Correlation Between Wear Response and Microstructural Evolution in Nanocrystalline Ni-W

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NNSA National Nuclear Security Administration

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Motivation & Background

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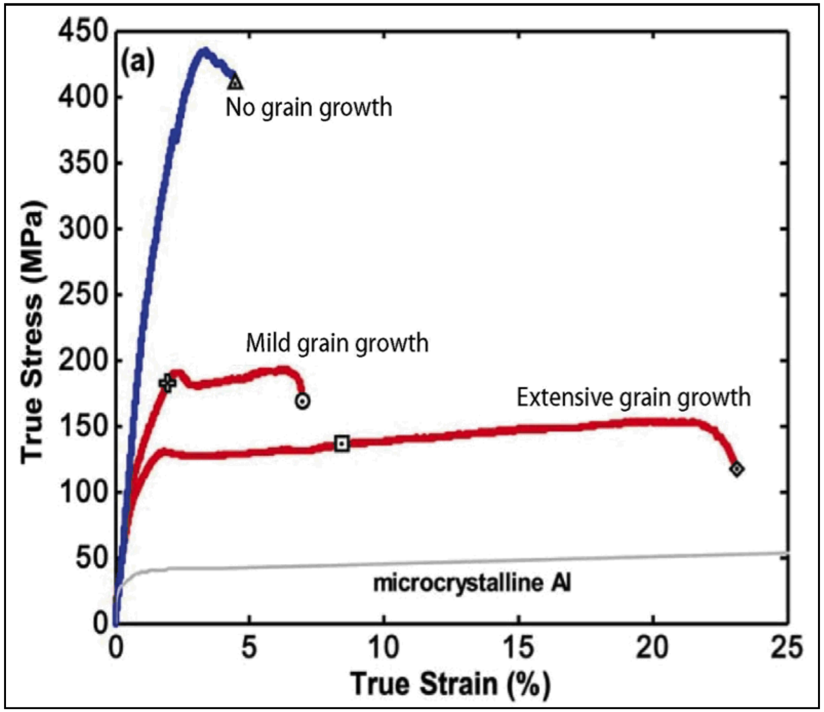
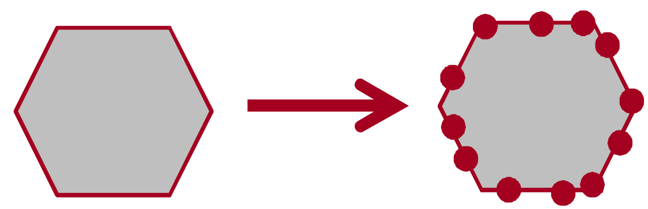


- Nanocrystalline (NC) metals have many advantages (strength, wear, fatigue, etc.)…
- BUT: they are *thermally and mechanically unstable*

Solute segregation at boundary

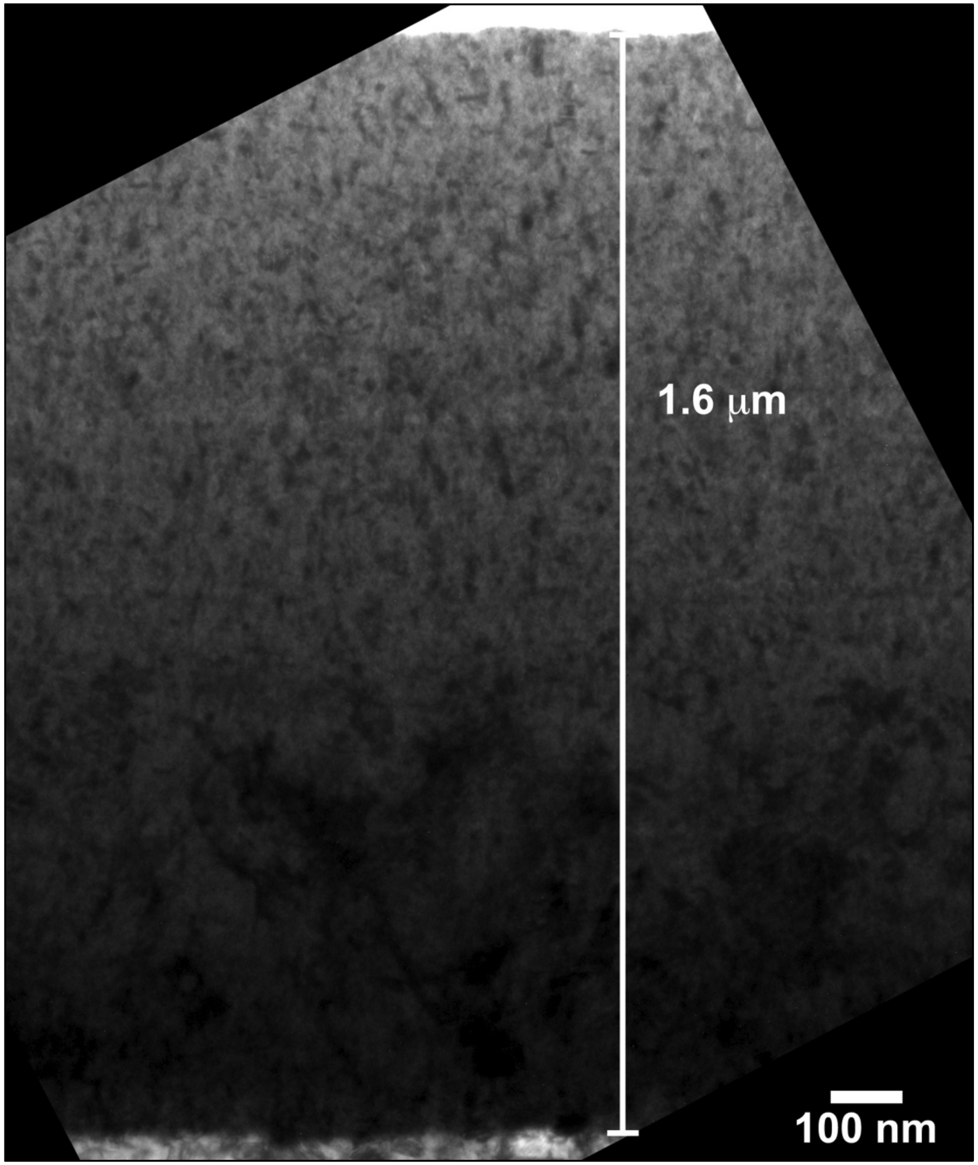


$$dG = \left[\gamma - \frac{N_\beta}{A} \Delta G_{seg} \right] dA$$

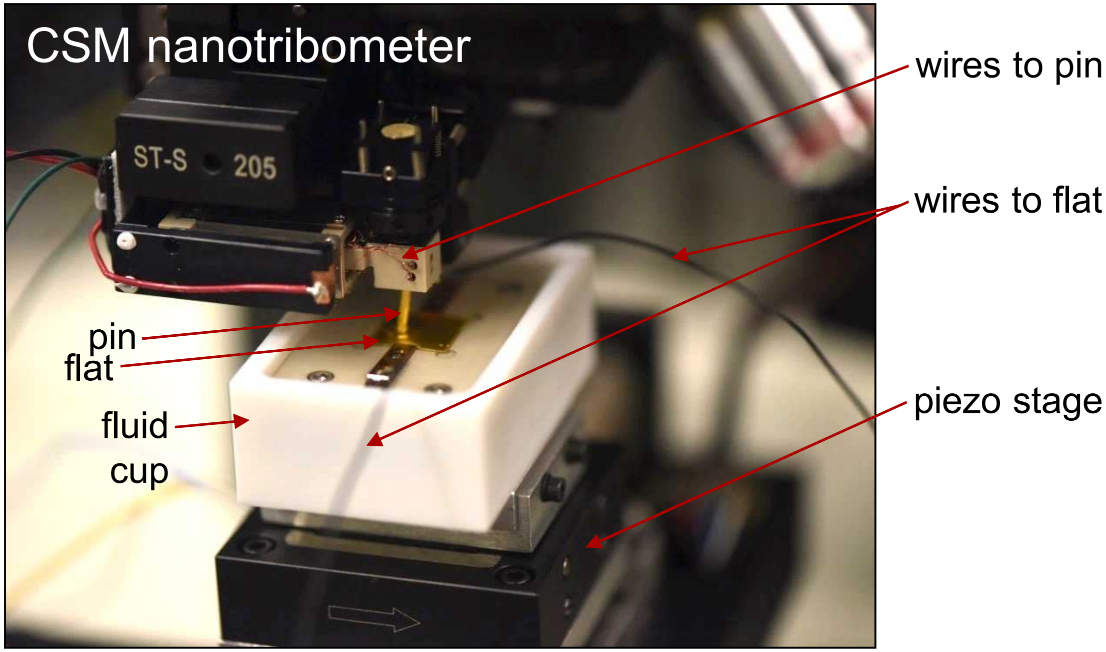
Considerable thermal stability through solute segregation → Extendable to mechanical stability?

Material Selection: Ni-W

- Electrodeposited Ni-20W, on brass substrate
- Film thickness of 1.6 um
- Starting grain size of 3-5 nm
- Demonstrated stability of grain size over 24 hours at up to 500 °C [Detor & Schuh]



Experimental Method



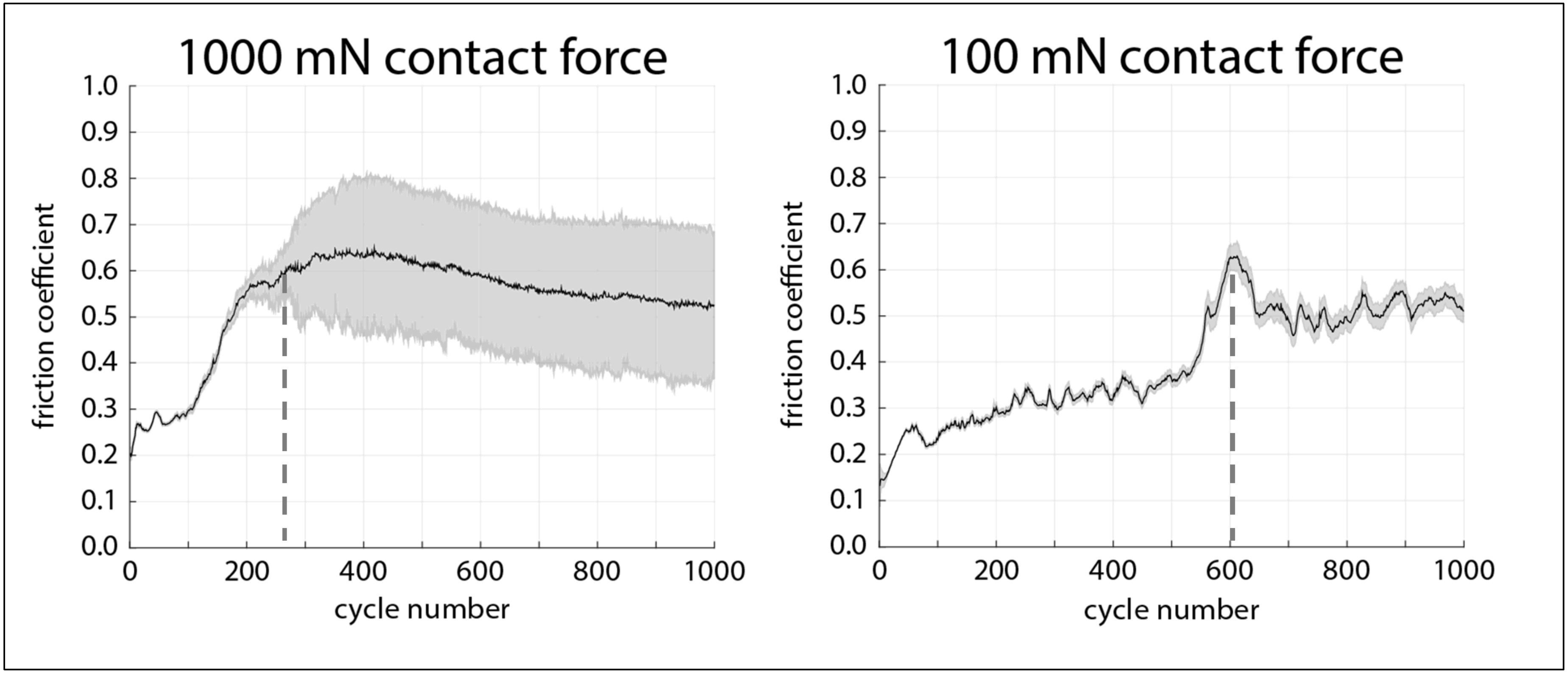
Test parameters:
- 1 mm/s sliding speed
- Bidirectional sliding
- 1.6 mm sapphire ball
- 2 mm track, in air

Three contact forces:
- 1 mN
- 100 mN
- 1000 mN

Goal to correlate measured friction coefficients, over a range of contact forces, with microstructural evolution

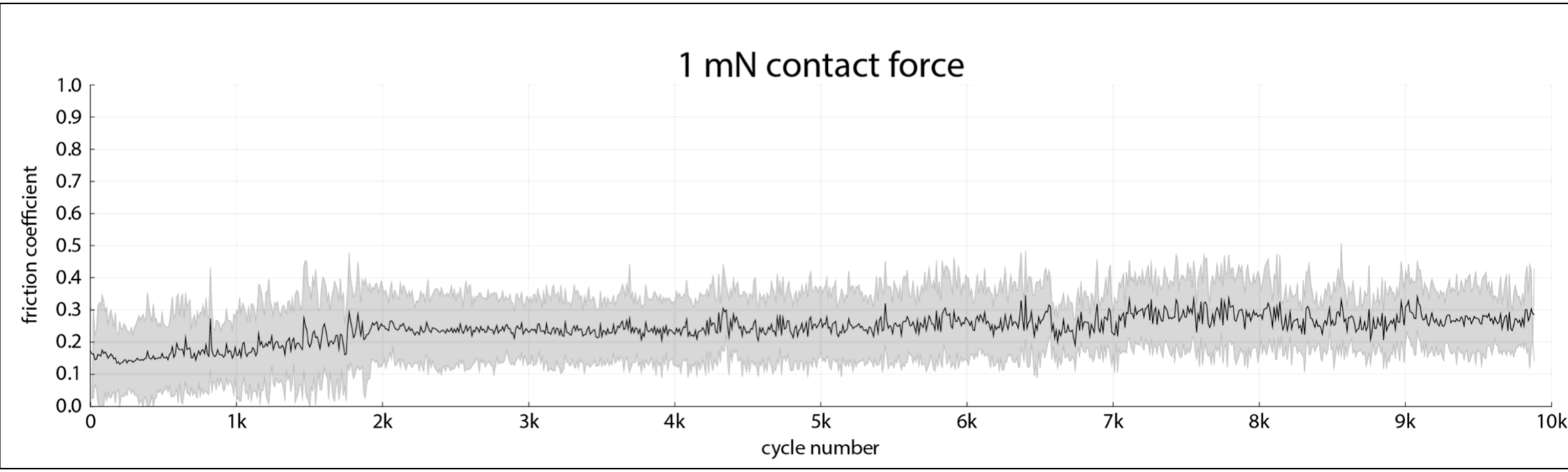
Cross-sectional samples for each wear track prepared for transmission electron microscopy (TEM) via focused ion beam (FIB)

Higher Contact Force Results



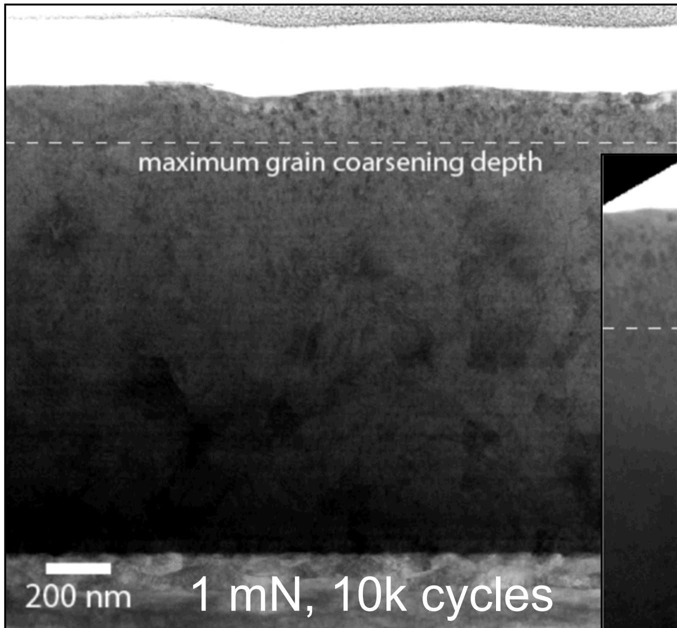
For the two higher applied contact forces, see transition from low COF (0.2-0.3) to high COF (0.6) within hundreds of cycles

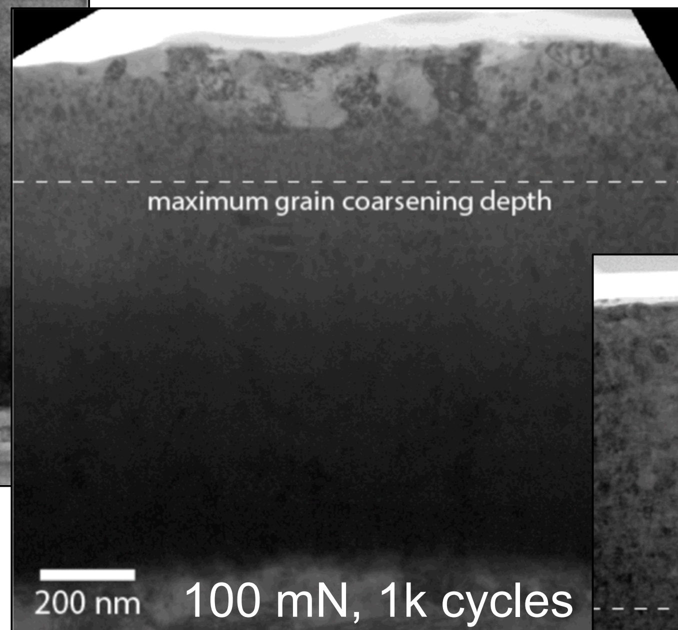
Low Contact Force Results

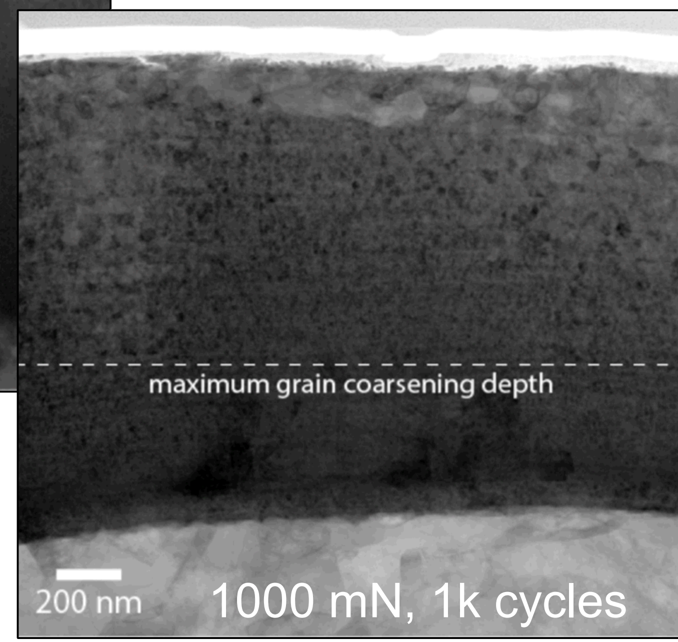


For the low applied contact force case, friction coefficient remains low (0.2-0.3) for test duration over 10,000 cycles

Microstructure in Ni-W Wear Tracks



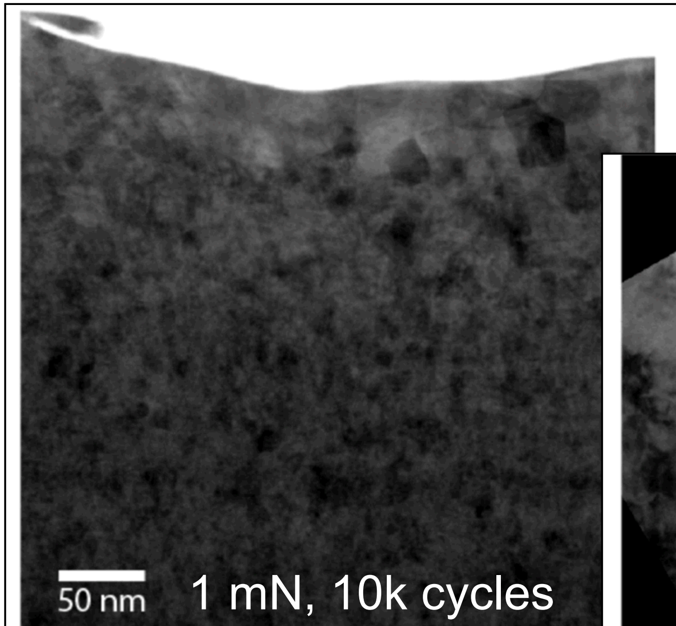


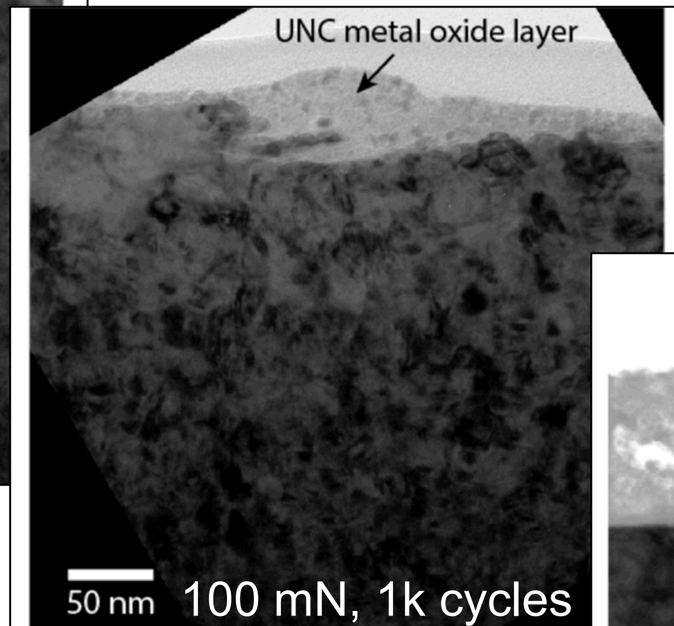


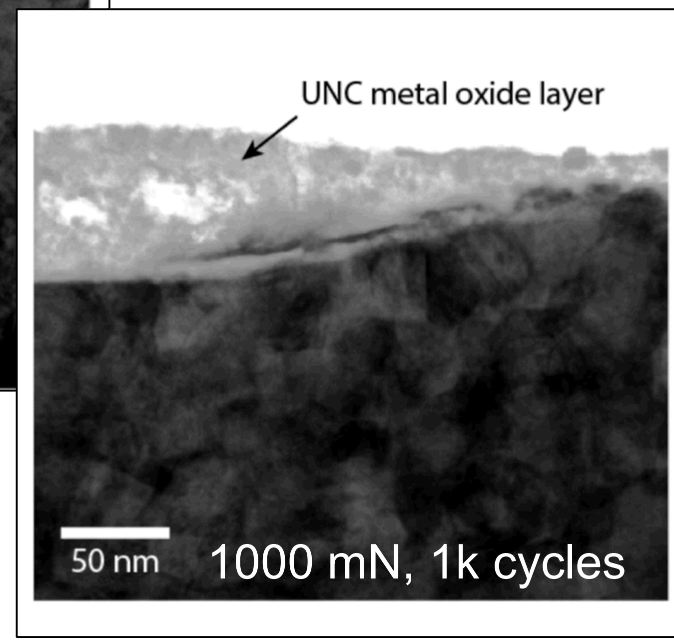
- Cross-sectional TEM shows microstructural evolution in each wear track

Grain coarsening depth and max grain size increases with increasing contact force

Microstructure in Ni-W Wear Tracks



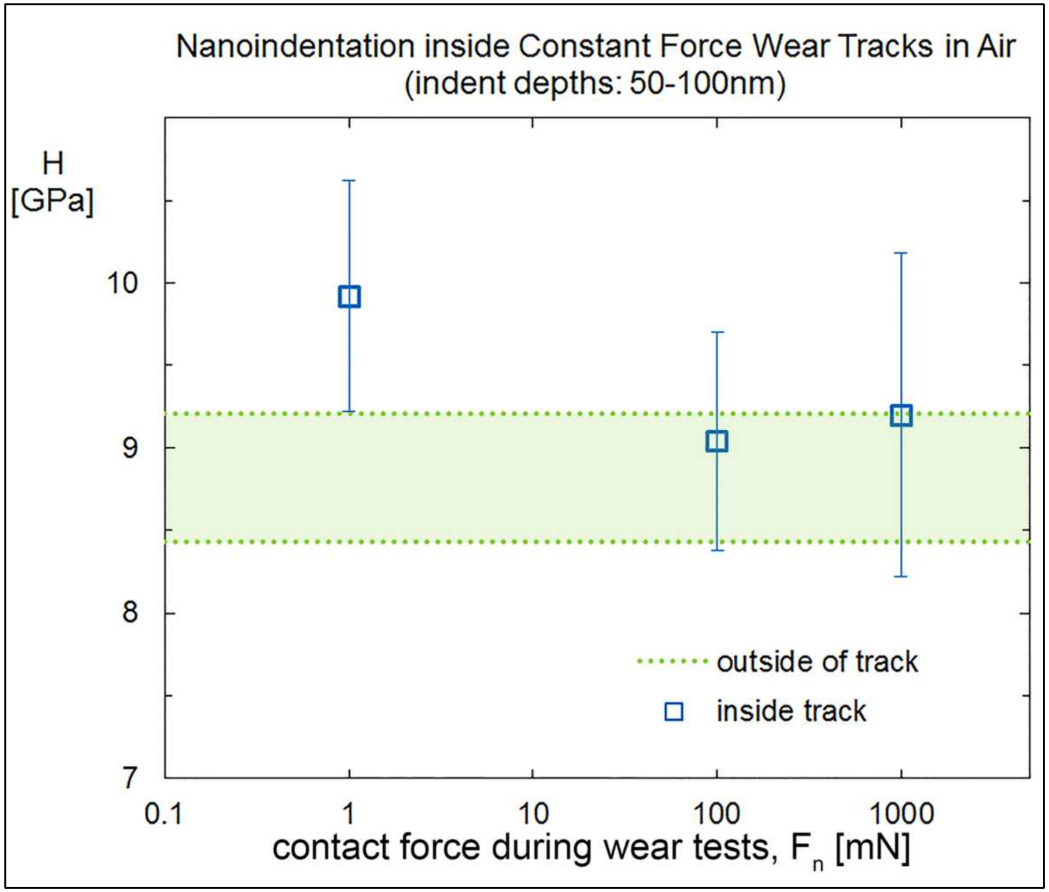




- Presence of metal oxide layer with increased wear

Grain coarsening depth and max grain size increases with increasing contact force

Increase in Hardness for 1mN Track

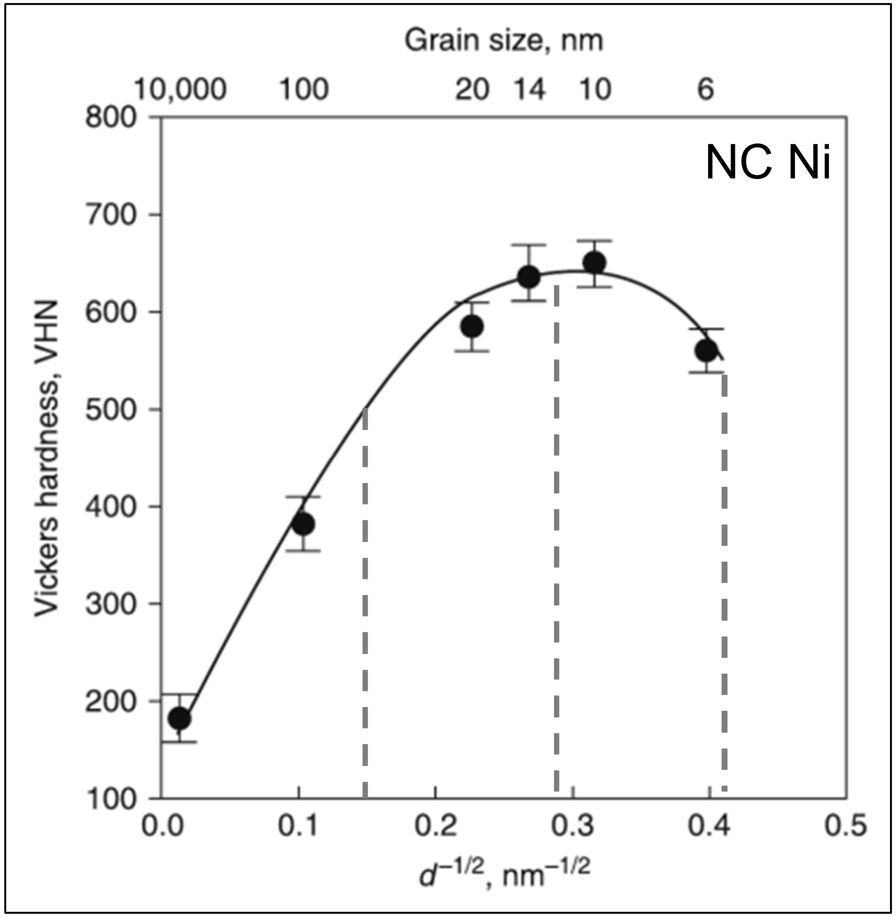


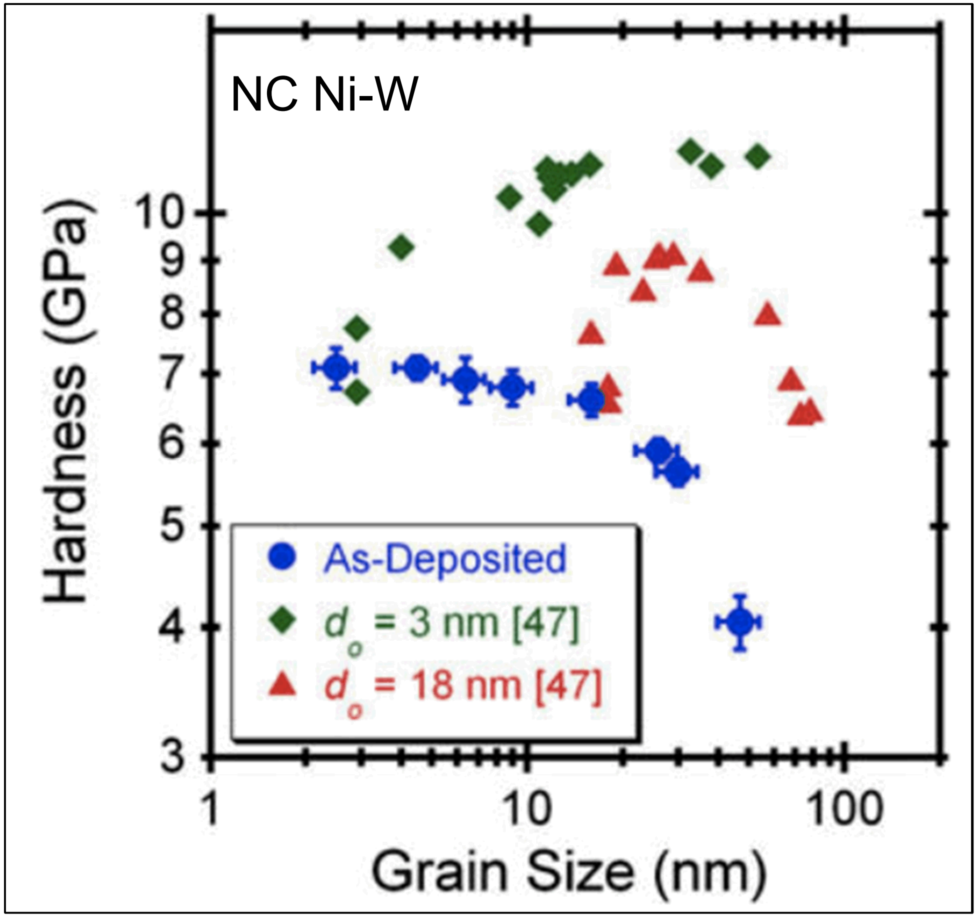
- Increase in hardness for 1 mN wear track
  - In comparison to higher force tests *and* to parent material

- Parent material
  ~ 5nm grains
- 100 and 1000 mN track
  ~ 50-100 nm grains
- 1 mN track
  ~ 10-20 nm grains

Higher hardness in 1mN track consistent with low coefficient of friction

Hardness for 1mN Track > As-Dep'd



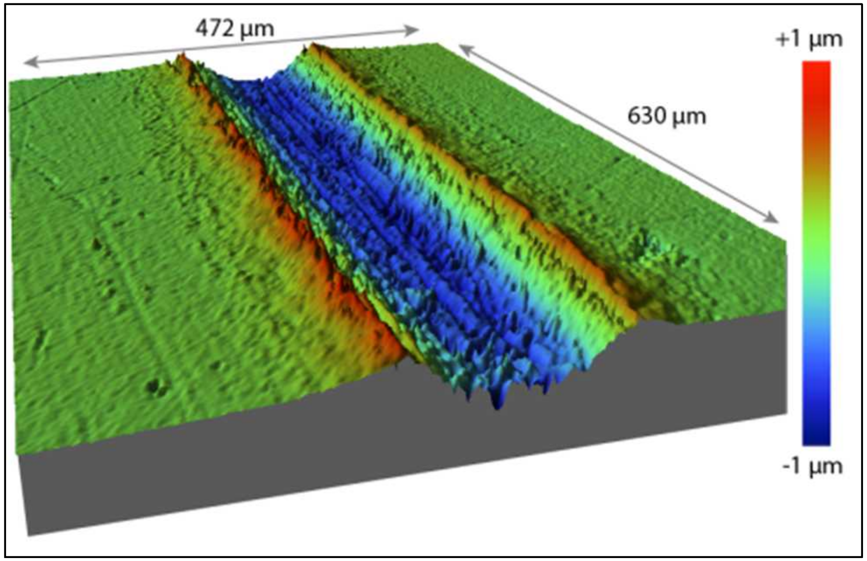


Higher hardness of evolved microstructure, compared to as-deposited microstructure, consistent with previous data

Erb, El-Sherik, Palumbo, Aust (1993); Rupert, Schuh (2010); Detor (2007)

Summary

- Tribological response of Ni-W measured over a range of contact forces
  - For high contact forces, 100 and 1000 mN, see transition to high friction within hundreds of cycles
  - For low contact force, 1 mN, low friction to *10000* cycles
- High friction tracks correlated to significant grain coarsening
- Low friction track correlated to retention of fine microstructure and higher material hardness



Binary NC alloys show potential for stability in both thermal and mechanical limits

Future Work: Stability Maps