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Calibration for stress measurement of Griggs-type high temperature and high pressure deformation apparatus

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1. Introduction

It is necessary to perform deformation experiments in appropriate temperature and pressure conditions equivalent to the inside of the earth to characterize rheological properties of rocks. There are several types of deformation apparatus using different confining media such as gases, liquids or weak solids (e.g., Tullis and Tullis, 1986). Liquid medium apparatus has a disadvantage that it cannot be used for temperatures above 500 ℃ because of prevention from alteration of oil. Gas medium apparatus has the most accurate stress measurements because of using internal force gauge. However, experiments are typically restricted to confining pressures less than 300 MPa. Solid medium apparatus can provide us high pressure (˜2.0 GPa) easily and safely. However, its stress measurements accuracy is low mainly because of frictions between the confining media and samples or loading piston (e.g., Tullis and Tullis, 1986).

Recently, comparison of stress measurements of Griggs-type apparatus with solid salt assemblies (SSA) and gas apparatus provide a calibration law for Griggs apparatus with SSA (Holyoke and Kronenberg, 2010). This calibration law allowed steady-state stresses to be measured accurately to within ±30 MPa. However, it was not able to reproduce elastic, transient and post-yield behaviors because the calibration law was obtained from the comparison of stresses measured only at 5% strain. Moreover, since the calibration was carried out in low confining pressure, influence of confining pressure to stress measurements of Griggs apparatus is not clear. Calibration law for Griggs apparatus in various deformation conditions are required for revealing detailed rheological properties of the lower crust and upper most mantle rocks. In this study, we derived a calibration law for stress measurements of Griggs apparatus by the master curve method.

2. Axial compression experiments and construction of master curves

Axial compression experiments were performed on high-purity metals (nickels and molybdenums) using a Griggs apparatus with SSA. Experiments were performed in several conditions (confining pressures: ˜300 MPa, ˜1200 MPa, ˜1500 MPa, temperatures: 600 ℃, 700 ℃, 800 ℃, strain rates: 2×10^{-4} /s, 2×10^{-5} /s, 2×10^{-6} /s). Measured stresses were consistent with results of the former study (Holyoke and Kronenberg, 2010) within ±30 MPa under the identical confining pressure of ˜300 MPa. Measured stresses tended to become higher with confining pressures. Logarithms of steady-state stresses almost linearly increase with confining pressures in the range of this study. Obtained mechanical data were analyzed based on high temperature viscoelastic constitutive law proposed by Shimamoto (1987). Then, a master curve which normalized temperatures strains and confining pressures was constructed. A master curve from mechanical data (Holyoke and Kronenberg, 2010) using gas apparatus was also constructed.

3. Derivation and application of a calibration law

Master curves were constructed from identical materials between Griggs and gas apparatuses under normalized temperatures, strains, and confining pressures. Therefore, it is considered that differences between both master curves are derived from distinction of various rheology components of two apparatuses. A calibration law for Griggs apparatus was derived from differences in both master curves. Applying the calibration law to stress measurements of metals using Griggs apparatus with SSA, it became possible to reproduce gas apparatus′s stresses not only at steady-state but also at elastic, transient and post-yield behaviors within an error of ±30 MPa. Moreover, calibration can be extended to higher confining pressure up to 1500 MPa. When the calibration law was also applied to the stresses of carbonate rock, although an error was at most ˜70 MPa, elastic to post-yield behaviors could be reproduced.

Keywords: rheology, rock deformation experiment, solid medium deformation apparatus