Direct measurement of reaction-induced stress during hydration reaction in MgO–H_2O system

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Hydration reactions in the crust and mantle accompanies large solid volume increase (several to tens vol%), which can generate stress, strain and fracturing. Thermodynamic estimation of maximum reaction-induced stress for serpentinization reaction is as high as 1.5 GPa (Kelemen and Hirth, 2012), which well exceeds the tensile strength of rocks. Actual hydration reactions observed in the field, however, have variations raging from reaction-induced fracturing (e.g., Jamtveit and Austrheim, 2010) to non-fracturing pseudomorphic replacement (e.g., Centrella et al., 2015). Suggesting that actual stress generation differs from the thermodynamic estimation. To understand the process controlling such variations in stress generation, we have conducted direct measurement of reaction-induced stress in MgO- H_2O system.

In MgO- H_2O system, periclase (MgO) reacts with H_2O to from brucite. The volume expansion of this reaction is 119%. Pressed powder pellet (initial porosity, ϕ_0 ~55%) and sintered (ϕ_0 ~14%) periclase were used as starting material. The samples were set in a uniaxial reaction cell, reacted with H_2O under fluid pressure of 0.2 MPa, and the solid pressure generated by the reaction was measured by load cell. We conducted experiments from 80 ˚C to 120 ˚C to change reaction rate and observe the difference of mechanical behavior.

During the pellet hydration experiments, stress increased to approximately ~40 MPa. Different behaviors of stress generation was observed for a temperature change. Particularly, stress increased monotonously at 80 ˚C, whereas remarkable stress relaxation was observed after peak stress at 120 ˚C. This finding suggests that reaction rate and deformation rate have temperature dependence. The additional experiments were conducted for investigating the temperature dependency of reaction rate and deformation rate in this system. As a result, it was revealed that temperature dependence of the shrinking strain rate was about four times larger than that of the reaction. The expansion strain rate by reaction was larger than shrinkage strain rate at <110 ˚C Whereas shrinkage strain rate gets larger than expansion strain rate at 110 ˚C. Therefore, observed changes of stress generation (monotonous stress increase at 80 ˚C and stress relaxation at 120 ˚C) was explained by the balance between reaction rate and deformation rate.

Hydration of sintered periclase generated higher stress than hydration of pellet (60 MPa). In the run product, brucite was observed at the periclase grain boundary. It is considered that the hydration occurred in initial porosity fractured periclase grain boundaries and fracture promoted additional hydration.

According to the result of experiments, it is suggested that the behavior of stress generation depend on the balance of reaction rate and deformation rate. The volume expansion during initial hydration may induce fracture along grain boundaries and promote additional hydration.

[References]

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