Diffusion creep of fine-grained olivine aggregates : Chemical and melt effects

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Since olivine is the major constituent mineral of the earth's upper mantle, flow properties of the upper mantle are often estimated based on flow laws of olivine aggregate which are determined by high-temperature creep experiments. In particular the viscosity of asthenospheric mantle plays a key role on plate tectonics because it decouples solid plates above and convective upper mantle below. Recently, the presence of a small amount of melt at the oceanic mantle asthenosphere has been suggested by some studies on seismic wave, electrical conductivity, and geochemistry (Hawley et al. 2016, Naif et al. 2013, Hirschmann 2010).
The effect of melt on rheology of olivine aggregates at dry conditions, however, has not been understood well yet. Deformation experiments on olivine aggregates synthesized from naturally derived mantle rocks (we refer naturally-derived olivine hereafter) showed that 4% melt-doped samples had a factor of 3 lower viscosity than undoped samples indicating a relatively small melt effect (Hirth and Kohlstedt 1995). Experiments on olivine aggregates synthesized from reagents using sol-gel methods (hereafter we call Sol-gel olivine) showed that the 4% melt-doped samples had a factor of 50 lower viscosity compared to non-doped samples indicating a very large melt effect. These previous studies have difficulties in determination of precise melt effect, 0.5 to 1 vol. % melt was observed even in non-doped naturally-derived samples presumably due to impurities (Hirth and Kohlstedt 1995). The change in viscosity due to adding of melt phase in sol-gel olivine can be due to the effect of impurities at grain boundaries which is known to have a large effect on the strength of polycrystalline oxide (e.g. Yoshida et al. 1997).
In this study, we synthesized olivine aggregates with and without impurities (CaO and Al_2O_3) by using a new technique and conducted high-temperature creep experiment on such synthesized olivine aggregates to investigate effects of chemical composition and presence of the melt phase on the creep properties of olivine aggregates.
The aggregates were prepared by applying vacuum sintering to nano-sized olivine powder synthesized from highly pure and fine-grained (<100 nm) raw powders (Koizumi et al 2010). Olivine aggregates with and without dopants of <1 wt% Al_2O_3, CaO, were prepared. Deformation tests on these samples showed that non-doped samples were deformed by grain boundary diffusion creep mechanism with no major difference in strength between non-doped and impurity-doped samples at temperatures below solidus of impurity-doped samples, while a reduction of a factor of 6 in viscosity was observed in impurity-doped samples with 0.05 vol. % melt at temperatures above solidus. FTIR analysis showed that both synthesized and deformed samples were dry. The strength of the non-doped samples was essentially identical to the aggregates by Faul and Jackson (2007), thus the difference in strength between previous studies can be explained solely by melt effect on olivine rheology.

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