February 19, 2021

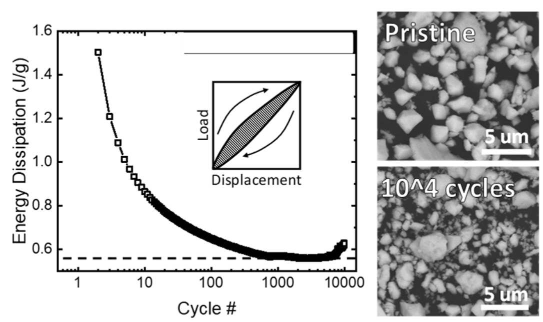
Energy Dissipation and Functional Fatigue in Granular Packings of Superelastic Ceramics

Hunter A. Rauch[1], R. Joey Griffiths[1], David Garcia[1], Yan Chen[2], Ke An[2], Hang Z. Yu[1]

[1]Materials Science and Engineering, Virginia Tech, [2] Neutron Sciences, Oak Ridge National Lab

Abstract

Superelastic and shape memory ceramics are exciting functional materials that combine the advantageous thermal, mechanical, and chemical behavior of zirconia-based ceramics with a recoverable shape change. This shape change is controlled by a reversible martensitic (no diffusion) phase transformation which can be triggered by stress, and dissipates mechanical energy as heat according to the large stress-strain hysteresis. Compared to metallic superelastic alloys, this hysteresis loop is quite large. Unfortunately, this transformation is well known to result in catastrophic failure of sintered zirconia bodies due to mismatch between the two phases – hence the range of stabilized zirconias, which generally do not transform. These transformation issues which plague sintered zirconia are mitigated by reducing the mechanical constraint, usually by utilizing micropillars, so-called 'oligocrystalline' structures, or granular packings. Of these material forms, granular packings – powders contained in a die – are by far the most economical and scalable avenue to access the large energy dissipation potential. In previous work, we showed that granular packings of superelastic ceramics display a unique 'globally continuous' mode of stress-induced transformation which lacks an apparent critical stress, owing directly to the interesting granular mechanics involved. In this talk, I will explain how these packings' behavior and characteristics evolve over a number of transformation cycles, including detailed results from *in situ* neutron diffraction and *ex situ* XRD to estimate micro- and nanoscopic contributions to fatigue. Load-displacement curves and neutron diffraction spectra show that the packings can still dissipate energy via the stress-induced transformation after many cycles. While superelastic ceramics do not support the same fatigue mechanisms that eventually limit transformation in metallic superelastic alloys, the superelastic ceramic packings do show evidence of irreversible changes, namely an eventual reduction of the particle size via fracture.



Semi-log plot of energy dissipated per loading-unloading cycle of a superelastic granular packing. The inset is a schematic of the hysteresis loop from a single cycle used to calculate the energy. On the right are two micrographs of the particles that comprise the granular packing before (upper) and after (lower) cyclic loading, which shows particle fracture.

Biography

Hunter Rauch is a PhD candidate in Dr Hang Yu's research group, expecting to defend in April 2021. He received his bachelor's degree in materials science from Penn State in 2016 and joined Virginia Tech the same year. Ceramic, metal, and composite processing and advanced characterization techniques are his biggest interests. His thesis covers the unique aspects of the phase transformation in granular shape memory ceramics, and he has presented his research at several conferences over the years.