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Mechanical behavior of synthetic silicate melt at the brittle-ductile transition: Experiments and modeling

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The mechanical properties of magma near the glass transition temperature have not been characterized yet, though this subject is of importance to the dynamics of volcanic eruptions. In this paper, we present an experimental investigation of the constitutive response of synthetic magma at various temperatures and strain rates. The low strain rate (below 0.001 1/s) compression tests were performed with a servo-controlled hydraulic facility (MTS-810). High-rate compression tests (~1000 1/s) were carried out by use of a Kolsky (Hopkinson) bar apparatus.

The material behaves as an elastic solid at low temperature and/or high strain rate, and as a viscous fluid at high temperature and/or low strain rate. A dominant feature of the material response in the transition region is that the stress increases linearly at a constant strain rate. Here we present two models which capture the main feature. One assumes that elastic stress increases due to accumulation of un-relaxed strain, while the other assumes that viscous stress increases due to work-hardening of the material. Comparing solutions of the two models with the result of a relaxation test suggests that work-hardening is an appropriate mechanism.

This study demonstrated some new features of the material. (1) The response in the transition region can be simulated using a work hardening model. (2) In the high-rate tests at a temperature much higher than the glass transition, the material elastically sustained stress of up to 1 GPa and fragmented into powder with little ductile flow. (3) The flow stress tends to be smaller in a jump test than that in a monotonic loading test with the corresponding temperature and strain rate, which may be due to viscous heating or due to a kind of memory of the strain rate in the previous stage.

The work-hardening (or strain rate hardening) and viscous heating are two competing and important processes controlling failure of ductile material. For magma, however, the main focus of previous research has been limited to examining the steady state viscosity and effects of viscous heating. The transient hardening behaviors tend to be regarded as un-relaxed elastic responses. On the other hand, the work-hardening nature is quite common for rocks in a ductile condition. It is also observed in a standard window glass. Here we present evidence that a non-crystalline magma also has the work-hardening nature in the transition between the solid-like and fluid-like states.