Fragmentation of vesicular viscoelastic material by rapid decompression

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The fragmentation of vesicular magma is a key phenomenon to determine the style of volcanic eruption. In order to understand the magma fragmentation, we performed a rapid decompression experiment using an analogous material of magma. Silicate magma has viscoelasticity, whose characteristics are approximated using a linear Maxwell model. The Maxwellian viscoelastic material has a relaxation time, which indicates the duration to relax stress in the material. The ratio of the relaxation time to characteristic time of deformation determines the material behavior as elastic solid or viscous liquid. The mechanics of fracture may depend on the solid/liquid transition of viscoelastic materials: The ductile fracture may occur when the material behaves as the viscous liquid, while the brittle fracture may occur by the propagation of flaw in the elastic solid.

The ratio of the relaxation time to the decompression time is important in the fragmentation of magma, because the decompression time characterizes the fragmentation in volcanic conduits. In addition to the decompression time, the porosity of the material and the initial pressure before decompression are also important parameters because pressurized gas in bubbles is the source to induce the fragmentation.

An analogous material of vesicular magma is maltose syrup with oxygen bubbles. The viscosity of syrup depends on water content and temperature, while the rigidity is constant. Since the relaxation time is defined as the ratio of viscosity to rigidity, we can control the relaxation time of syrup. Oxygen bubbles are generated from hydrogen peroxide with manganese dioxide as catalyst. We can control the porosity of the syrup by the amount of hydrogen peroxide.

The experiment facility consists of a high-pressure vessel and a large vacuum chamber. After the specimen is set in the vessel, the vessel is compressed to an initial high-pressure level. The vacuum chamber is decompressed to 10 kPa. There are double diaphragms between the vessel and the chamber. The vessel is decompressed by rupturing the diaphragms. Occasionally, an orifice is placed beneath the diaphragm to reduce the decompression rate. The response of the specimen is observed through window by high-speed photography. Pressure change of vessel is measured by pressure transducer. The initial high-pressure is set at 2MPa or 3MPa. The decompression rate is from 0.1 MPa/s to 280 MPa/s. We used the specimen having the porosity of 6% or 12% and the viscosity from 10^5 Pa.s to 10^9 Pa.s.

Different experimental conditions yield remarkable change in response of the specimen. We classified the response into three modes: (a) brittle fragmentation without expansion, (b) fracture after small ductile expansion, (c) ductile expansion without fracture. The mode (a) seems to be brittle fracture and the mode (b) seems to be ductile fracture.

The ratio of relaxation time to the decompression time dominates the change of the response. In the case that the initial pressure is 3MPa and the porosity is 6%, the mode (a) is observed when the ratio is smaller than unity and the mode (b) appears when the ratio is from unity to 50. Reducing the initial pressure prevents the response from the mode (a) fragmentation. The porosity of specimen doesn't have significantly influence on the critical time ratio of change in the fragmentation mode.

These results indicate the relaxation time, the decompression rate and the amount of decompression determine the mode of fragmentation.