

Laboratory experiments, high angular-resolution EBSD, and micromechanical modelling reveal residual stresses and their distribution in deformed olivine

Lars Hansen (1), David Wallis (1), Imogen Kempton (1), Ricardo Lebensohn (2), and Angus Wilkinson (3)

(1) University of Oxford, Department of Earth Sciences, Oxford, United Kingdom (lars.hansen@earth.ox.ac.uk), (2) Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, USA, (3) University of Oxford, Department of Materials, Oxford, United Kingdom

During high-temperature deformation of rocks, stresses are predicted to be distributed heterogeneously throughout the constituent grains. After unloading, much of this stress is potentially retained in the aggregate as residual stress, a phenomenon that may have large-scale geodynamic implications. After large stress changes in the solid Earth (e.g., glacial unloading or post-seismic relaxation), residual stresses can affect the immediate mechanical response of the rocks. Furthermore, examination of residual stresses in naturally deformed rocks additionally presents an opportunity to learn about ancient deformation events.

These residual stresses arise from the anisotropic nature of the mechanical properties of minerals and from the heterogeneous substructures that form within grains (e.g., dislocation arrays and subgrain boundaries). This heterogeneity is therefore related to mechanical interactions on short (e.g., between individual dislocations), intermediate (e.g., between groups of dislocations), and long (e.g., between grains of differing orientation) spatial scales.

We examine residual stresses in upper mantle analogues with three different methods. First, stress-dip tests were conducted on olivine single crystals at temperatures greater than 1250°C in a new uniaxial deformation apparatus with a piezoelectric actuator. These experiments reveal that the average residual stresses stored in deformed single crystals can be on the order of 50% of the applied differential stress. However, the magnitude of residual stress is likely a function of crystal orientation during deformation. Second, high angular-resolution electron backscatter diffraction (HR-EBSD) allows the residual stresses in deformed single crystals and polycrystals to be mapped with <1 micron spatial resolution. HR-EBSD mapping reveals stress heterogeneities on the order of differential stresses applied during deformation. Stresses averaged over each map are in reasonable agreement with the outcome of stress-dip tests. Third, we implement an elasto-visco-plastic spectral micromechanical model to predict the full stress field in a deforming olivine aggregate. An EBSD map of an experimentally deformed aggregate was used as the input microstructure, and predicted stresses are compared to those measured by HR-EBSD.

Observations from the three different methods confirm that both stress heterogeneities during deformation and residual stresses remaining after external unloading can be on the same order as the applied stress during deformation. As such, these results provide important new constraints to be incorporated in future geodynamic simulations. Furthermore, cross validation of HR-EBSD with stress-dip tests and numerical simulations suggests HR-EBSD is a viable tool for assessing residual stresses in previously deformed rocks. We will attempt to tune the numerical simulations to best predict observed residual stresses such that simulations can be used to interpret stress distributions observed in natural rocks deformed in ancient tectonic events.