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Stress calibration of Griggs-type deformation apparatus with solid salt assemblies

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Mechanical properties of rocks and minerals can be quantitatively studied by deformation experiments under high-temperature and high-pressure conditions relevant to the Earth's interior. 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 have the disadvantage that they cannot be used for temperatures above 500 ℃ because of prevention from alteration of oil at high temperature. Solid medium apparatus can provide us high pressure safely and stably for a long time. However, stress accuracy is not high due to frictional forces between pressure medium and load piston or samples (e.g., Tullis and Tullis, 1986). Gas apparatus has most accurate stress measurement because of the usage of internal load cell; thus measured stresses do not include frictional forces. However, experiments are restricted to confining pressures less than 200 MPa in Japan due to safety issues on the usage of high-pressure gas. Therefore, solid medium apparatus is necessary for generating high temperature and high pressure required to investigate rheological behaviors of rocks and minerals in lower crust or uppermost mantle.

Recently, comparisons of mechanical results obtained for metals at the same confining pressure, temperatures and strain rates deformed in a Griggs apparatus with solid salt assemblies (SSA) and a gas apparatus provide calibration for Griggs apparatus with SSA (Holyoke and Kronenberg, 2010). This calibration law allowed differential stresses to be measured accurately to within $\pm$30 MPa. However, we have not been able to reproduce elastic, yielding and post-yield behaviors because the calibration law was obtained by the comparison of strengths at 5% strain of mechanical results. Calibration law for measured stresses using Griggs apparatus in all deformation behaviors are required for revealing detailed rheological behavior of rocks and minerals.

In this study, we performed axial compression experiments on high-purity nickels to measure differential stresses using a Griggs apparatus with SSA at Tohoku University. Samples were given by Drs. Holyoke and Kronenberg. Experimental conditions were confining pressures of 300 and 1200 MPa, temperatures of 600, 700, and 800 ℃ and strain rates of 2×10^{-4}, 2×10^{-5} and 2×10^{-6} /s. Measured differential stresses agreed with results of the former study within $\pm$30 MPa under the identical confining pressure of 300 MPa. However, differential stresses were larger with confining pressure. We analyzed obtained mechanical data of nickels based on the high temperature viscoelastic constitutive law developed by Shimamoto (1987). We made the master curve which normalized temperature and strain conditions. In the same way, we also made the master curve from mechanical data of nickels using a gas apparatus (mechanical data are from Holyoke and Kronenberg, 2010). Master curves were made of mechanical data of the identical material between Griggs apparatus and gas apparatus under normalized temperature and strain conditions. Therefore, difference in master curves is thought to be derived from apparatus and assembly. We derived calibration law for Griggs apparatus from difference in master curves. Applying this calibration law to differential stresses of nickels obtained using Griggs apparatus with SSA, it became possible to reproduce gas apparatus's differential stresses not only steady state but also elastic, yield and post-yield behaviors within the systematic error of $\pm$30 MPa. However, the error was $\pm$70 MPa when the calibration law was applied to the mechanical data of carbonate rock. Moreover, unlike gas apparatus, measured differential stresses using Griggs apparatus tend to become larger with confining pressures. Therefore, it is necessary to investigate the effect of confining pressures on measured stresses in the calibration law.

Keywords: rheology, deformation experiment, calibration of Griggs-type apparatus