Mechanism of fragmentation of vesicular magma with non-uniform distribution of bubbles

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Brittle fragmentation is a key process in explosive eruption. Estimation of the decompression time in real explosive events indicates that the style of fragmentation is to be “brittle-like fragmentation” (Kameda et al., JVGR 2013), which was defined as the solid-like fracture of the material whose bulk rheological properties was close to fluid state. In this presentation, we clearly show the internal non-uniform structure of bubbles which is a major source of crack development that may lead to brittle-like fragmentation. This scenario was proposed based on our previous experiments (Kameda et al., JGUM 2014).

We used syrup containing bubbles as material of specimen because syrup has large rigidity close to magma, and can have wide range of viscosity like magma. The rapid decompression apparatus was used to simulate the fragmentation. It consisted of a pressure container whose top was sealed by a plastic film. First we compressed the specimen placed in the container by nitrogen gas. Second we heated electrically the nichrome wire adhered on the film. The rapid decompression was caused by the rupture of the film due to the heat of nichrome wire.

The specimen was hemisphere whose size was about 20 mm in diameter and 10 mm in height. The viscosity of each specimen was chosen from three values (10, 50, and 100 MPa・s) and the void fraction before the decompressionφ_0 was varied from 4% to 40%. The initial pressure just before the decompression was 2 MPa, and the characteristic time of decompression was about 3 ms.

To observe the internal structure of specimen, we conducted X-ray CT imaging at SPring-8. We took the radiograph images with the resolution of 15.5 μm/pixel. The CT imaging was conducted three times (after and before the compression and after the decompression). We observed the dynamic behavior of specimen during decompression by radiography using the same optical setup as the CT imaging. We simultaneously observed it by high speed imaging using a visible light source. We reconstructed the volumetric 3D model of the specimen based on the CBP method.

A typical example of fragmentation captured by high speed imaging is shown in Fig. 1. This experiment was conducted under η=50 MPa・s,φ_0=7.6 %. As shown in Fig. 1, the partial fragmentation occurred at 2.1 ms after the decompression was started. Reconstructed 3D image of the specimen is shown Fig. 2. As shown in Fig. 2, the specimen contains a large bubble with a small satellite bubble close to the large one (green broken line). These two bubbles are triggers of the fragmentation shown in Fig. 1. We also observed all the specimen fragmented into pieces even if its viscosity was the same as that shown in Fig. 1. Therefore, it is concluded that whether to fragment or not depends on the bubble distribution.

Next, we conducted finite element analysis of the specimen under the rapid decompression. The COMSOL Multiphysics ver. 5.0 was used as calculation platform. In order to reduce computational cost, we used a simplified 3D model of the specimen in the experiment (Fig. 2). In the model, we extracted just around the primary large bubble with a satellite small bubble. The specimen was assumed to be a Maxwell fluid whose physical properties were equal to those of syrup measured in previous study.

As shown in the result (Fig. 3), the maximum stress occurred between the two bubbles. Preliminary result (Kurokawa et al. JGUM 2015) shows that the stress concentration occurs on the surface of satellite bubble, and it leads to the increase of brittleness (Ichihara et al. JGR 2010) at the time when the stress reaches the critical value of fracture. Compared the calculation result of surface stress field with the surface crack distribution captured by high speed photography, we found that the surface crack propagates along the line of large stress concentration. This fact indicates that we can predict the brittle fracture.

Keywords: Magma, Fragmentation, X-ray CT, FEA

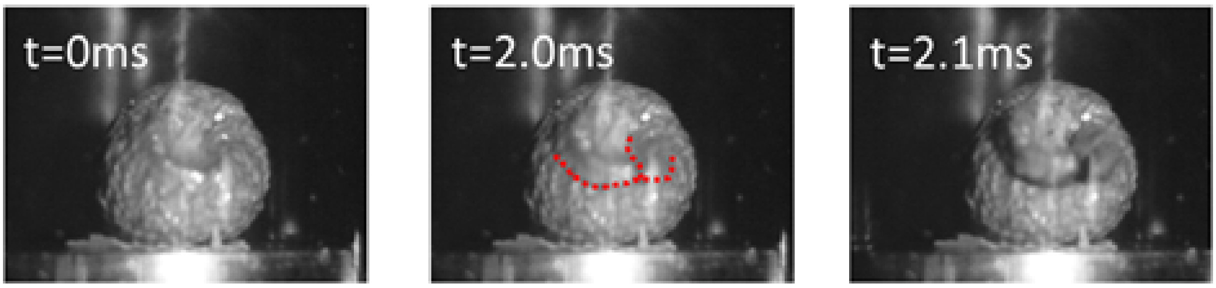

Fig.1 High-speed video images of fragmentation

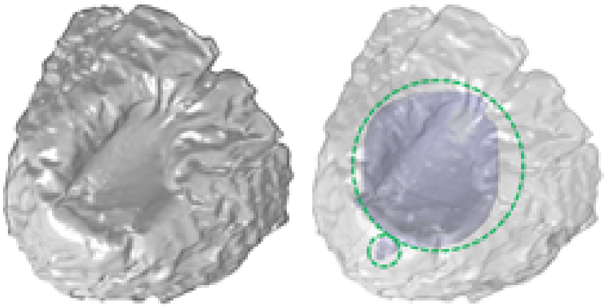

Fig.2 Surface and primary pores

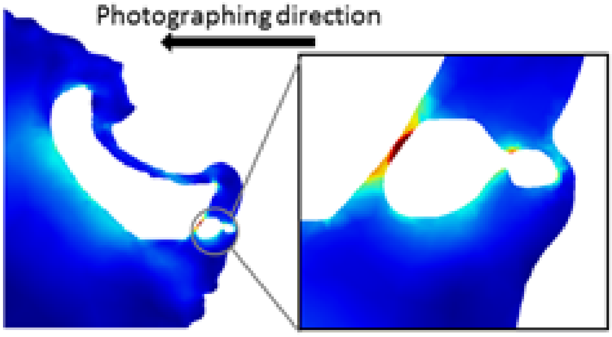

Fig.3 Stress at primary pores