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Comparison of in situ micromechanical time dependent plasticity techniques: micropillar compression, nanoindentation and micro-tensile tests

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Objectives

- Comparison of strain rate jump tests performed in: uniaxial tension, uniaxial compression and triaxial nanoindentation
- Comparison of strain rate sensitivity and activation parameters, obtained from experiments that cover the range from bulk to nanoscale

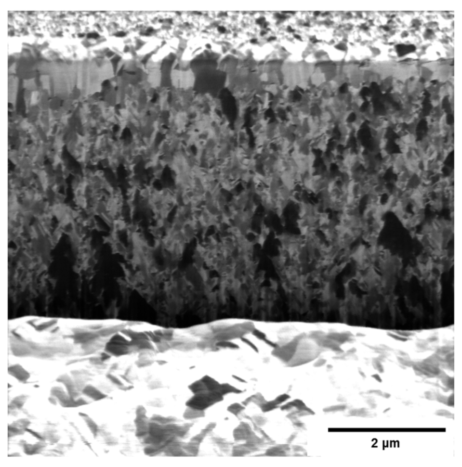
Introduction

Electrodeposited nanostructured metals are attractive for producing micro components due to fabrication (design flexibility and dimensional accuracy) and mechanical property (high strength, ductility) considerations [1-4]. However, their mechanical characterization, especially for thin films is not straight forward. This study aims at the development and validation of suitable uniaxial testing methods for mechanical characterization of these microcomponents.

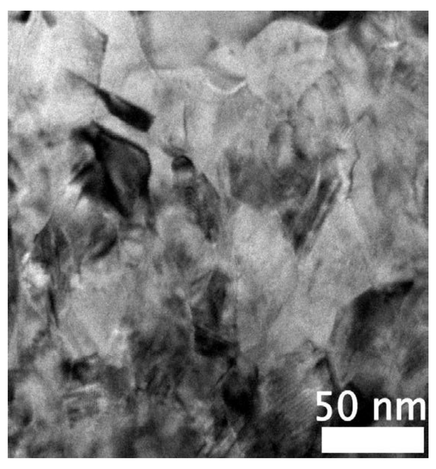
Material

- Electrodeposited nanocrystalline nickel (sulfamate bath), grain size ~30nm
- Deposition of micro parts in LiGA-molds (~250 µm thickness)
- Microstructural characterization: XRD, ion channeling contrast imaging, TEM

Ni micro components, deposited into LIGA-mold



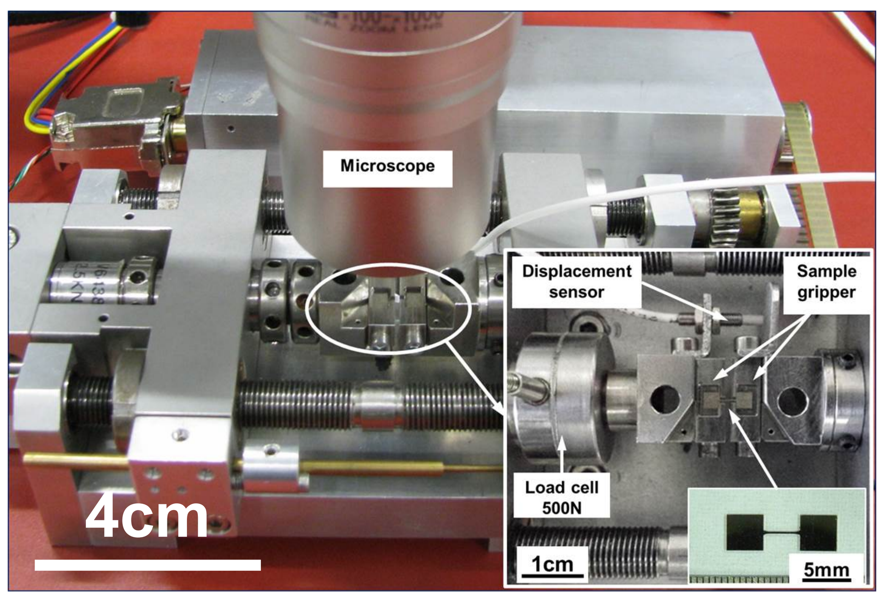
Ga-FIB CS of Ni deposit (Ion channeling, 30kV, 80pA)



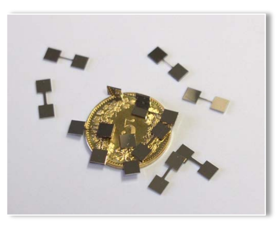
TEM CS of Ni deposit (STEM, 200kV, 0.7nm)

Micro bulk tensile testing of miniaturized samples

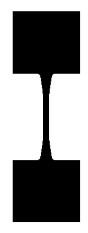
- Bulk tensile tests are uniaxial, straight forward to perform and well understood
- Modification of a commercial Kammrath & Weiss tensile stage for testing LIGA samples
- Dogbone shaped micro-tensile specimen: gauge 0.15µm x 0.25µm
- Strain measured using digital image correlation (DIC)



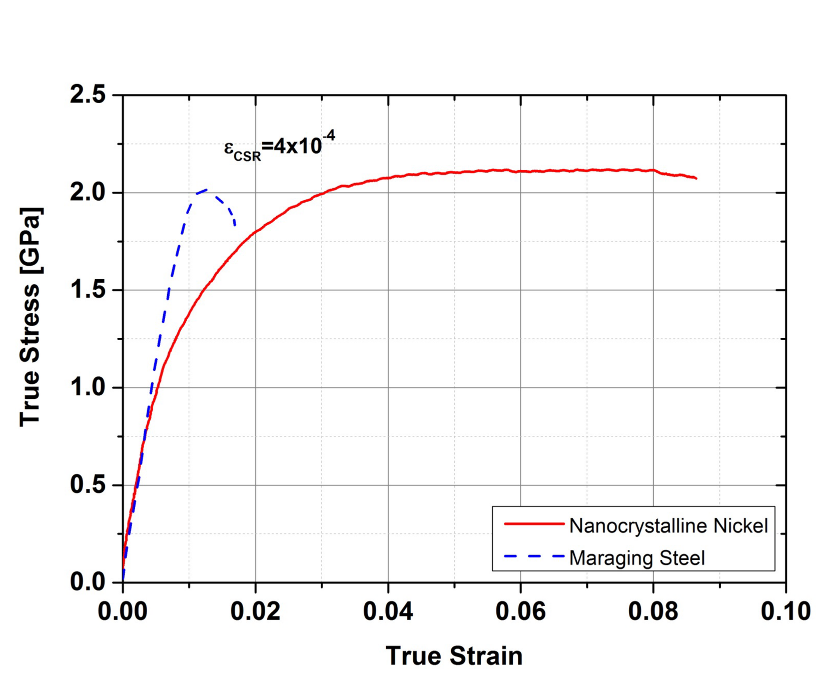
LiGA Tensile Specimen



Dimensions:
Gauge length: 4mm
Gauge width: 0,15mm
Thickness: 0,25mm



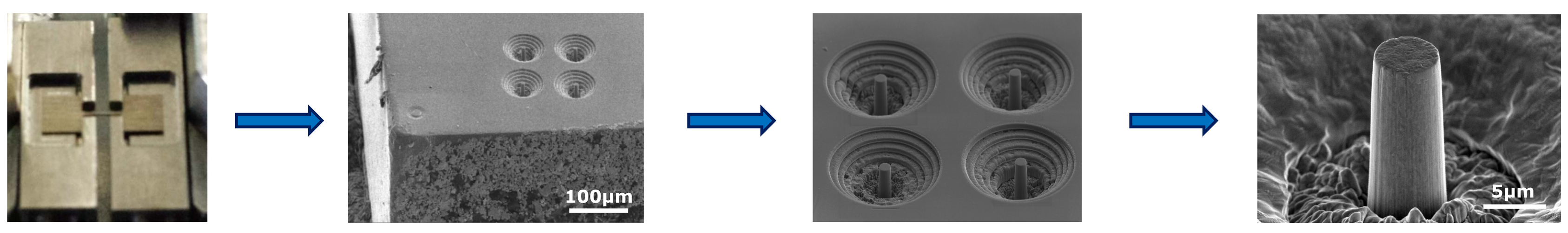
Above: LiGA micro specimen dimensions
Left: In-Situ tensile stage (Kammrath & Weiss) with modified displacement sensors, load cell and gripping system



- Stress-strain curves from miniaturized tensile test
- Maraging steel is the current industrial standard for fabrication of microcomponents
- Test of standard metrials yield textbook results → *validation*

Tensile stress-strain curves of nc Ni and maraging steel

Micropillar preparation with Ga-FIB

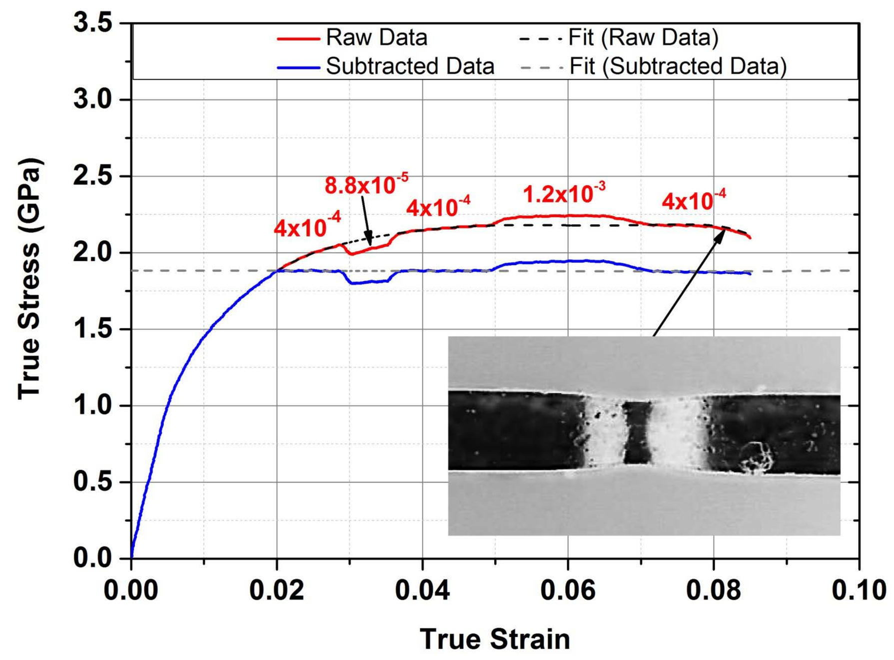


- Micropillars machined in the undeformed gripping section of tensile specimen
- Allows for multiple tests on one single sample
- Better comparability of test results

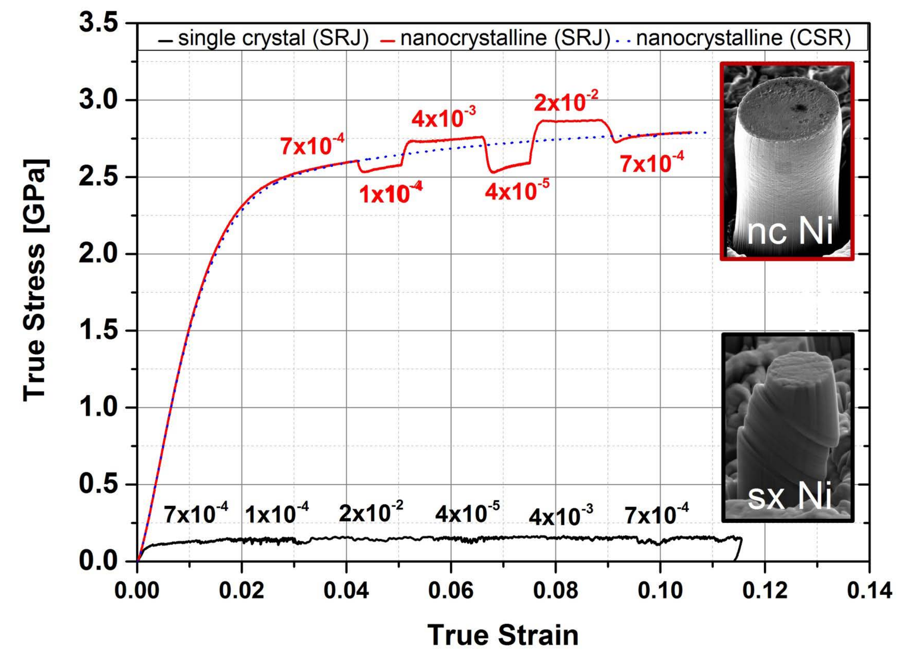
Strain rate jump (SRJ) tests

Recently, there have been attempts at extracting the strain rate sensitivity exponent from micromechanical tests: nanoindentation [6] and micropillar compression [7]. This study aims at an overall comparison of results from room temperature SRJ tests on the same sample (nanocrystalline Ni) using uniaxial tension, micropillar compression and nanoindentation:

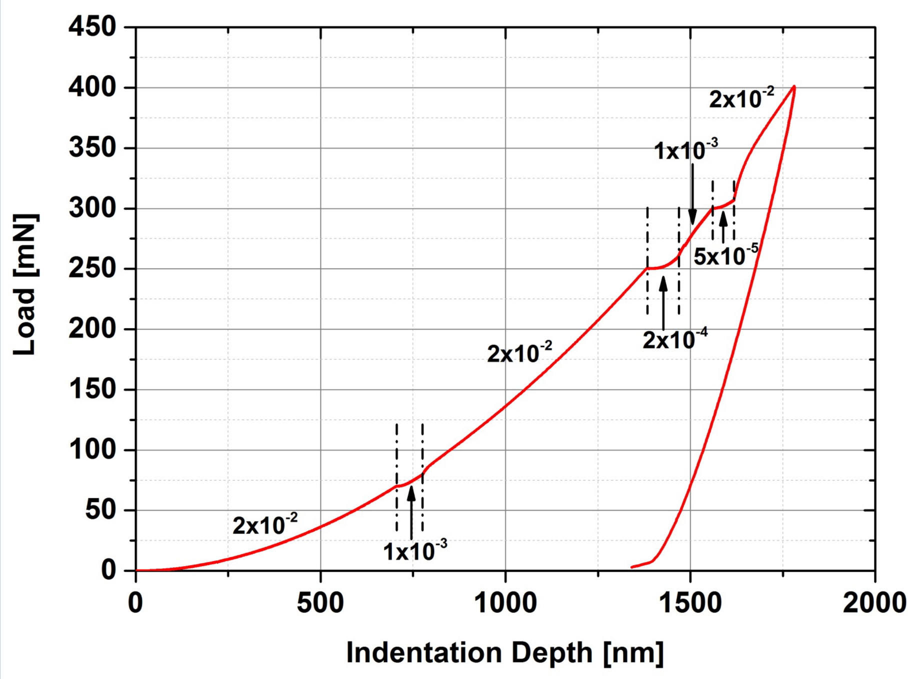
- Nanoindentation and microcompression SRJ tests performed on the failed sample from uniaxial tensile SRJ test.
- Similar strain rates used for all three tests
- Strain rate varied over three orders of magnitude



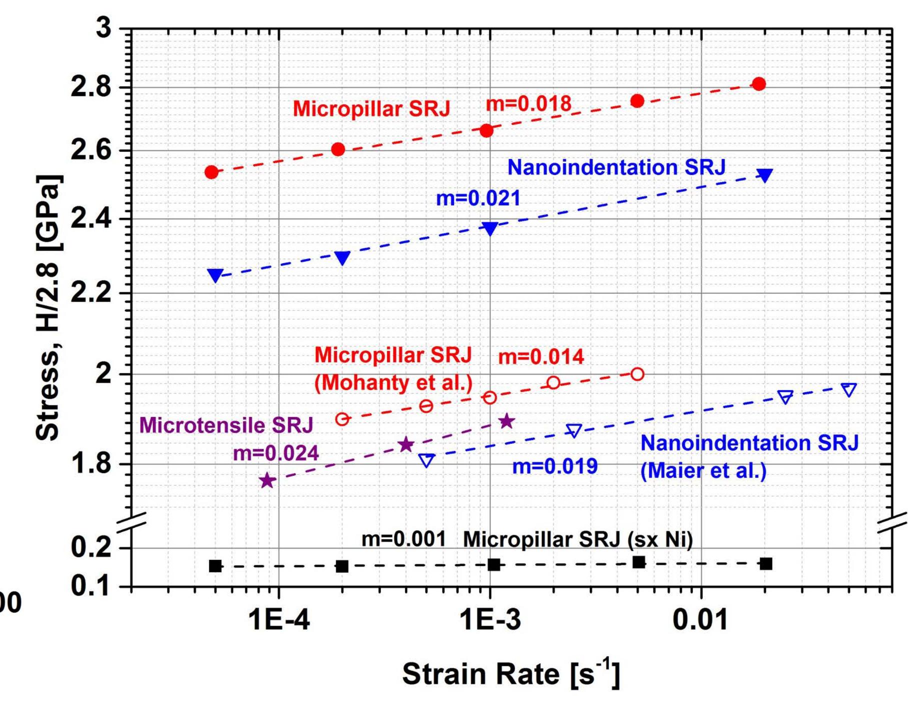
Stress-strain curve and a polynomial fit obtained from uniaxial microtensile SRJ tests. Jumps have been performed over one order of magnitude. Flow stress stabilizes immediately after each jump. The numbers represent applied strain rates (s^{-1}).



Stress-Strain curve of micropillar SRJ test on nanocrystalline nickel (red) and single crystal nickel (black). The blue curve was obtained from a CSR compression test on the same nanocrystalline nickel.



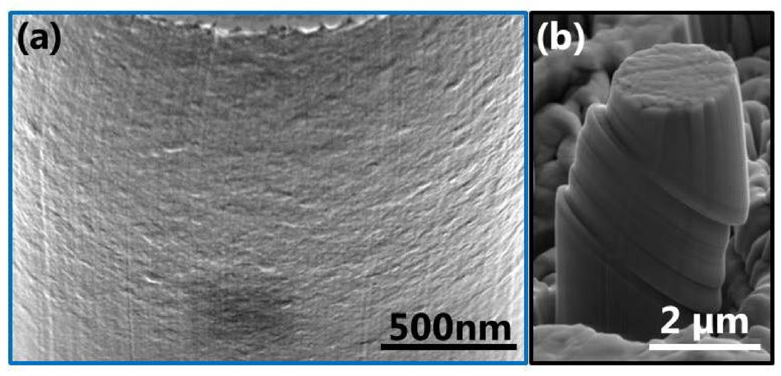
Load-displacement curve obtained from nanoindentation strain rate jump test. Strain rate varied by chaning $\dot{P}/P$ ratio over four orders of magnitude.



Log-log plot of stress vs. strain rate comparing the results of SRJ tests in uniaxial tension (micro-bulk), micropillar compression and nanoindentation. Hardness values from nanoindentation have been converted to flow stress by dividing with a factor 2.8 [6]..

Results and conclusions

- Three different micromechanical measurement techniques for assessing SRS were applied on the same nanocrystalline nickel specimen to study the comparability and consistency of the test results
- Consistent strain rate sensitivity exponent *m* values were obtained from all three tests. Excellent agreement with literature values [6,7].
- The obtained apparent activation volume $10b^3$ for nanocrystalline nickel is consistent with grain boundary diffusion processes and dislocation glide based plasticity
- Due to the typical grain size variation in electrodeposited metals it is likely that both mechanisms are active at the same time
- This study suggests that the techniques compared herein can be reliably and inter changeably used to measure SRS accurately in a wide variety of materials



Postcompression high-resolution scanning electron micrographs: (a) nanocrystalline nickel showing displaced grains distributed throughout the pillar and (b) single-crystal nickel showing deformation confined to discrete slip bands traversing the pillar..

Please see also: J. Wehrs et al: "Comparison of In Situ Micromechanical Strain-Rate Sensitivity Measurement Techniques", JOM, August 2015, Volume 67, Issue 8, pp 1684-1693

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Work in progress

- Investigation of time dependent plasticity phenomena in nanocrystalline thin films: relaxation, creep and strain rate jump tests at elevated temperatures
- Investigation of mechanical properties of nanocrystalline nickel-tungsten alloys for improved thermal stability

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