脆性塑性遷移領域における過剰間隙水圧下での石英せん断帯のレオロジー：水と間隙率の効果

Rheology of the fluid-overpressured quartz shear zone at the brittle-plastic transition: effects of the aqueous fluid and porosity

*岡崎 啓史[1]、Burdette Eric[2]、Hirth Greg[2]
*Keishi Okazaki[1], Eric Burdette[2], Greg Hirth[2]

1. 海洋研究開発機構高知コア研究所、2. ブラウン大学
1. Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 2. Department of Earth, Environmental & Planetary Sciences, Brown University

Large earthquakes typically nucleate near the depth limit of seismogenic zones and the source region of the tectonic tremor locates down dip extensions of seismogenic zones. In these areas, high V_p/V_s ratios are commonly observed, indicating the presence of the aqueous fluid up to 5 vol% (e.g., Peacock et al., 2011). Thus, it is important to understand how the water content and the pore structure affect the rheology of polycrystalline materials.

We conducted deformation experiments on quartz aggregates using a Griggs-type deformation apparatus. Silica gel were used as the starting material, which contain fluid-filled porosity of ˜22% for as-is sample, ˜15% for pre-dried at 120C, ˜16% for pre-dried at 450C and ˜7% for pre-dried at 900C in the experimental condition based on calculations both from the hot-press experiment and from the measurement of the recovered samples. Hydrostatic experiments within the alpha-quartz stability field at a pressure of 1.5 GPa and 900C indicate that gel-origin hot-pressed samples are composed of quartz and no relict of amorphous material is present. The average grain size is about 12 μm, and the grain shape is equigranular and no crystallographic preferred orientation (CPO) is observed.

The measured stress from general shear experiments on porous quartz aggregates at the equivalent strain rate of 1.5 x 10^{-4} 1/s, pressures of 1.1 and 1.5 GPa and the temperatures of 800–900C is significantly lower than predicted by the wet quartz flow law (e.g., Koch et al., 1989, Hirth et al., 2001, and Tokle et al., 2018, submitting), and shear stress decreased with increasing porosity. The stress exponent n at the temperature at 800–900C is 2.8–5.2 indicating that the dislocation creep and semi-brittle flow of quartz presumably controls the overall rate-behavior in the quartz shear zone, while n at the temperature of 500–700C is 4.7–19 indicating that brittle fracture and/or semi-brittle flow controls the overall rate-behavior in the quartz shear zone in this condition.

S-C’ mylonitic structure characterized by the CPO and water segregation is observed in recovered samples from the temperature of 800–900C. A-axis of quartz aligned parallel to the P direction. We also found an evidence for strain localization along R_1 riedel shears, which structure is characterized by high porosity zones. In contrast, deformation experiments on cores of quartzite show dislocation creep at this pressure/temperature condition.

The low flow stress and R1 reidel shear zones suggest that the stress enhancement process (Hirth and Kohlstedt, 1995) is activated by the high volume amount of water or perhaps the effective pressure law is still applicable and the sample deforms by a semi-brittle flow process. The strength of the water-saturated high-porosity quartz shear zone can be explained by the combination of quartz flow law (e.g., Koch et al.,

1989; Tokle et al., submitting) and the brittle strength of quartzite reported by Hirth and Tullis (1994) including the effect of porosity on both brittle (Vernik et al., 1993) and plastic strengths (Cooper et al., 1989) and a BPT constitutive law (Shimamoto and Noda, 2014). The mechanical data is well explained by the combination of those theoretical and empirical equations. Our result suggests that a few % of porosity makes a drastic weakening in the quartz shear zone overall from brittle to fully plastic regime. For example, porosity of ~5% will decrease the shear stress by 40%.

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