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Factors controlling shear rupture roughness: An insight from field and laboratory experiments

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Faults and fracture surfaces record the history of slip events through a range of structural features in tectonically active zones. Slickensides, among them, prove to be the most prominent evidences of such slip movements. These linear features give us crucial information about the mechanical processes associated with shear surface roughness formation. We conducted extensive field survey in the Singhbhum Shear Zone, Eastern India, and report shear fractures of varying surface roughness from deformed quartzites. Shear surfaces encountered in the field study varied from very smooth, devoid of any lineation to strongly rough with prominent slickenlines.

For better understanding of the varied surface roughness, we performed analogue laboratory experiments. The experimental results suggest that the fracture orientation and the mode of shear failure are potential factors that control the fracture roughness. We used cohesive sand-talc models for the analogue experiments with varying sand:talc volume ratio, ranging from pure sand to pure talc variant. Experimental models with pure sand composition underwent Coulomb failure in the brittle regime. With subsequent increase in talc content, the behavior of failure switched to plastic yielding in the ductile regime. This transition from coulomb failure to plastic yielding produced a remarkable variation in the shear surface roughness characteristics. Shear surfaces formed by Coulomb failure are smooth and devoid any slickenlines, whereas, those formed by plastic yielding show prominent presence strongly linear roughness, defined by cylindrical ridge-grooves along the slip direction.

Shear surface roughness defined by linear irregularities become more prominent with increasing fracture orientation (θ) to the compression direction (θ = 30° to 60°). Increase in θ promotes the formation of smooth slickenlines at the cost of rough zones. For critical analysis and understanding of these features we develop a new computational technique. The technique is based on controlled optical images to map the shear surface geometry from field casts and laboratory samples. Binarization of the irregular surface images (cantor set) provides 1D fractal dimension (D), which is used to quantify the roughness variability, and the degree of their anisotropy in terms of ΔD (difference in D across and along the slip direction). From numerical models, we finally show onset of wave instability in the mechanically distinct rupture zone as an alternative mechanism for slickenlines formation.