

Title

Bulk vs. Nano-Indentation Stress-Relaxation of δ -Phase Plutonium Alloys: Methodology, Parameter Extraction, and Compliance Corrections

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Abstract

The mechanical performance of δ -phase plutonium (Pu) alloys is governed by time-dependent relaxation processes that are difficult to capture across length scales. This work presents a comparison between macroscopic stress-relaxation experiments on bulk specimens and high-resolution nano-indentation relaxation tests on the same alloys. Bulk samples were subjected to compression deformation in a 10 kN screw-driven mechanical test frame and held at constant displacement for 2 to 3 minutes. The resulting stress-relaxation curves were fitted to a logarithmic decay model ($\Delta\sigma(t) = C_1 \ln[1+(t/\tau)]$) to extract a characteristic relaxation time (τ) and the material constant (C_1). A compliance-correction scheme was applied by measuring the machine stiffness with a reference specimen and subtracting it from the raw load-displacement data, yielding true material compliance.

In comparing to nano-indentation stress relaxation measurements; key differences between the two approaches are highlighted: (i) bulk tests probe homogeneous, uniaxial stress states whereas nano-indentation samples a confined, triaxial field; (ii) parameter extraction in bulk data relies on direct strain control, while nano-indentation demands indirect strain estimation from contact area; (iii) compliance correction in bulk experiments is a non-linear subtraction, whereas nano-indentation demands a geometry-dependent, non-linear correction.

Despite these methodological disparities, the extracted τ and C_1 values show reasonable agreement for all investigated δ -phase compositions, demonstrating that nano-indentation can reliably reproduce bulk relaxation behavior when proper compliance corrections are applied. The results provide a robust multiscale framework for assessing time-dependent mechanical properties of Pu alloys and inform future modeling of their long-term performance.

Keywords: δ -phase plutonium, stress relaxation, bulk compression testing, nano-indentation, compliance correction, logarithmic decay model.