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Brittle-to-ductile transition during extreme loading rates

Zeev Reches (1), Yuval Boneh (2), Xiaofeng Chen (1), Shalev Siman-Tov (3), and Amir Sagy (4)

(1) Geology and Geophysics, University of Oklahoma, Norman, OK, USA (reches@ou.edu), (2) Earth and Planetary Sciences, Washington University, St. Louis, MO, USA (haboneh@gmail.com), (3) Inst. of Earth Sciences, Uebre University, Jerusalem, Israel (Shalevst@gmail.com), (4) Geological Survey of Israel, Jerusalem, Israel (asagy@gsi.gov.il)

The extreme loading rates that accompany earthquakes rupture, unstable fracturing and impacts, invoke a gamut of deformation mechanisms in the loaded rocks. It is expected that brittle deformation would dominated these events due to their high strain-rates and short durations. However, field and experimental observations reveal common occurrence of brittle-to-ductile transient features. We present here experimental observations of such features in high-velocity shear experiments of ten rock and powder types (carbonates, granite group, gypsum). The structures and mechanical properties include (a) low friction, hard, polished surfaces built of a lithified mosaic of ultra-fine grains; (b) formation of one micron diameter rolls made of aggregated powder grains that lead to friction reduction; (c) local melt in granite; (d) dependency of frictional strength on mechanical power density and heating; (e) shear induced recrystallization in carbonate powder; and (f) highly smooth slip surfaces formed of agglomerated ultra-fine grains. We propose that these microstructures were primarily affected by two processes: (1) rock pulverization into ultra-fine grains of 20-50 nanometer size that are highly reactive chemically (fast cementation and recrystallization), melt at lower temperature than bulk solid, and deform plastically; and (2) deformation localization within slip zones that are on the scale of micron thick. This localization leads to intense heating under localized shear or at fracture tip. The short duration of the experiments suggests that these microstructures are in a transient stage and did not reach equilibrium.