Grain-size effect on thehardness of olivine

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The yield strength of oceanic lithosphere, which controls lithospheric flexure [Zhong and Watts, 2013] and formation of the plate boundaries [Tackley, 2000], is often corresponded to the strength of olivine, the dominant mineral in the upper mantle [e.g., Mei et al., 2010]. Yield stress of the mineral can be obtained from the hardness of the mineral measured by conventional indentation tests [Evans and Goetze, 1979], while corresponding such measured yield stress to that of the lithosphere has been a matter of debate [Iddrissi et al., 2016; Kumamoto et al., 2017]. The experimentally obtained yield stress (~1 GPa) is much larger to account the lithospheric deformation, which seems to require only a few hundreds of MPa [Zhong and Watts, 2013].
In this study, we examine the relationship of the strength of olivine with grain sizes. We carried out Vicker' s indentation test to measure the microhardness (Hv).
Load of 0.49 - 1.96 N was applied for the indentation test with a holding time 15 s. The test ware performed for five Fe-free olivine and two Fe-bearing olivine samples with grain size ranging from 0.17 to 0.89 μm. We also tested single crystals of olivine: synthetic Fe-free olivine single crystal, natural Fe-free olivine single crystal from Mogok, Myanmar (Fe content > 0.1 wt%) and Fe-bearing olivine ($Mg_{1.8}Fe_{0.2}SiO_4$) Kohistan, Pakistan [Bouilhol et al. 2009]. Indented surfaces were observed by field emission scanning microscope (FESEM). Dimensions of the indents and fracture lengths were measured in SEM images. We successfully indented to obtain reliable H_V from all the polycrystalline samples. Essentially the same H_V were obtained by changing loads. The largest Hv was 13 ±0.4 GPa from 170 nm grain-size sample, while the HV decreases with increasing grain size to 11 ±0.3 GPa for 890 nm grain size sample. Fe-free and Fe-bearing samples exhibited essentially the same Hv at the similar grain sizes. All the Hv from the polycrystalline samples are larger than the Hv of the single crystals, whose values are comparable to those reported in Evans and Goetze [1979]. The Hv from the polycrystalline samples show linear relationship with d^{2}, well following Hall-Petch relation. Further, the Hv from single crystals are plotted at d of +∞ in the relationship obtained from the polycrystalline samples indicating our Hall-Petch relation captures all the size effect in olivine.

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