TEMPERATURE-DEPENDENT DYNAMIC PLASTICITY OF MICRO-SCALE FUSED SILICA

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As the miniaturization of fused-silica micro-components progresses [1], we need to understand and predict their micro-scale strength and plasticity. This study focusses on the behavior of fused silica micro-pillars at high temperatures and variable strain-rates. We have tested 160 micro-pillars with a diameter of 1.6 µm at temperatures between -120°C and 600°C and strain rates between 10-3 s-1 and 1 s-1. Moreover, we have carried out post-compression synchrotron-based ptychographic X-ray computed tomography (PXCT) on a subset of these plastically deformed micro-pillars. Finally, we simulated the mechanical behavior at ambient temperatures by FEM. A non-linear temperature dependence was found for both the absolute yield strength and the strain rate sensitivity of the yield strength. Between -120 °C and 300 °C, the yield strength (6–8 GPa) and strain-rate sensitivity (≤ 0.03) varied only marginally. However, at 600 °C, a significant decrease in yield strength (2.5–4.5 GPa), accompanied by an increase in strain-rate sensitivity to 0.09, was observed. The corresponding deformation mechanisms appear to transition as follows: Shear-localization and shear-promoted densification at 25 °C; homogeneous shear-flow and densification limited by radial cracking at 300 °C; and unconstrained shear-flow and limited densification due to weak confinement strength at 600°C. FEM results support these observations while separating geometric from material-intrinsic effects. These results suggest that the classification of fused silica as a glass that deforms predominantly through densification[2] should be challenged, at least under uniaxial compression. The degree of densification does not significantly vary as a function of strain, pointing at a significant contribution of shear flow. Overall, these results provide a new perspective on the interplay of various deformation mechanisms that accommodate plasticity in fused silica and their temperature-dependence. Particularly salient appears the softening that leads to unconfined shear flow at temperatures as low as 0.5 Tg. While miniaturization does lead to increased strength compared to bulk sizes, it is crucial to realize that softening of the material due to increased temperature will be pronounced already much below the glass transition temperature. Importantly we also introduce the use of a novel X-ray nano-tomography technique that now matches the required contrast and spatial resolution to investigate plasticity enabling mechanisms in amorphous materials. Finally, we discuss important considerations of instrumentation to perform micromechanical experiments at such extreme conditions.

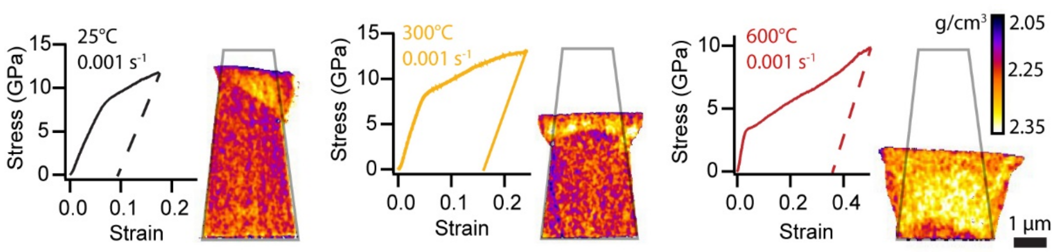

Figure 1 – Stress-strain curves and nano-tomographic reconstructions

References
[1] Kotz, F. et al., Nature, 544, 2017, 337–339.
[2] Neely, J. E., Mackenzie, J. D., J. Mater. Sci. 3, 1968, 603–609.