Temperature dependency of reaction-induced stress during hydration reactions and its controlling processes: Experimental constraints in MgO-H_2O system

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Water-rock reactions, especially hydration reactions in the mantle and crust are characterized by large solid volume changes up to ~50%. Such large solid volume changes induce stress and strain, which can generate fractures and promote fluid pathways. The driving force for such reaction-induced stress is the Gibbs' free energy released by the reactions, and thermodynamically estimated stress is as much as several GPa for serpentinization (e.g., Kelemen and Hirth, 2012) and for hydration of mafic rocks. However, there are few experimental measurements for reaction-induced stress, and the actual stress generated by hydration reactions, and their controlling factors remain unknown.

To understand the controlling factors of reaction-induced stress, we have conducted direct measurement of reaction-induced stress in MgO-H_2O system. Hydration reaction in this system is MgO + H_2O →$Mg(OH)_2$, which accompanies solid volume increase of +116%. The starting materials are pressed powder pellet of periclase with ~55% porosity. Samples were put into a uniaxial, constant volume-reaction cell, and were reacted with H_2O under 0.2 MPa fluid pressure, and the solid stress generated by the reaction was measured in-situ. To investigate the mechanical behavior with different reaction rate, the reaction temperature was varied from 80 to 120°C.

For all the experiments, the solid pressure generated by the reaction reached >30–40 MPa. Systematic changes of the mechanical response were observed for different temperature: under lower reaction temperature (<100°C), the solid stress monotonously increase with time, whereas under higher reaction temperature (>110°C), solid stress has significant relaxation after peak stress. The peak stress is highest at 100–110°C and is lower for lower/higher temperature.

Additional kinetic analysis of hydration reactions and uniaxial deformation experiments show that the temperature dependency of hydration reaction rate is ~10 times increase with ΔT = 50°C, and that of deformation rate is ~40 times increase. Analysis of the expansion strain rate by the reaction and shrinkage strain rate by deformation suggest that the former gets smaller than the latter at temperature >110°C. Therefore, the observed peak stress dependency on reaction temperature can be explained by the balance between expansion strain rate by the hydration reaction and shrinkage strain rate by the deformation.

These experimental results suggest that the actual stress generated by hydration reaction is governed by the balance between reaction rate and deformation rate. In this talk, the variation of mechanical response of hydration reactions observed in fields are discussed in terms of balance between reaction rate and deformation rate.

[References]

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