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Development of appratus for cyclic deformation experiment using partially molten samples: an approach to seismic wave attenuation

Kazuhiro Fujisawa[1]; Yasuko Takei[1]

[1] ERI, Univ. Tokyo

Seismic wave attenuation (Q^-1) is an indicator of temperature and/or liquid content in the Earth interior. Large attenuation in general occurs in the frequency band with the limited width. In order to predict Q^-1 in the seismic frequency range, we need to reveal the characteristics of the band: center frequency, width, and Q^-1 at the peak. Hence, the importance has been recognized on cyclic deformation experiments conducted in a broad frequency range as an approach to those characteristics. For partially molten samples, it has been observed in the cyclic deformation experiments in shear mode that QS^-1 is significantly increased by melting (e.g., Jackson et al, 2004). In the seismological analyses using body waves, however, QP^-1 has been measured with much more reliability than QS^-1, and large QP^-1 has been obtained for the regions where partial melting is expected (e.g., Tsumura et al, 1998). It is therefore necessary to undertake an approach to not only QS^-1 but also QP^-1. In this study, we intend to conduct cyclic deformation experiments in longitudinal mode by using partially molten rock analogue samples. We have developed the apparatus in which we can measure Q^-1 for Young Modulus (E) in the range of 1 mHz – 100 Hz.

A cyclic uniaxial load is applied to a sample of cylindrical shape with height 80 mm and diameter 40 mm. Young modulus of the sample is as small as about 3 GPa. A multilayered piezoelectric actuator (resonant frequency ~3 kHz, force ~100 N) is used as a loading system. The stress (~30 kPa) is measured by using load cell installed in the sample head, which transmits the load from the actuator to the sample. The strain is determined from the displacement of the sample (about 10^-6 m), which is measured by using a laser displacement meter with a resolution of 10^-8 m. Strain amplitude can be as small as 10^-5, so that the data are not affected by crack opening and sample non-linearity.

Q^-1 of the sample is determined from phase difference between the stress and the strain. For appropriate determination by using the phase, inertial vibration should be small. In the present apparatus, resonant frequency of the sample is as large as 5 kHz, and inertial effects are negligible at 100 Hz. Further, mechanical coupling between the sample and the apparatus is important to avoid frictional energy dissipation. A constant uniaxial load is therefore applied to the sample in addition to the cyclic load.

A binary eutectic system of organic materials (borneol and diphenylamine, eutectic temperature = 43^O C) is used as a partially molten rock analogue. The pore geometry is characterized by the dihedral angle, which is close to that of rock + melt system (Takei, 2000) and controlled by temperature in the range of 35^O – 17^O. The grain size and pore geometry can achieve almost steady state after 100 hours under constant temperatures. Samples having no melt also are used in the same way as partially molten samples.

Preliminary measurements using an acrylic plastic sample has been conducted. We obtained QE^-1 as large as 0.05 in the range from 1 mHz to 30 Hz. The result was reproduced in the repetitive measurements. We did not observe dependence on strain amplitude in the range of 10^-6 to 10^-5. QE^-1 estimated from dispersion of E agrees well with that determined from the phase difference. From the above results, we can verify that the obtained data of QE^-1 are reliable.