American Mineralogist, Volume 91, pages 517–525, 2006

Plastic flow of pyrope at mantle pressure and temperature

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ABSTRACT

Despite the abundance of garnet in deforming regions of the Earth, such as subduction zones, its rheological properties are not well defined by laboratory measurements. Here we report measurements of steady-state plastic properties of pyrope in its stability field (temperature up to 1573 K, pressure up to 6.8 GPa, strain rate ~10^{-5} s^{-1}) using a Deformation-DIA apparatus (D-DIA) coupled with synchrotron radiation. Synthetic pyrope (Py_{100}) and natural pyrope ($Py_{70}Alm_{16}Gr_{14}$) are both studied in a dry environment. Transmission electron microscopy (TEM) investigation of the run products indicates that dislocation glide, assisted by climb within grains and dynamic recrystallization for grain-boundary strain accommodation, is the dominant deformation process in pyrope. Both synthetic-and natural-pyropes' stress and strain-rate data, as measured in situ by X-ray diffraction and imaging, are best fitted with the single flow law:

$$\dot{\varepsilon}(s^{-1}) = 3.5\begin{pmatrix}+4.8\\-2.0\end{pmatrix}\times 10^{6}\times\sigma(\mathrm{GPa})^{(3.2\pm0.7)}\exp-\frac{(270\pm40)\times10^{3}}{\mathrm{R}T(\mathrm{J/mol})}$$

where $\dot{\varepsilon}$ is the strain rate, $\sigma = |\sigma_1 - \sigma_3|$ is the differential stress, R is the gas constant and T the absolute temperature. Synthetic forsterite and synthetic pyrope were stacked along the uniaxial compression direction in the same cell assembly during deformation to compare their strength at mantle condition. Forsterite is observed to be stronger than pyrope, deforming at a rate about 10% slower than the pyrope at 5.2 GPa and 1573 K. San Carlos olivine and natural pyrope were compared in a similar fashion at 6.8 GPa and 1473 K. In this case, San Carlos olivine deformed 2~3 times faster than natural pyrope. The experimental data suggest that pyrope is stronger (by more than a factor of 4) than the dominant mineral (olivine) in the upper mantle when temperatures exceed 1273 K.

Keywords: Garnet, high pressure, high temperature, synchrotron X-ray imaging, stress, strain