HIGH STRAIN RATE PLASTICITY IN MICROSCALE GLASS

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Key Words: High strain rate, micropillar, amorphous, shear transformation zone, plasticity

Understanding the materials behavior at high strain rates is critical for the design of structures subjected to accidental overloads such as crash testing of vehicles and impact resistance of surface coatings. From a scientific perspective, experimental determination of high strain rate properties at the micro- and nano-scale will allow the bridging of time scales between atomistic simulations and experiments, leading to a direct comparison between the two methods. Despite many efforts to expand the range of micro and nanomechanical testing in terms of forces, temperatures and loading conditions, the achievable strain rates are still around $10^{-5}\,s^{-1}$ to $10^{-2}\,s^{-1}$. This limited range of strain rates is primarily due to lack of testing platforms capable of simultaneous high-speed actuation and high-speed sensing of microscale displacements and millinewton loads. This presentation will report, a piezo-based experimental methodology for conducting high strain rate *in situ* micropillar compression testing at rates upto ~2000/s inside a scanning electron microscope (SEM), including a brief overview of the advantages and challenges of microscale high strain rate testing compared to traditional macroscale, Kolsky bar based, high strain rate testing.

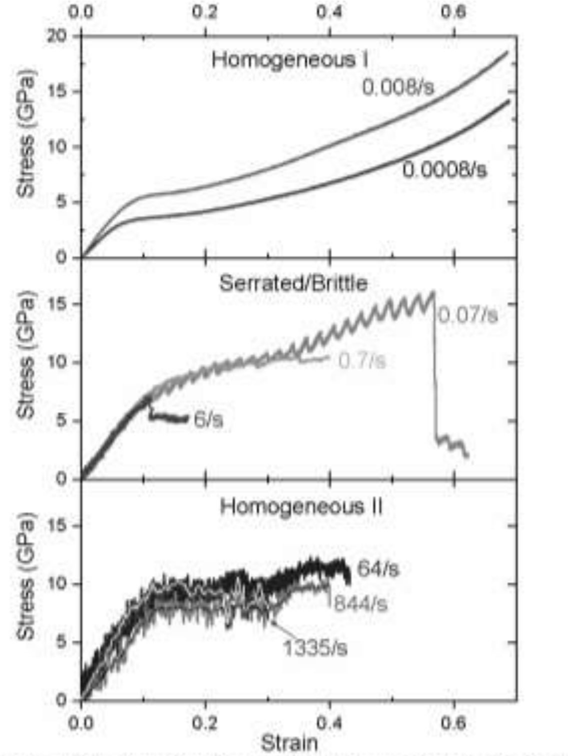

Figure 1: Rate-dependent stress-strain response of microscale glass

Glass is a ubiquitous material with recent applications in the MEMS industry as a more robust alternative to silicon in applications such as high frequency resonators and actuators. Such applications of microscale glass require a clear understanding of their dynamic properties to assess their reliability and crashworthiness. But the mechanical properties of microscale glass are known only at quasi-static strain rates (<~0.1/s). In this presentation, the deformation and failure of microscale glass will be presented as a function of strain rate across 8 orders of magnitude upto 1330/s, using *in situ* micropillar compression tests in an SEM. Contrary to macroscopic experiments, glass micropillars show a remarkable ductile-serrated-brittle-ductile transition in deformation behavior as the strain rate is increased from 0.0001/s to 1335/s, as shown in Figure 1. Further, the atomistic mechanisms behind such dynamic plasticity behaviors of glass will be explained using a combination of high-resolution SEM imaging, analytical modeling and finite element simulations. At the slowest strain rates (<0.008/s) microscale glass deforms almost infinitely with a smooth stress-strain behavior; a result of the applied strain being accommodated entirely by the thermally activated shear transformation zones (STZs). At the intermediate strain rates (<0.7/s), the stress-strain behavior is serrated, with each stress-drop corresponding to a respective propagated shear band. Specifically, at a strain rate of ~6/s the microscale glass fails in a purely brittle-like manner, as the speed of shear band propagation is too high to accommodate a large strain. Thus, the deformation of microscale glass at these intermediate strain rates can be attributed to *shear band propagation* kinetics. Interestingly, at even higher strain rates (~60/s to 1335s), the glass micropillars can again sustain significant ductility before failure. The increased plasticity in glass micropillars at these high strain rates will be attributed to the ability of microscale glass to efficiently partition the applied strain to simultaneously nucleated (but not propagated) multiple shear bands aided by the bulk heating of the micropillar. Thus, at such high strain rates, the deformation behavior is controlled by the *shear band nucleation* kinetics.