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Numerical analysis of the behavior of a viscoelastic body containing gas bubbles by rapid decompression

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Brittle fragmentation of vesicular magma is considered to be a trigger of explosive volcanic eruptions. Ichihara and Rubin (2010) defined the brittleness as a dominant parameter of the brittle fragmentation of magma. They concluded that the brittle fragmentation occurred when the brittleness of magma was close to unity. Kameda et al. (2013) reported that the brittle-like fragmentation occurred in their laboratory experiments even if the brittleness of specimen was lower than unity. They suggested that the brittle-like fragmentation was initiated by the crack developed from the interior of the specimen due to non-uniform spatial distribution of bubbles. After the partial fragmentation occurs, the rapid decompression around the fracture surface induces sequential fragmentation events.

In this study, to verify the scenario of the brittle-fragmentation proposed by Kameda et al., we simulated numerically the behavior of a Maxwell viscoelastic body including a few bubbles due to rapid decompression. We examined the evolution of the differential stress and brittleness around the bubbles in viscoelastic body.

We used COMSOL multiphysics ver. 5.0 as the platform for our numerical analysis. We employed axial symmetry model as the space dimension, and generalized Maxwell viscoelastic model as the viscoelastic model. In the first case (Case 1) of our calculation, we set the calculation area as a hemisphere (a quarter of a circle which radius was 100 mm), and arranged two spherical bubbles in the area. The large bubble (radius is 20mm) was located at the central point of the hemisphere. Another small bubble (radius is 5 mm) was located at the isolate position beneath the large bubble, and its central point was placed on the symmetry axis of the hemisphere. The physical property of the viscoelastic body and the profile of decompression were the same values as the laboratory experiment. We assumed the internal pressure of bubbles remained a constant value.

In Case 1, the stress concentration is observed at the surface of small bubble facing the large bubble. In contrast, smaller differential stress is observed at the surface of large bubble facing the small bubble. To investigate this reason, we calculated the numerical analyses (Case 2, 3) using the geometry of Case 1. In Case 2, internal pressure was applied only on the large bubble. In Case 3, the internal pressure was applied only on the small bubble. These results showed stress concentration is observed at the surface of small bubble only in Case 2.

We propose the following scenario of stress concentration: There is the influence range on the distribution of differential stress around the bubble. The range spreads as the size of bubble becomes large. If the bubble exists in the influence range of differential stress produced by the other bubble, stress concentration occurs on the surface of bubble.

In Case 4, we calculated the time variation of the brittleness with considering the change of the internal pressure of the bubble due to its expansion. We calculated the stress field around a single bubble placed spherically symmetric position in the domain. The volume of the bubble is equal to the sum of the volume of the bubbles in Case 1. We assumed that the internal pressure of the bubble varied isothermally. The results showed the time variation of the brittleness on the bubble's surface in Case 4 was not so different from Case 1. On the other hand, the maximum value of the differential stress around the bubble was developed steeper in Case 1 than in Case 4. This means that the critical brittleness, which is defined as the brittleness at the time when the maximum differential stress reaches the critical fracture stress, is higher in Case 1 than in Case 4.

In conclusion, (1) Stress concentration occurs at the bubble's surface in the case where neighboring bubbles are close to their bubble radii. (2) The critical brittleness at the position where stress concentration occurs becomes large.

Keywords: Magma, Viscoelasticity, Fragmentation, Numerical analysis