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Hydration and Weakening of Ringwoodite Induced by Dehydration of Hydrous Minerals

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1 Introduction

Hydrous minerals within subducting slabs transport water into the mantle transition zone (410–660 km depth). During subduction, dehydration of these hydrous minerals releases water that can be incorporated into olivine and its high-pressure polymorphs, collectively known as nominally anhydrous minerals (NAMs). Water is well known to enhance plastic deformation in mantle minerals, and significant hydrous weakening has been demonstrated for olivine, the dominant mineral of the upper mantle. In contrast, the influence of water on the mechanical properties of mantle transition zone minerals remains poorly constrained [1-3]. In particular, it is still unclear to what extent hydration weakens ringwoodite, the dominant mineral in the mantle transition zone, and consequently affects the strength of subducting slabs. In this study, we conducted high-pressure deformation experiments under conditions simulating the dehydration of hydrous minerals in subducting slabs, using a D-111 high-pressure deformation apparatus combined with synchrotron X-ray diffraction. Here, we report the preliminary results on the hydration and rheological weakening of ringwoodite.

2 Experiment

We attempted to hydrate ringwoodite by utilizing water released during the dehydration of hydrous minerals. Two experimental approaches were employed: (I) hydration of pre-synthesized ringwoodite by water diffusion, and (II) synthesis of hydrous ringwoodite through the olivine-to-ringwoodite phase transformation accompanied by dehydration of hydrous minerals. Polycrystalline ringwoodite and an olivine single crystal were used as the starting materials for approaches (I) and (II), respectively. The starting materials were placed inside cylinders of hydrous minerals (talc or antigorite). All experiments were conducted in an open system without using a metallic capsule. In situ X-ray diffraction observations were carried out at the PF-AR NE-7 beamline using a D-111 type high-pressure deformation apparatus [4]. The hydrous minerals were first dehydrated at 18–20 GPa and 853–1273 K to provide a source of water for the hydration of ringwoodite, followed by isothermal deformation experiments on ringwoodite at 773–1273 K.

3 Results and Discussion

Based on the in-situ X-ray diffraction measurements and SEM observations of the recovered samples, the dehydration reactions of antigorite at ~18–20 GPa are summarized as follows:

(A) Antigorite → Phase D + superhydrous Phase B (ShB) + 4.3 wt.% H_2O at ~850-1123 K.

(B) Antigorite → Ringwoodite + Phase D + 9.4 wt.% H_2O at ~1123–1273 K.

(C) Antigorite → Ringwoodite + Stishovite + 13 wt.% H_2O above 1273 K.

Compared with previous studies conducted in closed systems [5], the complete dehydration reaction (C) occurred at temperatures approximately 200 °C lower under the present open-system conditions. In addition, the partially dehydrated assemblage (B) was identified for the first time under these experimental conditions.

The water contents of recovered ringwoodite produced by method (I) after reaction (A) and by method (II) after reaction (B) were 429–747 and 1337–2775 wt. ppm H_2O, respectively. Considering that the starting ringwoodite contained approximately 370 wt. ppm H_2O, only limited hydration was achieved by the diffusion method (I). This is likely because the diffusion distance of water was too short under the present experimental conditions.

Fig. 1 shows the stress–strain curves of ringwoodite obtained by method (I). Within the limited range of water contents achieved in this study, no clear dependence of flow strength on either temperature or water content was observed.

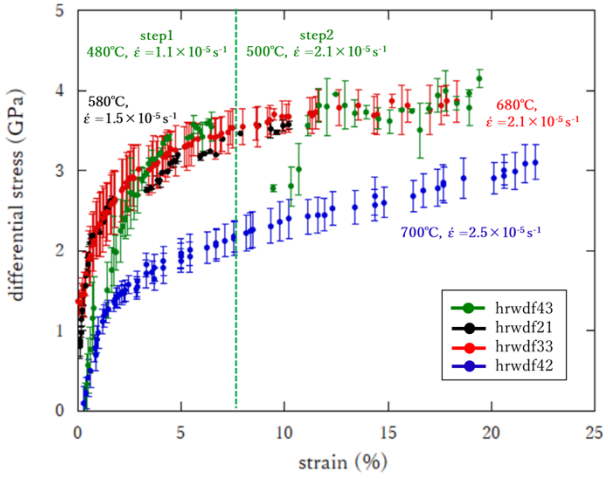

Fig. 1. Stress–strain curves of ringwoodite deformed in the hydration experiments using the water-diffusion method (method I). Runs #21, #33, and #42 experienced dehydration reaction (A) prior to deformation, whereas run #43 was annealed at 840 °C for 1 h between steps 1 and 2 to induce reaction (A). The recovered ringwoodite contained 456–738 wt. ppm H_2O, indicating only limited hydration.

The temperature dependence of flow stress changes markedly around 1200 K, where dynamic recrystallization of ringwoodite was also observed in SEM images. This observation suggests a transition in the dominant deformation mechanism from the Peierls mechanism to dislocation creep. Flow stress was lower in the more hydrous samples, particularly at higher temperatures. Although these preliminary results suggest that water weakening of ringwoodite becomes more significant in the dislocation creep regime, the variation in water content achieved in the present study remains limited, preventing a quantitative evaluation of the water dependence of ringwoodite strength. Furthermore, the measured mechanical data include deformation of both the ringwoodite sample and the surrounding capsule region, where hydrous phases were also present. Further refinement of the experimental configuration is therefore required to isolate the intrinsic rheological behavior of hydrous ringwoodite.

References

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