

Consideration on transient rheology of magma: Possibility and importance of 'thixotropy'

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Transition from flow to fracture of magma is one of the most important diverging points in volcanic processes. The non-Newtonian mechanical property of magma is considered to be an essential factor governing the transition. Two mechanisms have been proposed: (1) Magma has Maxwell-type visco-elasticity. It responds elastically in a time range shorter than the structural relaxation time, and viscously in a longer time range. Therefore, it is expected to be broken in a brittle way, when it is subject to large stress within a certain time. (2) Magma is a shear-thinning fluid, that has a viscosity decreasing with increasing strain rate. The viscosity decline is notable above a critical strain rate which is smaller than the relaxation strain rate by a few orders. When the strain rate exceeds the critical value, it is accelerated by the decrease of the viscosity until the point that the internal structure cannot respond and fracture occurs.

Although the above two mechanisms are often referred in combination, they are substantially opposite with each other. The former suggests that magma becomes solid-like towards fracture, while the latter that magma becomes more fluid.

Ichihara (2006) proposed a constitutive equation for transient behavior of magma. It is assumed that the shear-thinning behavior observed in steady creep tests is due to change of internal structure in response to the applied stress and that the structural change needs a certain characteristic time to respond. Considering the delay of the viscosity change, both of the Maxwellian viscoelasticity and the shear-thinning viscosity are represented. It is suggested that not only strain rate but also strain acceleration is important in stress accumulation in transient processes.

Actually, the delayed response of the viscosity (viscoelasticity) is one of common rheological properties, which is called thixotropy. Thixotropy is always (in principle) to be expected from any shear-thinning mechanisms, since changes in any of internal states take some time to come about (Barnes, 1997). Therefore, it is reasonable and important to take account of the thixotropy in any constitutive equations used for transient behavior of magma to fracture or fragmentation.

Bagdassarov and Pinkerton (2004) has pointed out thixotropy of bubbly liquid that has shear-thinning viscosity and discussed its importance in transient behavior of magma. In the bubbly liquid, the internal structure which determines the viscosity is the bubble shape and is represented as a function of strain rate instead of stress. The shear-thinning property is equivalent in a steady state, whether the viscosity is a function of stress or strain rate. However, the two system are different in a transient processes.

In the present paper, effects of thixotropy on stress-strain and stress-strain rate profiles in transient processes are investigated. Two systems are compared: one with a shear-thinning viscosity as a function of stress and the other with that as a function of strain rate. Then the constitutive equations are applied to calculate stress accumulation in extension of a rod and expansion of a spherical shell bubble. Possibility and importance of thixotropy in magma fragmentation are discussed.