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Frictional heating causes high-velocity weakening of gouge; inference from specimens with different thermal conductivity

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Various mechanisms such as (1) temperature rise in slip zones due to frictional heating, (2) powder lubrication, and (3) formation of weak materials like silica gel have been proposed as mechanisms for dramatic weakening of fault gouge at high slip rates. In friction experiments using rocks as host specimens on both sides of gouge, slip rate and/or normal stress had to be changed to produce different temperature conditions. However, different test conditions may change deformation mechanisms making it difficult to separate the effects of temperature rise in causing high-velocity weakening of gouge. We show in this presentation that different temperature conditions in gouge can be attained by using host specimens with different thermal conductivities, and our results indicate that the frictional heating plays an important role in causing the high-velocity weakening of gouge.

Uniaxial strength of rocks reduces by several hundred times due to thermal fracturing during high-velocity friction experiments with host rocks, making it difficult to conduct high-velocity friction experiments at normal stresses higher than several MPa. Experiments can be done at normal stresses up to about 30 MPa with host rocks reinforced with aluminum rings, but metal-metal friction or frictional melting of aluminum is involved with the experiments. We have been seeking for designing a sample cell that can sustain much higher normal stresses, but finding materials that exhibit similar frictional behaviors to those of rocks has been a difficult task. One of the coauthors (AN) found that TiAlV alloy has a thermal conductivity as low as those of rocks, and we decided to perform a series of high-velocity friction experiments on Longmenshan fault gouge from Hongkou outcrop (illite 47%, quartz 41%, smectite 3%, kaolinite 3% and chlorite 2%) using host specimens with different thermal conductivities. Experiments were done with a rotary-shear low to high-velocity friction apparatus at Institute of Geology, China Earthquake Administration, at slip rates of 0.5, 1.0, 2.1 m/s and at a normal stress of 1 MPa. Host specimens were made with gabbro (thermal conductivity of 3.3 W/mK), TiAlV alloy (5.8 W/mK), stainless steel (15 W/mK) and brass (123 W/mK). Both gabbro and TiAlV alloy exhibits marked slip weakening and their behaviors are quite similar. Whereas weakening is suppressed dramatically with brass, and stainless steel shows intermediate behaviors between gabbro/TiAlV allow and brass. Temperature measurements in the stationary host specimens and FEM analysis with COMSOLE software revealed that an average temperature in slipping zones in the outer-half of the gouge ranging from 90 to 300 degrees Celcius was attained by using those materials. Friction coefficient at the end of runs decreases from 0.65 to about 0.1 with an increase in the average temperature, and the results indicate that the temperature rise is important in causing the high-velocity weakening of gouge. Powder lubrication cannot explain the results. We have started to compare the results with modified flash heating theories (Rice, 2006, JGR; Noda, 2008, JGR; Proctor et al., 2014, JGR; Platt et al., 2014, AGU). TiAlV allow is an ideal material for making sample cells for high-normal stress experiments.

Keywords: fault gouge, friction of fault, high-velocity weakening of fault, high-velocity friction experiments