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In-situ X-ray observations of creep behaviors during the post-spinel transformation under lower mantle conditions

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1 Introduction

The post-spinel transformation, that is a decomposition reaction of $(Mg,Fe)_2SiO4$ ringwoodite into $(Mg,Fe)SiO_3$ bridgmanite and (Mg,Fe)O ferropericlase, occurs at the upper and lower mantle boundary. This is a eutectoid reaction with alternating fine lamellar structure in the colony texture, and superplastic flow of the fine-grained post-spinel assemblage after the degeneration of the colony may be responsible for rheological weakening and aseismicity of the lower-mantle slab [1, 2]. Experimental studies using analog materials at several GPa have shown that the single-crystal like eutectoid colony deforms by dislocation creep, and the degeneration is an important process for rheological weakening [e.g., 3]. However the direct experimental study has not been conducted so far. Here we report experimental results on the post-spinel transformation using mantle materials under uniaxial stress.

2 Experiment

We conducted syn-deformational post-spinel transformation experiments in $(Mg,Fe)_2SiO_4$ by in-situ X-ray observation method using D-111 type deformation apparatus at the synchrotron facilities of PF-AR NE-7. The starting material is a synthesized polycrystalline ringwoodite. The sample was uniaxially deformed at ~22-28 GPa and ~800-1350°C with increasing temperatures (~0.08° C/s) or pressures (~0.6 GPa/h) to cause the post-spinel transformation. 2D-XRD patterns and radiography images were taken every ~1-5 min to obtain stress-strain and transformation-time curves. The strain rates were 4.8-23 x 10^{-5} s-1 after the initiation of the transformation. The final strains and transformed fraction were ~30-60% and ~50-100%, respectively.

3 Results and Discussion

An example of creep behaviors with and without the post-spinel transformation is shown in Fig. 1. The ringwoodite deformation reached steady state at the strain of ~5% and the stress of ~4 GPa, and then exhibited slightly weakening with temperatures, which can be interpreted by Peierls mechanism. The flow stresses of newly appeared bridgmanite and ferropericlase are generally smaller than that of ringwoodite, and measured to be ~0.5-1.1 GPa and ~0-0.7 GPa, respectively. The weakening of ringwoodite became more significant at higher than ~1000-1200°C, which may result from the phase transformation and/or the transition in flow mechanism to dislocation creep.

The flow stress of bridgmanite is much smaller than that expected in dislocation creep [4], and can be reasonably interpreted by diffusion creep considering not colony size but degenerated grain size and the Si diffusivity [5]. Our study demonstrated that the degeneration of the post-spinel eutectoid colony readily occurs during the syn-deformational transformation, leading to rheological weakening by superplastic flow of the post-spinel assemblage.

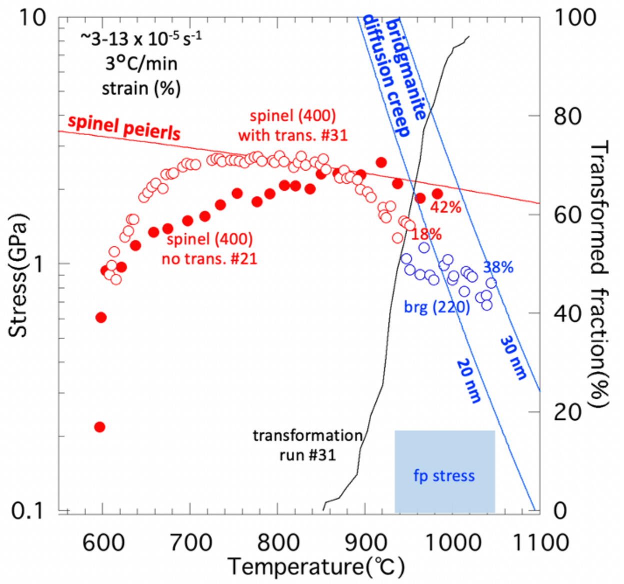

Fig. 1: Creep behaviors with (open circles) and without (solid circles) the post-spinel transformation during temperature ramping at ~20-27 GPa. Flow stresses of the parental ringwoodite (red), and the newly appeared bridgmanite (brg) and ferropericlase (fp) can be measured by in-situ X-ray observations. Transformed fraction can also be monitored as shown in black line. The diffusion creep strength calculated based on the Si diffusivity is shown in blue lines.

References

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