the friction coefficient is almost constant at low work rates, whereas it becomes smaller with approaching to natural conditions (e.g. Di Toro *et al*., 2011; Mizoguchi and Fukuyama, 2010, Int. J. Rock Mech. and Min. Sci.). We investigated this relationship using the present data, and found a sudden and clear reduction of the friction coefficient at the work rate higher than 10^{-2} MJ/m^2s. The clear dependency of the friction on the work rate indicates that the weakening property of rock friction is governed by the work rate rather than the slip velocity. Di Toro *et al*. (2011) suggested that the work rate is proportional to a rate of temperature increase on a fault and the heating causes various transitions of rock mineral properties, which leads to the frictional weakening. In the present experiments, similar mechanisms should work and weaken the fault strength. However, we found that the meter-sized rock friction starts to decrease at the work rate one order of magnitude lower than that of the small gabbro specimens. This difference may come from the heterogeneity of the shear stress on the fault. From the point of view, we calculated heterogeneous stress distribution on the simulated fault produced by the present apparatus, and then, we estimated the weakening property of macroscopic friction depending the work rate under the estimated stress condition. We further estimated the weakening property in the case that additional stress heterogeneity was given on the fault surface. The results reveal that stronger stress heterogeneity can make more decrease in the macroscopic friction, which suggests that the rock friction has scale dependency, because such spatial heterogeneity will become strong in larger scale.

Keywords: Rock friction, Biaxial friction experiment, Scale dependency, Work rate