Recent progress in the experimental studies on plastic deformation under high-pressures and temperatures

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Rheological properties of mantle minerals play an important role in controlling the dynamics and evolution of Earth and other terrestrial planets. However, due to the technical difficulties, quantitative rheological data for geological applications have been obtained only at low pressures (less than 0.5 GPa, i.e., 15 km depth). In order to extend the pressure range of quantitative rheological studies, there have been some developments to design and operate new types of deformation apparati. In this talk, we describe the development of a new type of deformation apparatus, RDA (rotational Drickamer apparatus), and will present some new results on olivine, wadsleyite and ringwoodite.

The main goals in our design were (1) to conduct quantitative deformation experiments at least under the transition zone conditions (pressures higher than 15 GPa), and (2) to conduct large-strain deformation experiments to investigate the microstructural evolution such as the lattice-preferred orientation. To meet these goals, we decided to adopt a torsion test mode rather than compressional test. We modified the Drickamer apparatus (that has been operated to high-P and T for static experiments) by adding a rotational actuator. After increasing pressure and temperature, we apply torque to a sample to conduct a torsion test. There are two reasons why we chose a torsion mode. In the previous deformation apparatus, most of deformation experiments were conducted by compression. In a compression test, a piston that applies a deviatoric stress to a sample must move in unsupported (or weakly supported) regions. Consequently, the maximum pressure is limited by the strength of a piston that is ca. several GPa for WC. In contrast, in a torsion test, deformation is achieved by rotating one of the pistons relative to another. Therefore the support for a piston is nearly identical to a static experiment. Consequently, it is easier to conduct high-pressure deformation experiments using a torsion design. In addition, in a torsion mode, one can achieve large strains without much problems of heterogeneous deformation. We operate our RDA at Brookhaven National Lab where synchrotron X-ray is available. Both stress and strain are measured using X-ray diffraction and X-ray absorption imaging respectively.

The RDA has been operated pressure of 17 GPa and temperature of 2000 K. We have investigated the rheological properties of olivine, wadsleyite and ringwoodite. One major challenge in this type of study is to obtain results that can be applied to Earth and planetary interiors. In most cases, geological relevant flow law is so-called power-low creep, but it is not easy to obtain power-law creep flow law at steady-state because of the significant increase in creep strength of materials with pressure. To date, we have obtained a robust data set for power-law creep only for olivine. Our results show that the creep strength of olivine increases with pressure that is characterized by an activation volume of ca. 17 cc/mol. Wadsleyite is significantly stronger than olivine. But the data on wadsleyite and ringwoodite are likely from the Peierls mechanism regime and the direct comparison to olivine is not warranted.