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The influence of slip rate on slip dynamics and roughness evolution on limestone discontinuities

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The geometry of fault surfaces is a central factor in slip dynamics and earthquake phenomena. In this research we study the effects of sliding rate on friction, roughness and wear evolution, using direct shear experiments on self-affine rough interfaces. In order to isolate the effect of shear rate, a single prismatic fine grain limestone block is first fractured in tension mode, using the four-point bending testing methodology and then the fracture surfaces are scanned using a laser profilometer. Before shearing, we ensure a perfectly mating position between the two interfaces. The sample is then sheared to displacement distance of 10 mm under constant normal load of 5 MPa. The slip rate is fixed for a given run but varies from 0.1 microns per second to 50 microns per second in six tests. Values of shear stress and dilatation are monitored by LVDT type displacement transducers. After shearing, the surfaces are scanned again and their geometrical evolution is analyzed.

Our results show that in most tests the shear stress increases monotonically with displacement, exhibiting a distinct peak stress, followed by a stress drop. We find that during the stress build-up stage, increase in slip rate is associated with increasing shear stiffness and decreasing peak friction. Strain weakening is observed beyond the peak friction. Additionally, a significant stress drop is characteristic to the relatively slow slip rates. The surface roughness evolution is examined and quantified along a range of scales between $\sim$ 0.01 and 100 mm. We find that post-shear roughness, in all tests and for the entire measured range of scales, is higher than the initial roughness, suggesting that under the applied normal stress of 5 MPa, damage is more pervasive than localized. Moreover, roughening is increases in surfaces subjected to higher slip rates and wear generation increases with rupture energy. We assume that the roughening mechanism is dictated by brittle deformation which is enhanced with increasing slip rate. The detected increase in wear volume as function of the fracture energy confirms this assumption. Our results suggest that increased shear rates in rough limestone surfaces increases the rock stiffness but at the same time decreases the ultimate resistance to shear.