Numerical analysis on the fracture of Maxwell fluid by phase field models

*Masaharu Kameda[1], Keita Yamanishi[1], Akinori Yamanaka[1], Mie Ichihara[2]

1. Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, 2. Earthquake Research Institute, The University of Tokyo

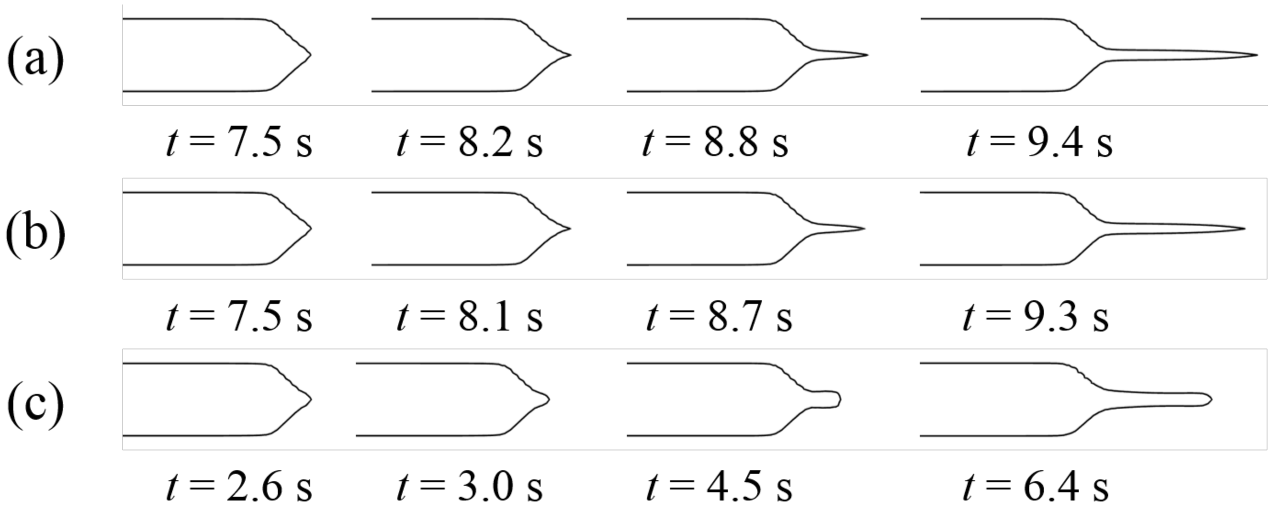
Brittle fragmentation of vesicular magma is a key process in explosive eruption. Recent estimation on the decompression time in real explosive events indicates that the style of fragmentation is to be “brittle-like fragmentation” (Kameda et al. JVGR 2013). The solid-like fracture of the material occurs even if the bulk rheological properties is close to fluid state. We also found the fact that the spatial inhomogeneity of bubble distribution is a major source of crack development that lead to brittle-like fragmentation (Kameda et al. Sci. Rep. 2017).

In order to model our findings by numerical approach, we propose a continuum description of fracture in viscoelastic fluid using the phase field fracture model developed by Kuhn et al. (Comput. Mat. Sci. 2015). The phase-field modes with sharp interfaces consist in incorporating a continuous field variable so-called “order parameter,” by which the magma and the bubbles (or the cracks) are distinguished. The evolution of fracture is obtained implicitly by solving the coupled mathematical models formed by the phase field fracture model and the dynamics of the material. A commercial multiphysics solver (COMSOL) is used as the platform of numerical simulation. The phase field fracture model is solved using PDE solver of COMSOL. The dynamics of the material is calculated using conventional finite element analysis (FEM) prepared in the solver, in which the rheology of unbroken magma is assumed to be a linear Maxwell fluid.

First, we simulated crack propagation in a two-dimensional notched plate in a tensile test at a constant extension rate. We obtained the extension of crack with a sharp tip in pure elastic body (Fig. 1(a)) or viscoelastic body with sufficiently high viscosity (Fig. 1(b)). On the contrary, in the viscoelastic liquid with moderate viscosity the blunted tip occurs after the crack extension starts (Fig. 1(c)). Subsequently, the crack propagates again due to further extension.

Second, we simulated crack initiation and propagation in a porous material, which is a sphere including a large bubble at the center. Additionally, we placed two satellite bubbles nearby the large bubble. The pressure at the outer surface of the material was reduced to generate the non-uniform stress field in the material. As a result, the plane crack was generated between the satellite bubbles. The crack reached outer boundary, then a sharp crack was opened. The computed time scale in the crack propagation was equivalent to the scale observed in the experiment (Kameda et al. Sci. Rep. 2017). This time scale is much smaller than the scale simulated with another phase field fracture model proposed by Karma et al. (Phys. Rev. Lett. 2001).

Keywords: Magma, Fracture, Phase field model


(a)
t = 7.5 s
t = 8.2 s
t = 8.8 s
t = 9.4 s
(b)
t = 7.5 s
t = 8.1 s
t = 8.7 s
t = 9.3 s
(c)
t = 2.6 s
t = 3.0 s
t = 4.5 s
t = 6.4 s