Measurement of bulk attenuation of polycrystalline sample by forced oscillation experiment

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Seismic attenuation, along with seismic velocity, is an important observable for seismological investigations of the upper mantle. In seismology, researchers usually consider that energy is not dissipated by volume deformation of rock, that is, bulk attenuation is 0, and that attenuation of seismic wave is solely due to shear attenuation. However, it is difficult to experimentally measure the bulk attenuation (= the imaginary part of complex bulk modulus / the real part of complex bulk modulus) of rock at high temperatures, and whether bulk attenuation is actually zero or not has not been confirmed yet. On the other hand, a recent seismological study reported that large bulk attenuation occurs in the Tonga-Lau mantle wedge (Wei & Wiens, 2020). Therefore, experimental study of bulk attenuation is needed. In this study, we developed a new experimental method for measuring the bulk attenuation of polycrystal at near solidus temperatures. In this presentation, we show the method with the results of a preliminary experiment using acrylic.

Using the custom-fabricated forced oscillation apparatus (Takei et al, 2014), we measure the apparent complex Young's modulus by constraining the upper and lower ends of a cylindrical sample so as not to be displaced in the radial direction. When the attenuation is sufficiently small, apparent complex Young's modulus at a given frequency can be approximately represented by a linear combination of the true complex bulk modulus and the true complex shear modulus. Each coefficient is a function of the aspect ratio (= radius / height) of the cylindrical sample, which can be given in advance using the finite element method. Therefore, by preparing several samples with different aspect ratios for the same material and measuring the apparent complex Young's modulus of these samples, the true complex bulk modulus and the true complex shear modulus can be determined independently. By doing this measurement for various frequencies, the complex bulk and shear moduli can be determined over a wide range of frequencies.

We performed a preliminary experiment using acrylic samples. Four cylindrical samples (radius = 15 mm, four types of heights = 65, 30, 15, and 10 mm) were prepared from a single acrylic rod. First, the apparent complex Young's modulus of one acrylic sample was measured at 13 frequencies from 1 mHz to 10 Hz. The measurement was repeated for several times, and the average and error were obtained for each frequency. This was performed for four acrylic samples with different aspect ratios. The present analysis is an overdetermined problem; for each frequency, four unknowns (real and imaginary parts of the true complex bulk modulus and true complex shear modulus) are solved from eight knowns (real and imaginary parts of the apparent complex Young's modulus obtained from the four samples). By solving this problem, we estimated the acrylic’ s true complex bulk modulus and true complex shear modulus independently with their errors.

The validity of the obtained results was confirmed by the internal consistency of the data; the Kramers-Kronig relationship was satisfied between real and imaginary parts. In addition, the complex bulk modulus and complex shear modulus of acrylic were measured in the engineering field (Yee & Takemori, 1982). The results obtained by this study are consistent with those. These results confirm the validity of the present method.

In the next step, in order to investigate bulk attenuation in the upper mantle, we plan to conduct experiments using organic polycrystals as a rock analog.

Keywords: Bulk attenuation, Upper mantle, Forced oscillation experiment