Extraction of reliable deformation activation parameters from nanoindentation tests covering strain rates from 0.00001 to 10,000 /s and associated changes in deformation mechanisms in metals

Suprit Bhusare[1], Rahul Cherukuri[1], Aloshious Lambai[1], Nidhin George Mathews[1], Jakob Schwiedrzik[2], Michler Johann[3], Rajaprakash Ramachandramoorthy[4], and Gaurav Mohanty*[1]

[1]Materials Science and Environmental Engineering, Faculty of Engineering and Natural Sciences, Tampere University, 33014 Tampere, Finland – Finland

[2]Laboratory for High Performance Ceramics, Empa Swiss Federal Laboratories for Materials Science and Technology, Ueberlandstrasse 129, 8600 Dübendorf, Switzerland – Switzerland

[3]EMPA Mechanics of Materials and Nanostructures – Switzerland

[4]Max Planck Institute for Sustainable Materials – Germany

Abstract

Deformation activation parameters like activation volumes, energies and rate exponents are considered as signatures of the material deformation behavior. With advances in micromechanical test techniques (e.g. nanoindentation and micropillar compression), there is a rapidly growing body of literature reporting these parameters extracted at small length scales. However, the reliability of the extracted deformation parameters from indentation tests is still largely unproven for indentation relaxation, creep and high strain rates. In cases where the activation parameters deviate significantly from standard/expected values, does it suggest that the rate controlling deformation mechanism(s) have changed at smaller length scales? Or are the results misleading, most likely due to artefacts of measurements and/or incorrect testing methodology and data analysis? This presentation will address this critical issue through case studies on both polycrystalline and single crystalline metals using both transient and high strain rate micromechanical tests. The focus will be on studying the deformation mechanisms in indentation across 10 orders of strain rates.

This presentation will address the issue of reliability of extracted deformation parameters through systematic micropillar compression and nanoindentation tests carried out on nanocrystalline metals that enable a direct comparison between different test techniques and the extracted parameters. The rationale for choosing nanocrystalline metals was that micro-compression of a large sized pillar (_˜ 2-5μm diameter) and nanoindentation to large depths ($> 1\mu$m) interrogates more than thousands of grains such that the test results can be considered to represent "bulk" behavior to enable a systematic comparison. Small grain size also avoids size effects in mechanical properties, typically observed in micromechanical testing on single crystals. Results from recently developed indentation stress relaxation tests will be presented and compared with other transient tests like strain rate jump and creep tests. The extracted strain rate exponents and activation parameters (activation volume and activation

*Speaker

energies) from transient tests provide valuable insights into the rate controlling deformation mechanism(s) in metals with respect to dislocation plasticity and grain boundary mediated processes. It will also report the changes in deformation mechanisms in indentation at high strain rates. High strain rate testing is attractive not only for testing materials under impact conditions, but also to bridge the timescales between atomistic simulations and experiments. Micropillar compression (up to 1000 /s) and nanoindentation (up to 10,000 /s) tests, performed on both polycrystalline and single crystal metals, will be presented to discuss changes in deformation mechanisms as a function of indentation depth, strain rate and grain size. We will report controlled constant strain rate nanoindentation up to 10,000 /s whereby the strain rate remains constant with indentation depth. This is in stark contrast to previous impact and rebound based indentation tests where the strain rate rapidly decreases with increasing depth. It is hoped that this study will pave the way for routine transient and high strain rate indentation tests for experimentally exploring deformation mechanisms as a function of structure, strain rates and temperatures in various other materials systems.