Weak Velocity Weakening of Augite with Concomitant Intergranular Pressure Solution under Hydrothermal Conditions

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Abstract

To fully understand the constitutive parameters and the associated mechanism in the velocity-weakening behavior of pyroxene observed in a previous study (He et al., 2013), we employed pure augite (clinopyroxene) as simulated gouge sample to run velocity stepping sliding tests under hydrothermal conditions with temperatures of 101-607 °C, effective normal stress of 200 MPa with 30 MPa pore pressure and axial loading rates of 0.1-1.0 μm/s. From our experiments, we found that: (1) Velocity-strengthening behavior was observed at temperatures of 101-203 °C, the steady-state velocity dependence transitioned to velocity weakening at ˜215 °C, and the velocity weakening persisted up to 607 °C, the highest temperature in our experiments. The absolute (b-a) values were revealed to range from 0.0009 to 0.0014, and the inferred average b/a values ranged from 1.15-1.18, both indicating quite weak velocity weakening at temperatures of 303-607 °C. (2) Inferred constitutive parameters through numerical fitting to rate and state friction laws show that the healing effect of friction (b value) has an increasing trend with temperature increase up to 403 °C, indicating an Arrhenius-type thermally-activated creep mechanism behind the healing effect. (3) In addition to microstructural observation of deformed samples that shows remarkable size reduction (crushed grains reduced to scales typically below 1-2 μm) in both intensely sheared regions and moderately sheared regions, ubiquitous precipitated particles (50-100 nm) with platy morphologies were observed to attach to the surfaces of crushed grains, which are typical signatures of intergranular pressure solution process, suggesting that pressure solution was commonly activated at intergranular contacts. (4) No recognizable crystalline plasticity was observed. Our microstructural observation together with the comparison of experimental data with model's prediction, implies that intergranular pressure solution process at the frictional contacts may be the most likely mechanism operating at the frictional contacts and governing the healing effect for augite.

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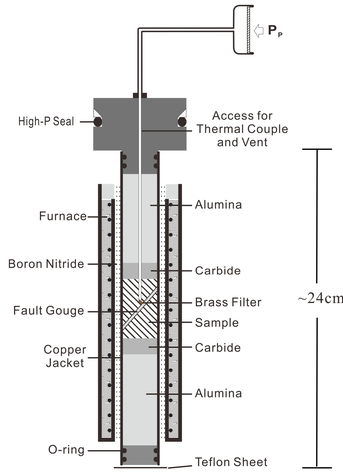
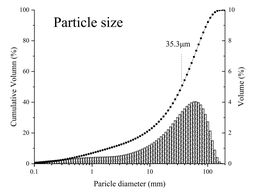
1. Introduction

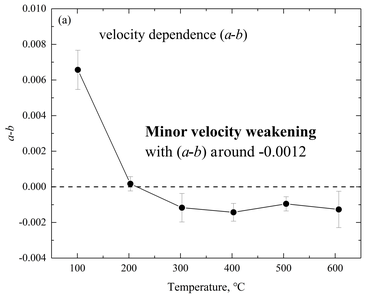
To fully understand the frictional sliding behavior of pyroxene and the relevant deformation mechanism, especially the mechanism responsible for frictional healing and velocity-weakening behavior, we employed augite (clinopyroxene) as simulated gouge sample material to run velocity stepping sliding tests at temperatures of **101—607 °C** and **~200 MPa effective normal stress** (confining pressure of 127 MPa with 30 MPa pore pressure) and axial loading rates of **0.1-1.0 μm/s**.

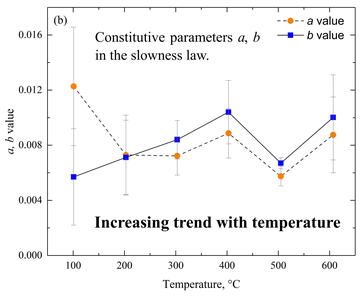


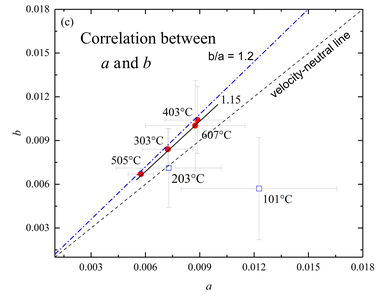


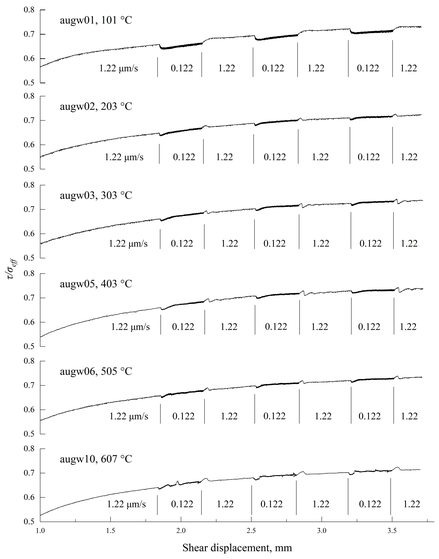
Schematic sample and furnace assembly and augite sample.

2. Result

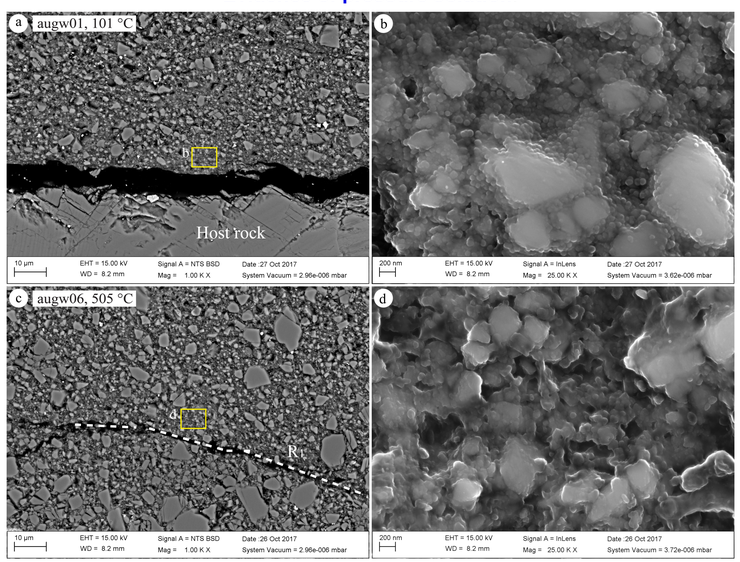




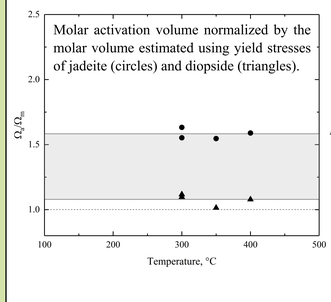


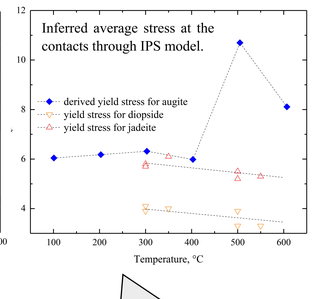


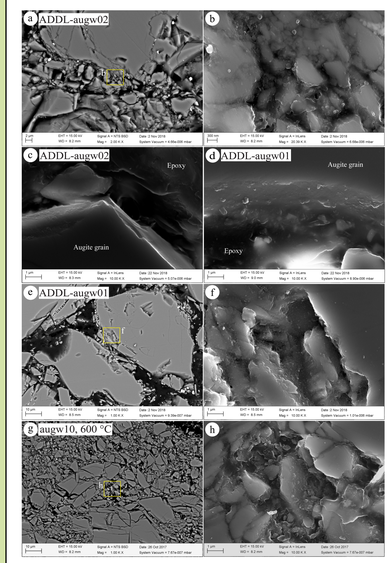
Evidence of pressure solution.



3. Analysis







BE model[1]:

denoting the evolution effect by crystalline plasticity

$$b_{BE} = \frac{d\mu_s}{d(\ln t)} = \frac{\tau_{tr}}{\sigma_{tr0}} \frac{RT}{\Omega_a \sigma_{tr0}}$$

Ω_a is activation volume

IPS model[2]:

denoting the evolution effect by intergranular pressure solution

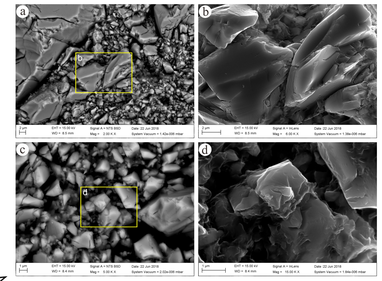
$$b_{IPS} = \frac{d\mu_s}{d(\ln t)} = \frac{\tau_{tr}}{\sigma_{tr0}} \frac{RT}{\Omega_m \sigma_{tr0}}$$

Ω_m is molar volume

◄ microstructural features of two supplementary tests.

The rate of pure dissolution is negligibly low .

Supplementary tests
ADDL-augw01:
effective Cp 2 MPa at 300 °C
ADDL-augw02:
effective Cp 97 MPa at 300 °C



▲ Microstructural feature of chemical etched deformed sample.

No crystalline plasticity observed.

Conclusion

1. Minor velocity weakening behavior was observed between 303 °C to 607°C. The absolute (*b*-*a*) values range from 0.0009 to 0.0014 with average *b*/*a* values between 1.15-1.18.
2. Inferred constitutive parameters show that the evolution effect has an increasing trend with temperature up to 403 °C.
3. For all deformed samples, ubiquitous precipitated particles (50-100 nm) with platy morphologies were observed to attach to the surfaces of crushed grains, which is a typical signature of intergranular pressure solution process .
4. The comparison between inferred activation volume in the creep equation and the molar volume, together with the observed signatures of the intergranular pressure solution and the absence in evidence of recognizable crystalline plasticity, implies that intergranular pressure solution may be the most likely mechanism governing the evolution effect for augite.

Acknowledgments and Reference

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