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High temperature shear zone formation around material heterogeneities: effect of boundary conditions during nucleation and transient evolution

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Rock deformation at depths in the Earth's crust is often localized in high temperature shear zones, which occur in the field at different scales and in a variety of lithologies. The presence of material heterogeneities is known to trigger shear zone development, but the mechanisms controlling initiation and evolution of localization are not fully understood, as is the effect of boundary conditions.

To investigate the effect of the loading configuration on shear zone nucleation, we performed torsion experiments under constant twist rate (CTR) and constant torque (CT) conditions in a Paterson-type deformation apparatus. The sample assemblage consisted of copper-jacketed Carrara marble hollow cylinders containing a thin plate of Solnhofen limestone oriented perpendicular to the cylinder's longitudinal axis. Under experimental conditions (900 °C temperature, 400 MPa confining pressure), samples were plastically deformed and the limestone, being about 9 times weaker than the marble, acts as a weak inclusion in a strong matrix. CTR experiments were performed at maximum bulk strain rates of ≈ 2*10-4 s-1, yielding peak shear stresses of 19-20 MPa. CT tests were conducted at shear stresses between 18 and 20 MPa, resulting in bulk shear strain rates of 1 - 4*10-4 s-1. Experiments were terminated at maximum bulk shear strains of ≈ 0.3 and 1.0.

Strain was localized within the host Carrara marble in front of the inclusion in an area (process zone) where grain size reduction is intense. The local shear strain is up to 10 times higher than the applied bulk strain at the inclusion tip, rapidly dropping to 2 times higher at larger distance from the inclusion. At both bulk strains, the evolution of microstructural and textural parameters is independent of loading conditions. Our results suggest that material heterogeneities induce stress concentration halos resulting in strain partitioning into localized shear bands. Progressive localization is associated with strain weakening accommodated by dynamic recrystallization and the development of a crystallographic preferred orientation of sheared grains. Loading conditions do not significantly affect localization during nucleation and transient (bulk shear strain ≈ 1) evolution stages. 2D Cartesian numerical modeling benchmarked to our experimental results successfully reproduces the qualitative aspects of strain localization and bulk stress-strain transients.

Locally, the presence of coexisting brittle deformation is observed regardless of loading conditions. The interaction between brittle and ductile deformation features is currently investigated by means of triaxial experiments at low confining pressures.