Rheological experiments of polyurethane foam toward simulating tube pumice

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Tube pumice is a common product of explosive silicic eruptions forming calderas. It is characterized by bubbles which elongate in one direction. Such bubble deformation is considered to occur in the processes of magma ascending in a conduit, which include vesiculation, flow, and fragmentation. It is expected that tube pumice has recorded information about some processes leading to a caldera eruption. In the preliminary experiment, we decompressed and inflated polyurethane foam (Ohashi et al., 2015, VSJ meeting). Polyurethane foam is a candidate of analogue materials to be used to simulate the formation processes of pumice because it undergoes vesiculation, flow, and solidification at ordinary temperature and pressure. Reproducing the tube pumice structure with polyurethane foam may help discovering the key factors to produce tube pumice. Here we present the time-dependent rheological properties of the polyurethane foam, which is specifically blended for our experiment.
Material : Polyurethane foam is a polymeric solid with a cellular structure. It is produced by mixing two polymeric liquids (polyisocyanate and polyol) with a catalyst and a foam stabilizer. Including a foam stabilizer prevents bubbles from coalescing and produces a homogeneous cellular structure by stabilizing their interfaces. To avoid such a structure, we use specifically blended polyurethane foam without the foam stabilizer in this study. This polyurethane foam has elliptical bubbles, which are larger than the usual one because of coalescing.
Apparatus and Procedure : We examine the temporal change of the rheology of the polyurethane foam from inflation to solidification. A rheometer (AR2000ex) is used with a concentric cylinder. The outer cylindrical cup is made of transparent polypropylene (inner φ=23 mm) and the rotating spindle is made of aluminum (outer φ=15 mm). An infrared thermometer is mounted at the side of the cup to record its temperature. The torque and the angle of the rotation are recorded by the rheometer and the growing height of the sample is measured in the video images. The data are used to calculate the stress and strain. In oscillatory tests, the amplitude ratio and the phase difference of the stress and the strain provide us with the storage modulus (G’) representing elasticity and the loss modulus (G’’) representing viscosity. We conduct three experiments. First, the temporal changes of G’ and G’’ are examined under oscillatory rotation with the frequency of 3.16 Hz and the strain amplitude of 0.1 %. Second, the frequency dependence is assessed by changing the frequency in a measuring cycle. Finally, a large strain is applied up to 10 at the strain rate of 0.2 (s^-1) while the material is solidifying. We look into the pore structure of the representative samples with X-ray tomographic imaging (inspeXio SMX-225CT, Shimadzu Co.).
Result and Discussion : In the initial stage G’’ is larger than G’ indicating the material is fluid. The torque gradually increases with the gelation, so that G’ is equal to G’’ in 20 minutes. After that, G’’ decreases and G’ converges into the constant value of $10^{6.3}$ Pa. It is known that the shear modulus of magma is about 10 GPa regardless of its temperature and composition (Dingwell and Webb, 1989). We find the shear modulus of the polyurethane foam used in this experiment is lower than that of magma by four orders. In the second experiment the crossing time when G’ is equal to G’’ is delayed as the frequency decreases. The inverse of the angular frequency at the crossing time is regarded as the instantaneous relaxation time. This result shows the relaxation time of the material gradually increases and the time scale in which the material transits from solid to liquid

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is quantified. Finally the X-ray tomographic imaging reveals that the sample of the third experiment with a large strain has elongated bubbles like tubes.

Keywords: Polyurethane foam, Tube pumice, Rheology, X-ray tomographic imaging

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