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The effect of annealing and grain growth prior to deformation on microstructure and strength of quartz gouge in shear experiments

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We conducted a series of shear experiments on quartz gouge in a Griggs-type solid medium deformation apparatus to investigate the effect of annealing and grain growth on the mechanical behaviour of quartz and to what extend it controls the microstructural development of fault gouge. The samples were deformed at confining pressures of 1.5 GPa at temperatures between 500°C and 1000°C at constant shear strain rates of $\sim$2.5x10^{-5} s^{-1}. The starting material is a crushed quartz single crystal (grain size <100 μm) with 0.2 wt% H_2O added. The powder is introduced in a 45° pre-cut in Al forcing blocks and the sample is placed in the apparatus. After pressurisation, the elongated splinters (average b/a = 0.51) are aligned subparallel to the shear zone boundaries resulting in a bulk particle fabric with an axial ratio b/a = 0.75. Annealing is simulated by introducing a hot-pressing stage (20 h at 1000°C/$\sim$1.5 GPa) prior to setting the temperature to the conditions of deformation. After hot-pressing the grains are approximately equant with b/a of the individual grains = 0.67 and a bulk axial ratio close to isotropic (b/a = 0.96).

Samples without hot-pressing show a negative temperature dependence of the peak strength. Continued deformation indicates steady-state stress for the high-temperature experiments whereas lower temperature experiments show strain hardening. At 700°C the hot-pressed sample is significantly weaker, at 800°C it is stronger than the sample without hot-pressing.

At the same time, hot-pressing does not affect the development of the crystallographic preferred orientation (CPO). The undeformed material - whether fresh gouge or annealed material - has a random CPO. With increasing shear strain, the CPO evolves towards an incomplete girdle. It also appears that hot-pressing has little effect on the final grain size distribution, on the shape preferred orientation of the deformed particles, or on the formation of a penetrative S-C' fabric.

On detail, however, differences can be noted. In hot-pressed material deformed at 700°C only few of the large clasts survive and the S planes are oriented at a higher angle ($\sim$34°) than in the fresh gouge ($\sim$14°). The dominant recrystallisation process is subgrain rotation (regime 2 after Hirth and Tullis 1992) while bulging (regime 1) dominates in the sample without hot-pressing. After deformation at 800°C, the hot-pressed sample is approx. 60% recrystallised, numerous large grains remain, and the foliation is weakly developed. The sample consisting of fresh gouge is almost completely recrystallised with only a few highly elongated large grains remaining. The resulting foliation is continuous and parallel.

The puzzling conclusion is that annealing and grain growth may affect the starting material in such a way that it can deform at higher or lower flow stresses than fresh gouge even if the microfabric and texture development during deformation are very similar. Particularly puzzling is the opposed behaviour of the annealed material at 700°C and 800°C. More detailed investigations are necessary before we conclude that the starting material influences the mechanical and microstructural behaviour to a great extent and can superpose the temperature effect.

References:
Hirth, G., Tullis, J., 1992. Dislocation creep regimes in quartz aggregates. JSG, 14, 145-159.