Nanomechanical Testing in Extreme Environments: High Strain Rate Nanoindentation at High Temperatures

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Introduction

Nanoindentation has traditionally been limited to room temperature and quasi-static strain rates (10^{-5} to 10^{-2} s^{-1}). However, recent advancements have extended its capabilities across a wide temperature range (-150 to 1000 °C) and enabled high strain rate testing up to 10^{5} s^{-1} under simultaneous extreme environmental conditions. With Alemnis' expertise in both high strain rate and variable temperature testing, we aim to push the boundaries by integrating these two parameters. This talk presents nanoindentation data obtained under extreme environmental conditions and varying strain rates, highlighting key technological and methodological advancements. The challenges associated with variable temperature testing, as well as the necessary innovations in instrumentation and experimental protocols, will be discussed through selected case studies. testing conditions.

Case Studies

As an example of nanoindentation under combined cryogenic temperatures and varying strain rates, we present a study where experiments were conducted in displacement control using a flat punch diamond indenter. Mechanical testing was performed at -110 °C, -50 °C, and 27 °C, with strain rates ranging from 10^{-3} to 500 s^{-1}. To enable these experiments, a novel in situ nanoindenter setup integrating low-temperature indentation with high strain rate capabilities was developed. This system allowed, for the first time, compression testing of nanocrystalline micropillars at sub-ambient temperatures and across a wide strain rate range inside an SEM [1]. For the case of high temperatures and varying strain rates, we present a study investigating the micro-mechanical behavior of fused silica micropillars under extreme conditions. Micropillars were tested at temperatures ranging from -120 °C to 600 °C and strain rates between 10^{-3} s^{-1} and 1 s^{-1}, representing a previously unexplored parameter space [2].

Furthermore, this talk will introduce a customized piezoelectric in situ nanomechanical test setup designed to explore rate-dependent hardness across strain rates from 10^{1} to 10^{5} s^{-1}. For the first time, this system enables constant indentation strain rates up to 10^{5} s^{-1}, overcoming the limitations of conventional macro- and microscale testing techniques. This advancement has made it possible to study the rate-dependent hardness of single-crystalline molybdenum, nanocrystalline nickel, and amorphous fused silica across this strain rate range [3]. Additionally, the methodology allows for post-deformation microstructural analysis at specific strain rates, offering valuable insights into material behavior under high strain rate conditions.

Concusions

These advancements in nanoindentation technology mark a significant step forward in understanding material behavior under extreme conditions. By integrating high strain rate capabilities with variable temperature testing, we can explore deformation mechanisms that were previously inaccessible. The combination of these advanced techniques enables a more comprehensive characterization of materials at small length scales, facilitating the development of next-generation materials for extreme environments. This work paves the way for future studies on rate-dependent deformation across a wide range of materials and testing conditions.

References

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