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Smoothing and roughening of slip surfaces in direct shear experiments

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Faults in the upper crust contain discrete slip surfaces which have absorbed a significant part of the shear displacement along them. Field measurements demonstrate that these surfaces are rough at all measurable scales and indicate that surfaces of relatively large-slip faults are statistically smoother than those of small-slip faults. However, post faulting and surface erosion process that might affect the geometry of outcrops cannot be discounted in such measurements. Here we present experimental results for the evolution of shear surface topography as function of slip distance and normal stress in direct shear experiments.
A single prismatic fine grain limestone block is first fractured in tension mode using the four-point bending test methodology and then the fracture surface topography is scanned using a laser profilometer. We then shear the obtained tensile fracture surfaces in direct shear, ensuring the original fracture surfaces are in a perfectly matching configuration at the beginning of the shear test. First, shearing is conducted to distances varying from 5 to 15 mm under constant normal stress of 2MPa and a constant displacement rate of 0.05 mm/s using two closed-loop servo controlled hydraulic pistons, supplying normal and shear forces (Davidesko et al., 2014). In the tested configuration peak shear stress is typically attained after a shear displacement of about 2-3 mm, beyond which lower shear stress is required to continue shearing at the preset displacement rate of 0.05 mm/s as is typical for initially rough joints. Following some initial compression the interface begins to dilate and continues to do so until the end of the test. The sheared tensile fracture surface is then scanned again and the geometrical evolution, in term of RMS roughness and power spectral density (PSD) is analyzed. We show that shearing smooth the surface along all our measurements scales. The roughness ratio, measured by initial PSD / final PSD for each wavelength, increases as a function of slip amount. The roughness measured after slip can be fitted by a power-law similar to that of the initial tensile surface.
In the next series of experiments a similar procedure is applied when the roughness evolution is measured as a function of increasing normal stress for a fixed displacement amount of 10 mm. While samples sheared under a constant normal stress of 5 MPa generated surface smoothing, shearing under normal stress of 7.5 MPa to 15 MPa exhibited surface roughening at the measured range of scales. We find that roughening is correlated with the attained peak shear stress values, stress drop (peak shear stress minus residual shear stress) and with wear accumulation, a novel measurement procedure of which is developed here. Analysis of the sheared samples shows that roughening is generated by sets of dense fractures that significantly damaged the sample in the immediate proximity to large asperities. This roughening is related to penetrative damage during transient wear in rough surfaces.