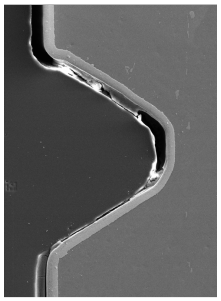
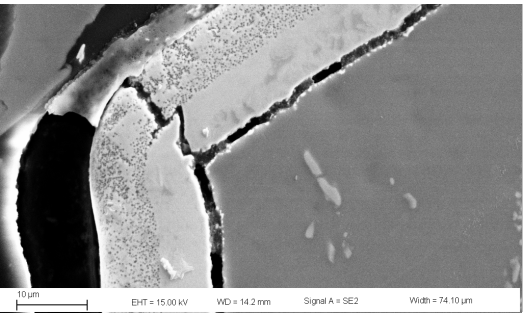
SAND2014-19992PE





Tribological Characterization of Hohman Plating Ni-PTFE Thin Films (ENOVA)

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In collaboration with:

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Brendan Nation and Graham Yelton

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Friction Tester

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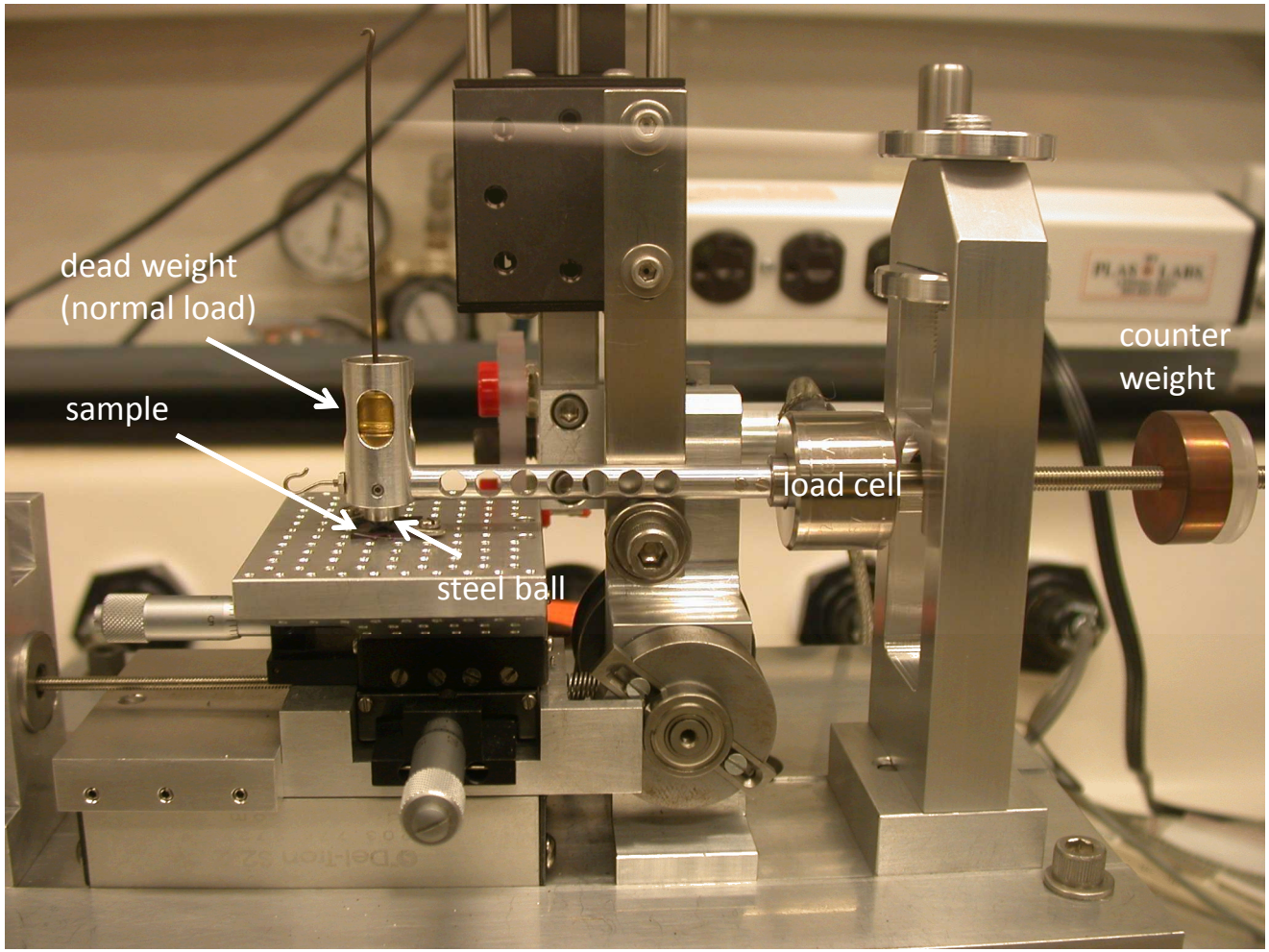
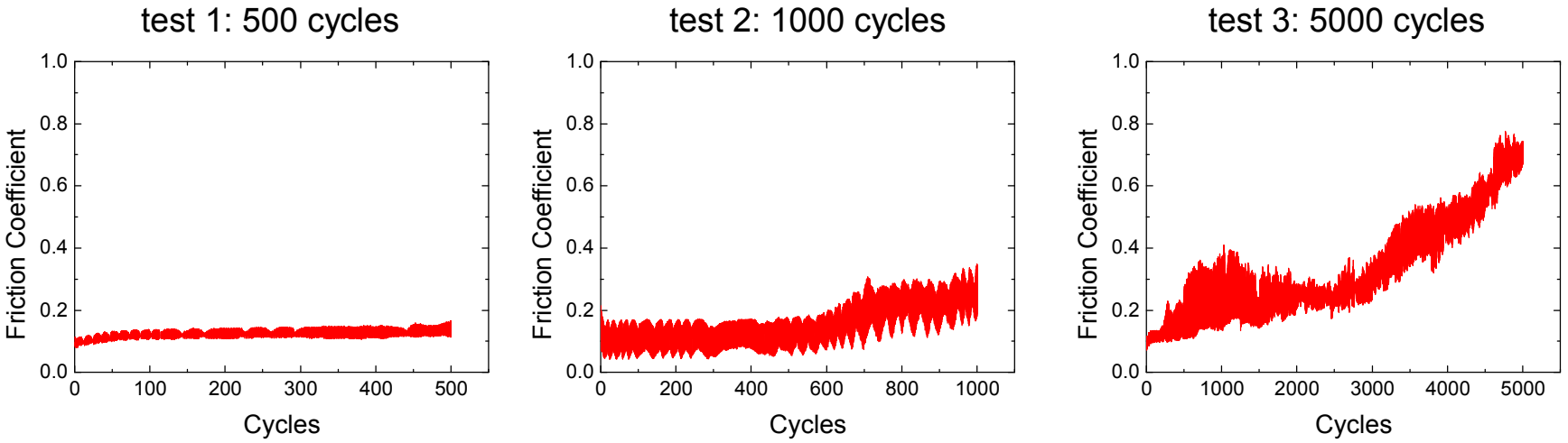
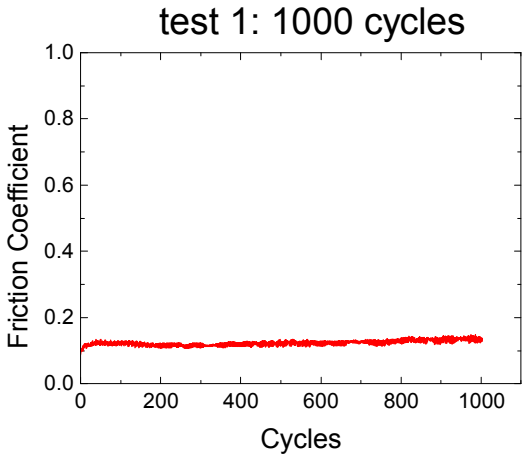


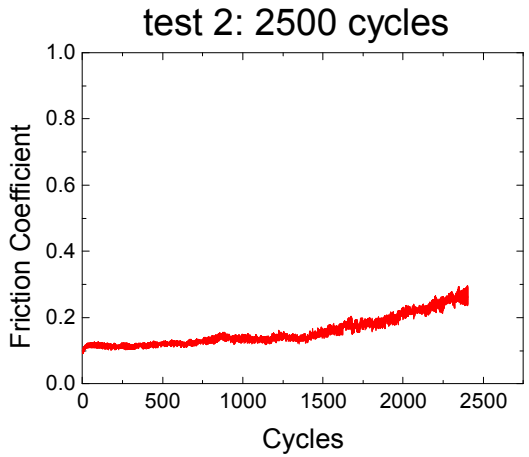
Friction data at 100 mN load



- These experiments were carried out using an 1/8” diameter 440C steel ball at 10g and 10 mm/s.
- The maximum (Hertzian) contact stress is approximately 290 MPa (42 ksi) -- relatively high

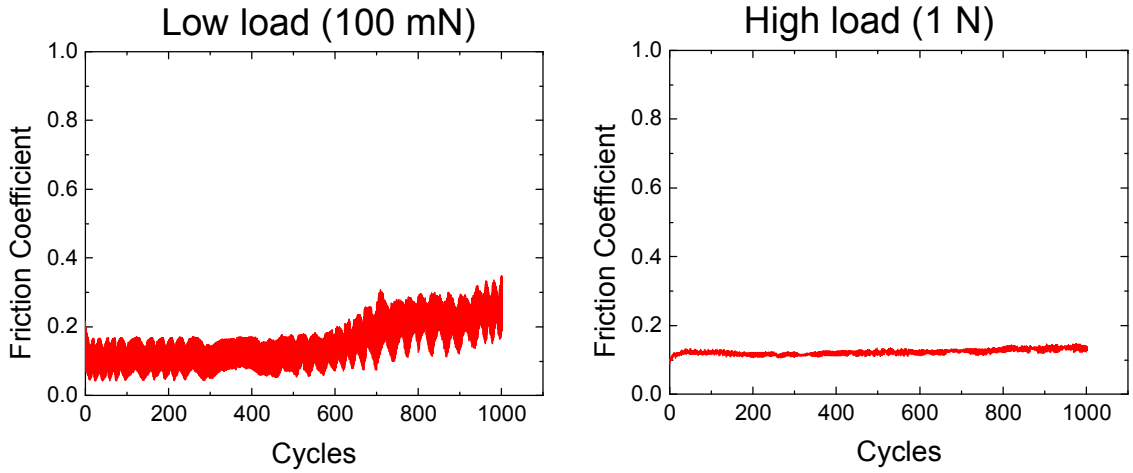
Friction data at 1 N load





- These experiments were carried out using an 1/8” diameter 440C steel ball at 100g and 10 mm/s.
- The maximum (Hertzian) contact stress is approximately 625 MPa (91 ksi)

Comparison



- Key Result: The friction rose faster for the gentler contact condition (paradoxical!)
- Hypothesis: The PTFE wears off at the gentler load, exposing Ni that is wearing too slowly to expose fresh PTFE to lubricate the contact… so friction rises

Even at relatively high loads, wear was very low

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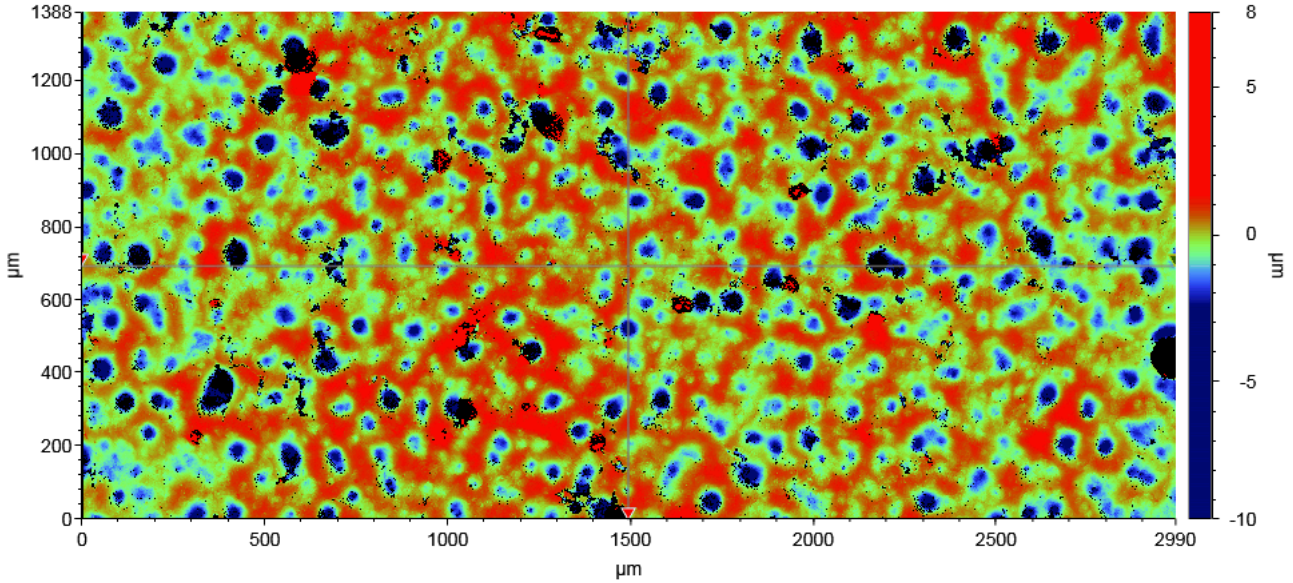
- Interferometer topographical map showing the roughness and surface texture of the Ni-PTFE coated 6061 Al block with 10 µin surface finish



- Actual average roughness was 24 µin (608 nm)
- The porosity is common in electroless plating of Ni coatings
- Wear was low (the 1k cycle wear track is in this image!)

Damage on Falex test specimen does not look commensurate, were the contact stresses similar?

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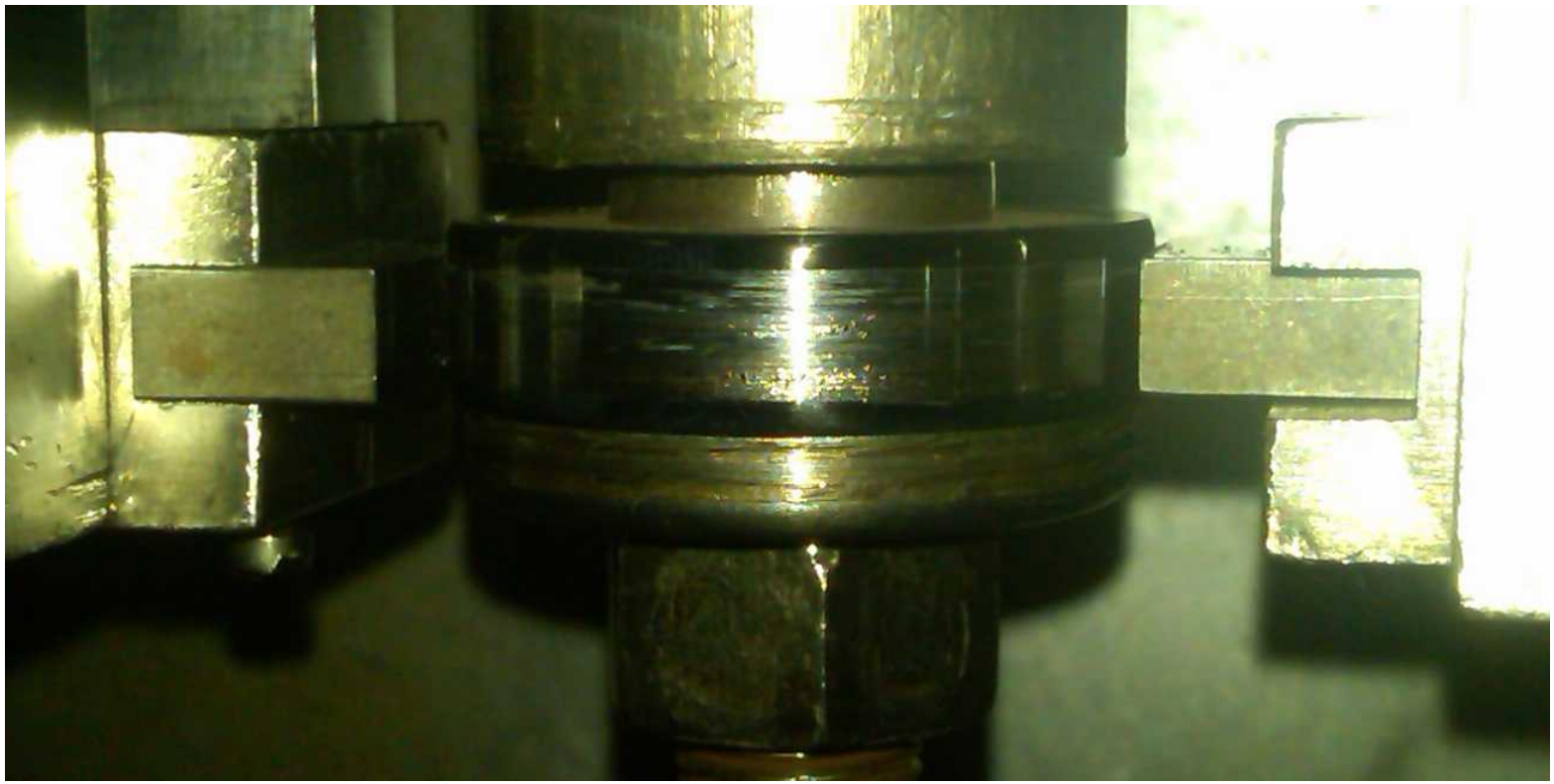
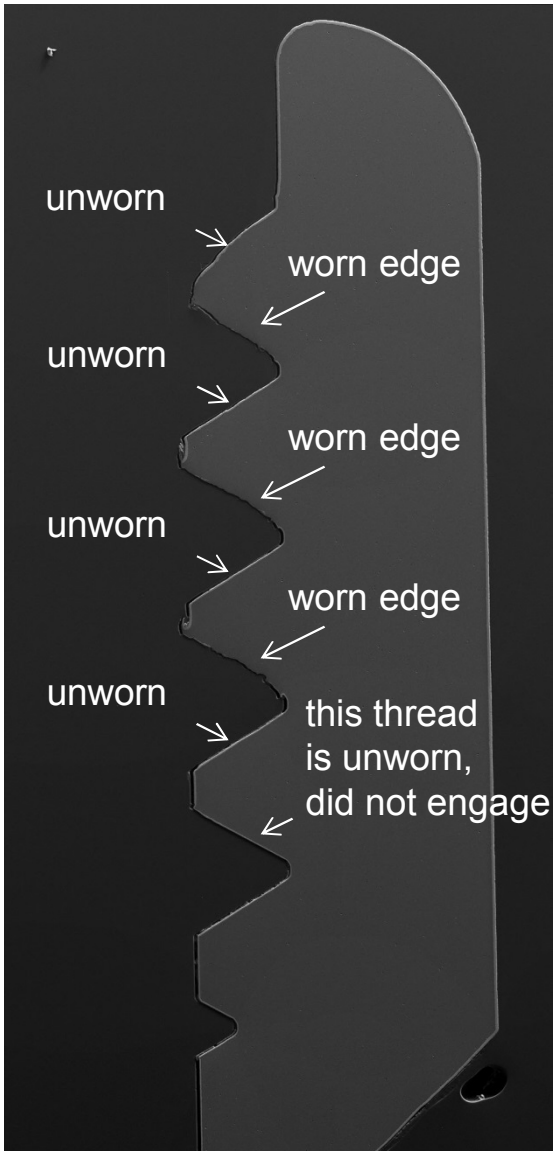


Images of sectioned cap, worn 1k cycles (seized?)

This is a stitched composite of SEM images for a worn (seized?) cap in cross-section. The next slides show closer views. You can see that the Ni-PTFE and Ni films are worn completely off only on the thread surfaces on one side (where they engage, see arrows in the image to the right)



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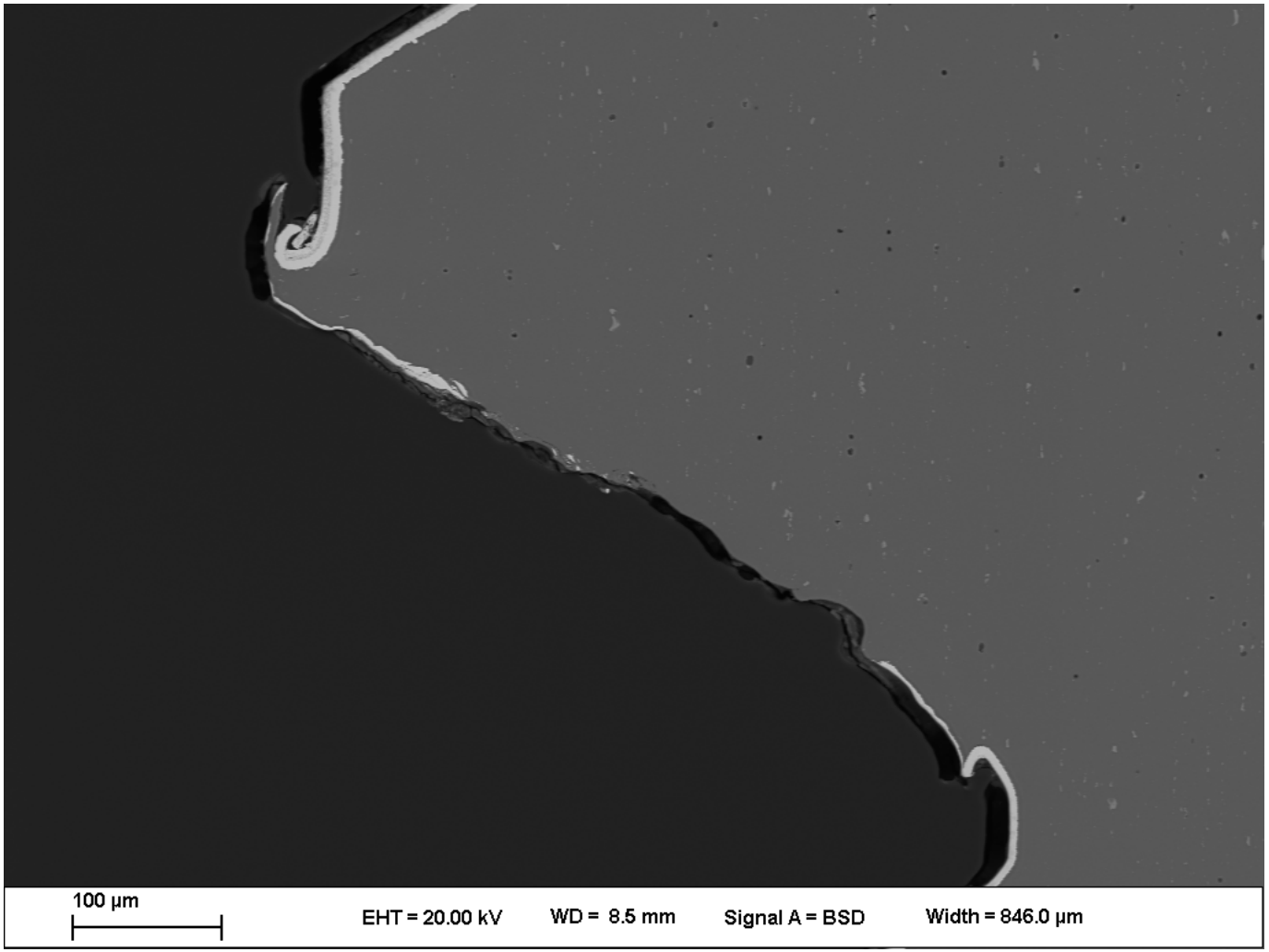
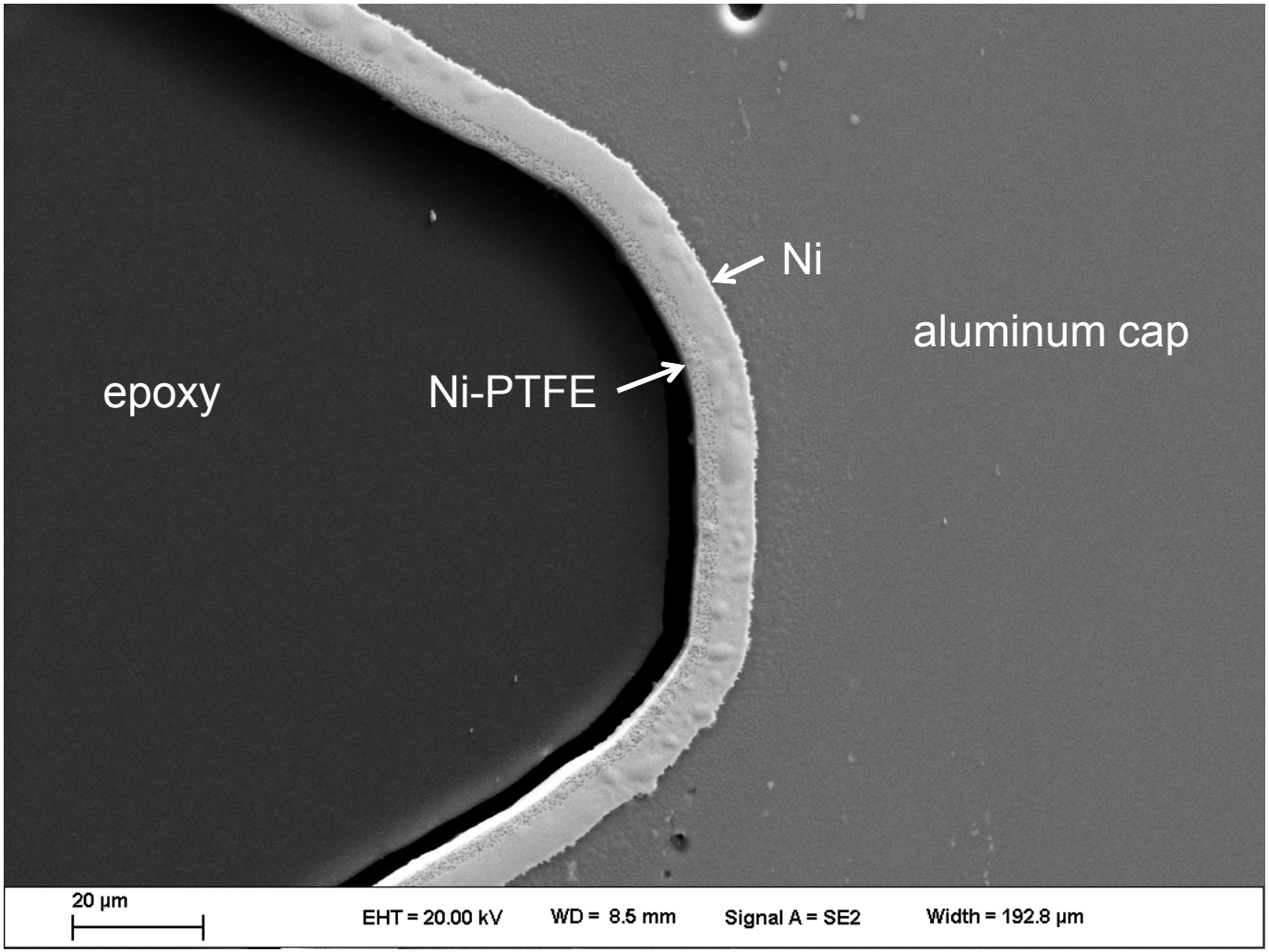
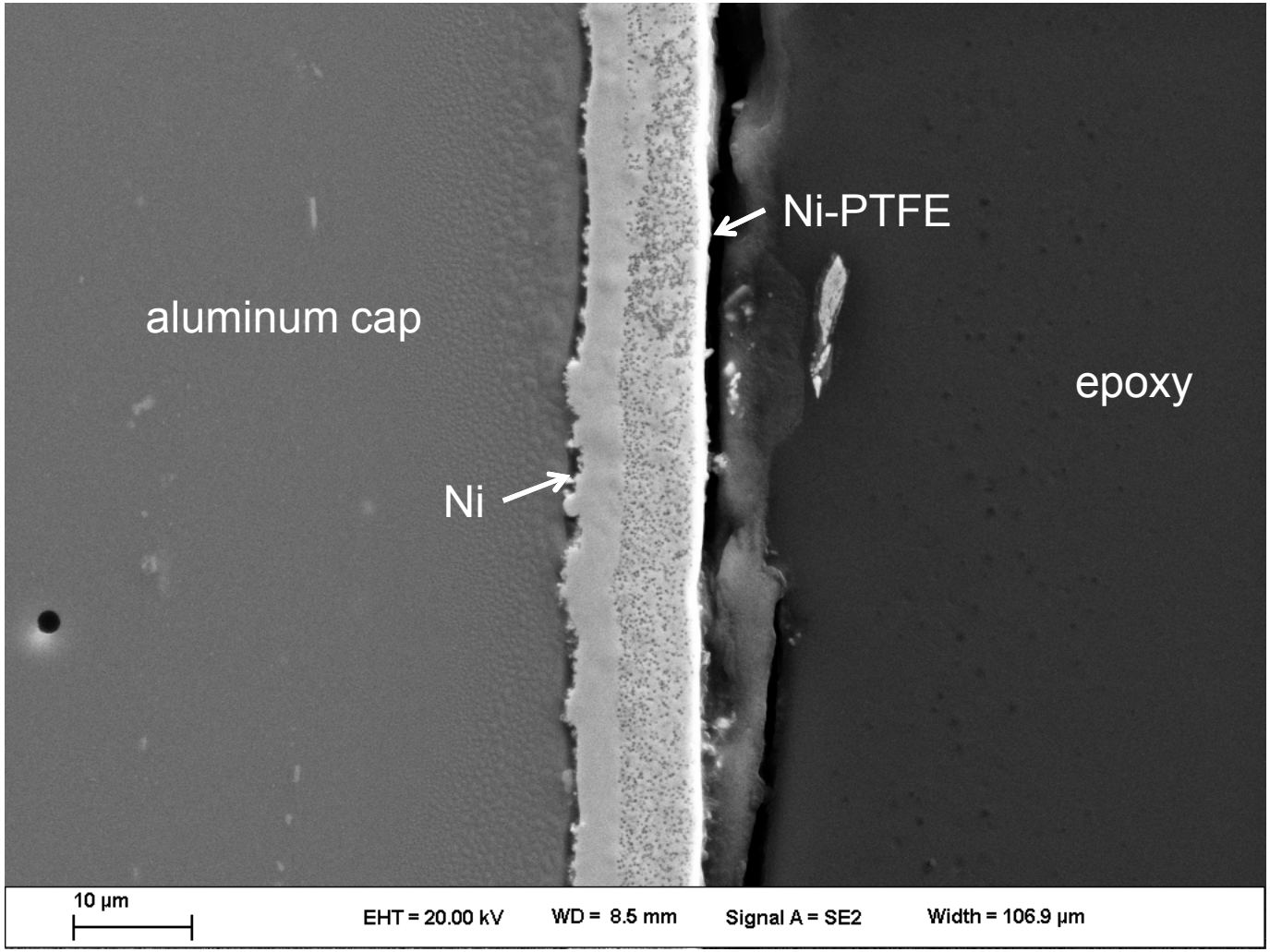
Highly damaged thread surface, coating almost completely worn through



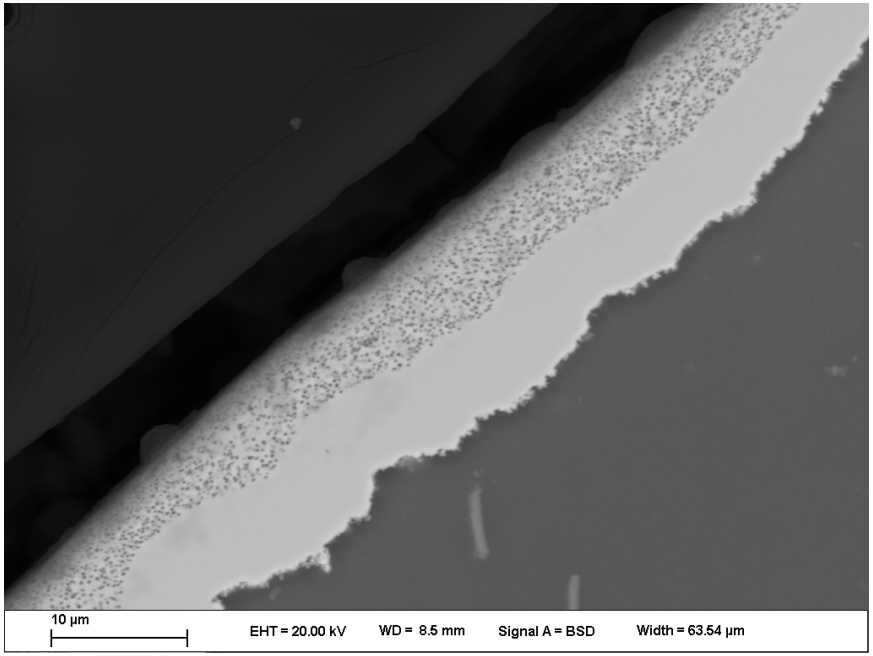
SEM of coating at the base of a thread that did not engage, so exemplifying what the coating looked like as-deposited



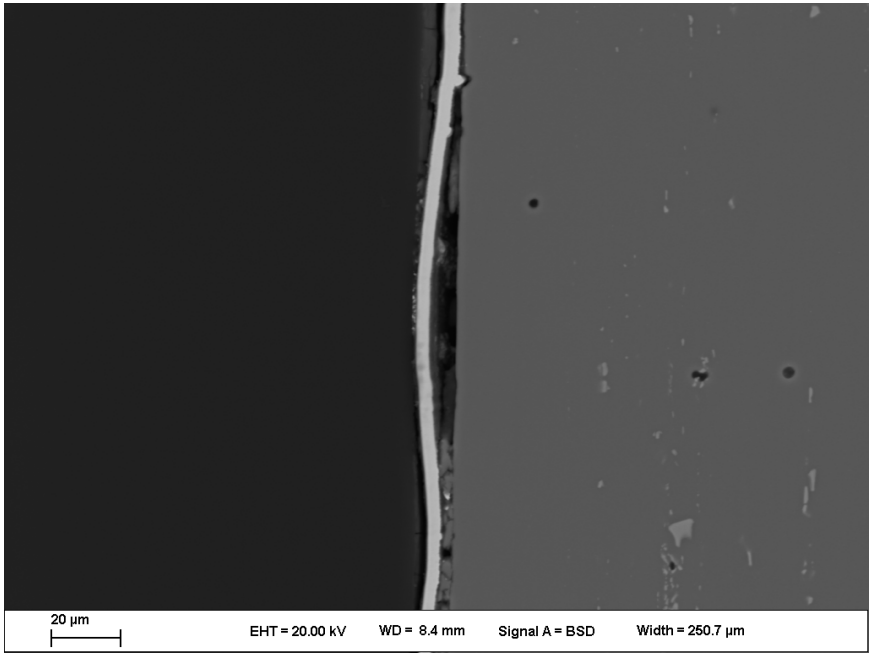
Now looking in an area near the base of the cap that also did not engage, there is evidence that the thickness of the Ni and Ni-PTFE layers is inconsistent throughout the part



SEM of untouched cap locations



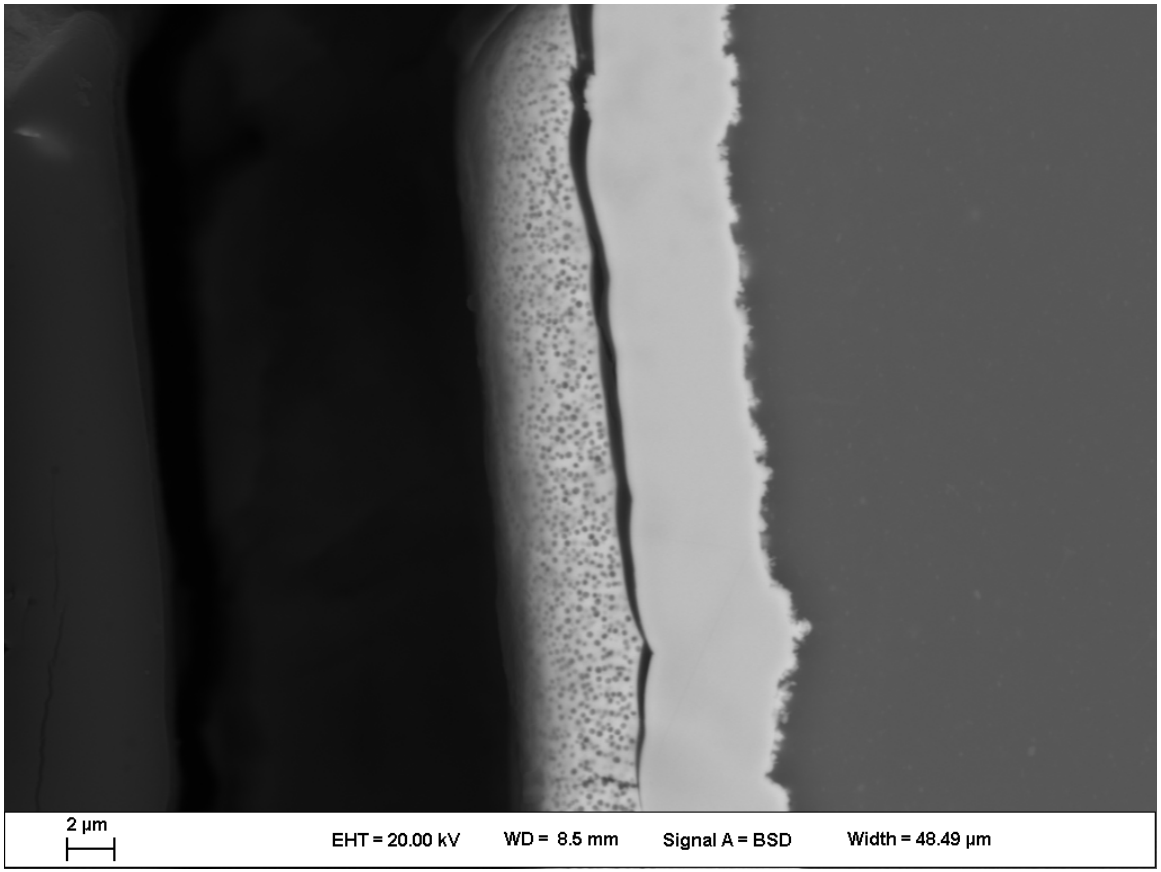
good adhesion to cap



bad adhesion to cap
(and Ni-PTFE layer
apparently missing!)

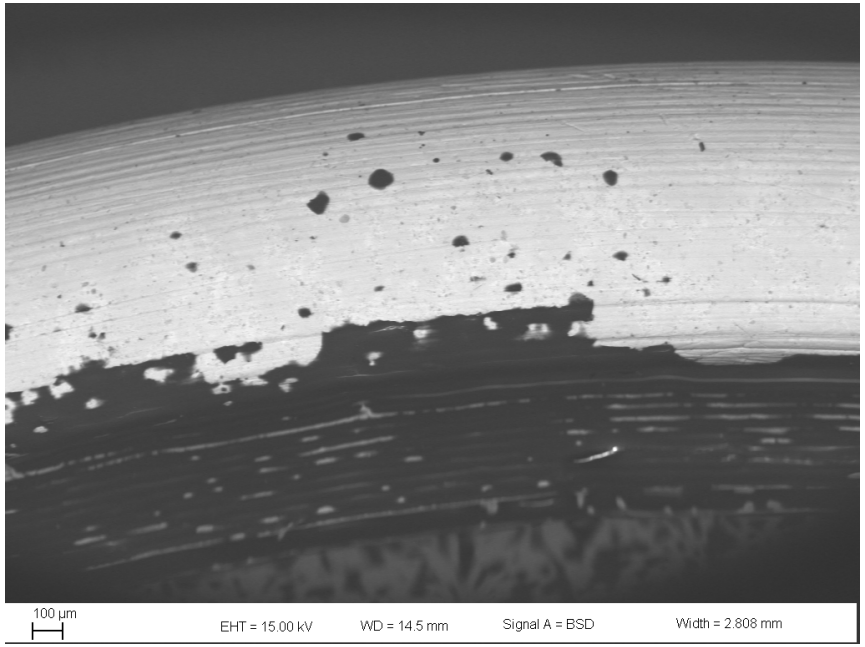
Missing Ni-PTFE in some areas…?

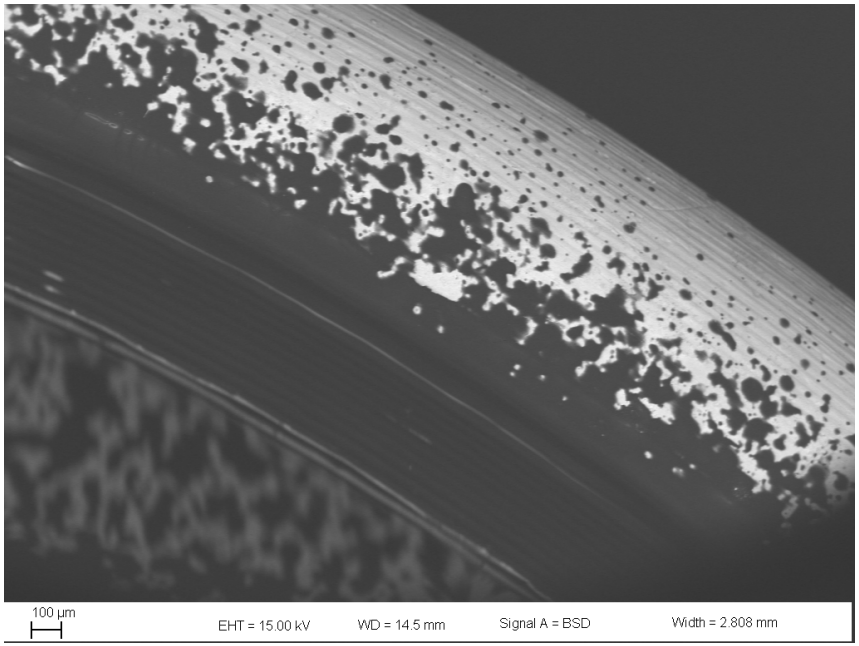
In some areas we saw that the Ni-PTFE layer was debonding from the Ni layer… which likely explains the missing Ni-PTFE in the previous image



Problems with contamination

Images of as-received (bagged) caps from KCP show significant amount of carbon contamination (machining oil residue?) all over the cap surface. Origin?



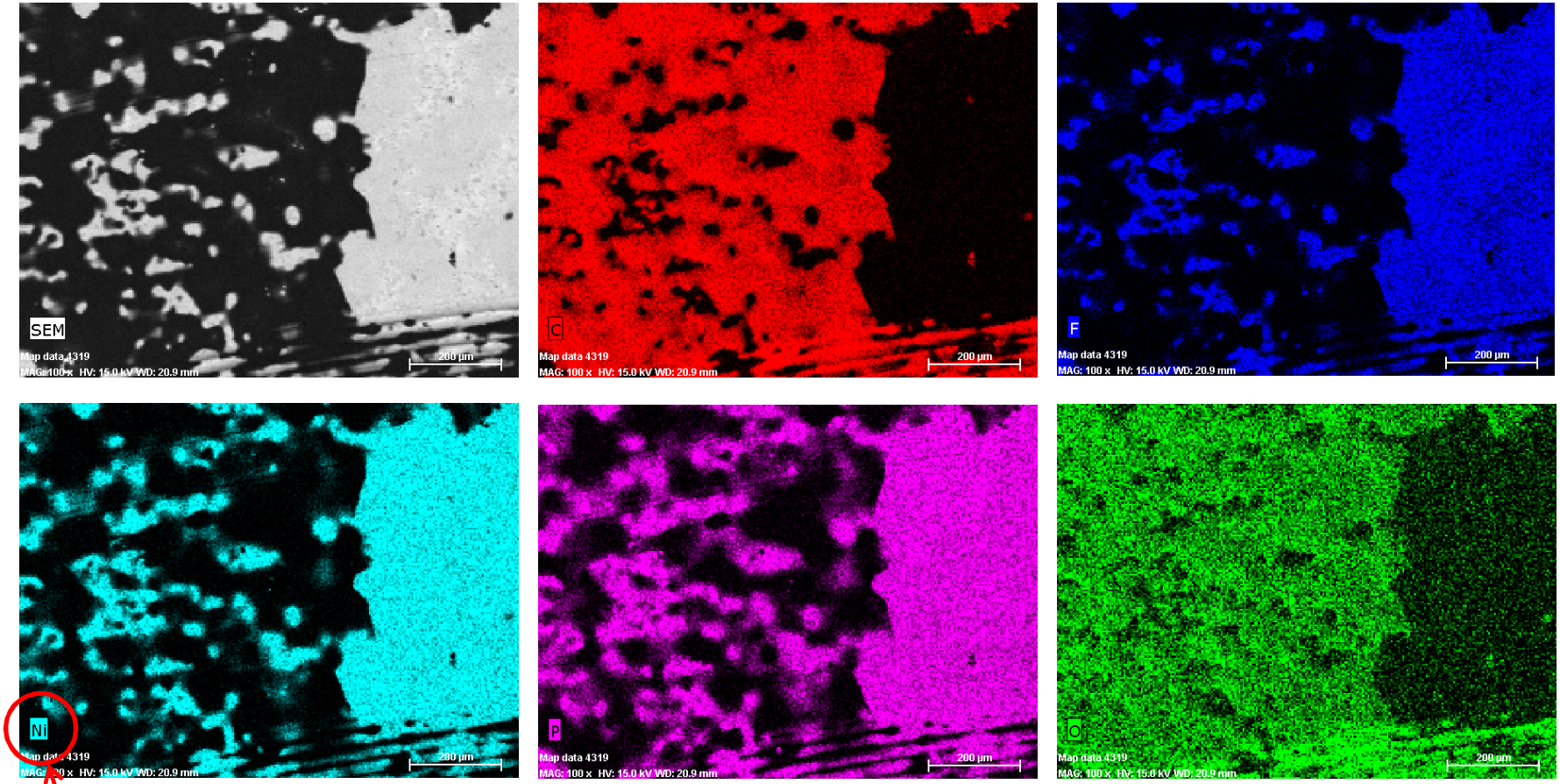


Summary of the as-received cap:

- There was so much contamination on the outside of the cap that it was not easy to image (lots of charging); it almost looked like an uninterrupted contaminant layer. Also, it was possible to see the contamination as “grittiness” using a simple optical microscope.
- A significant amount of contamination (grease/oil/plating bath crud?) was introduced somewhere between manufacturing and plating; it is likely this very contaminant that is smeared during use, leaving the patchy contamination we saw in the used cap

Problems with contamination

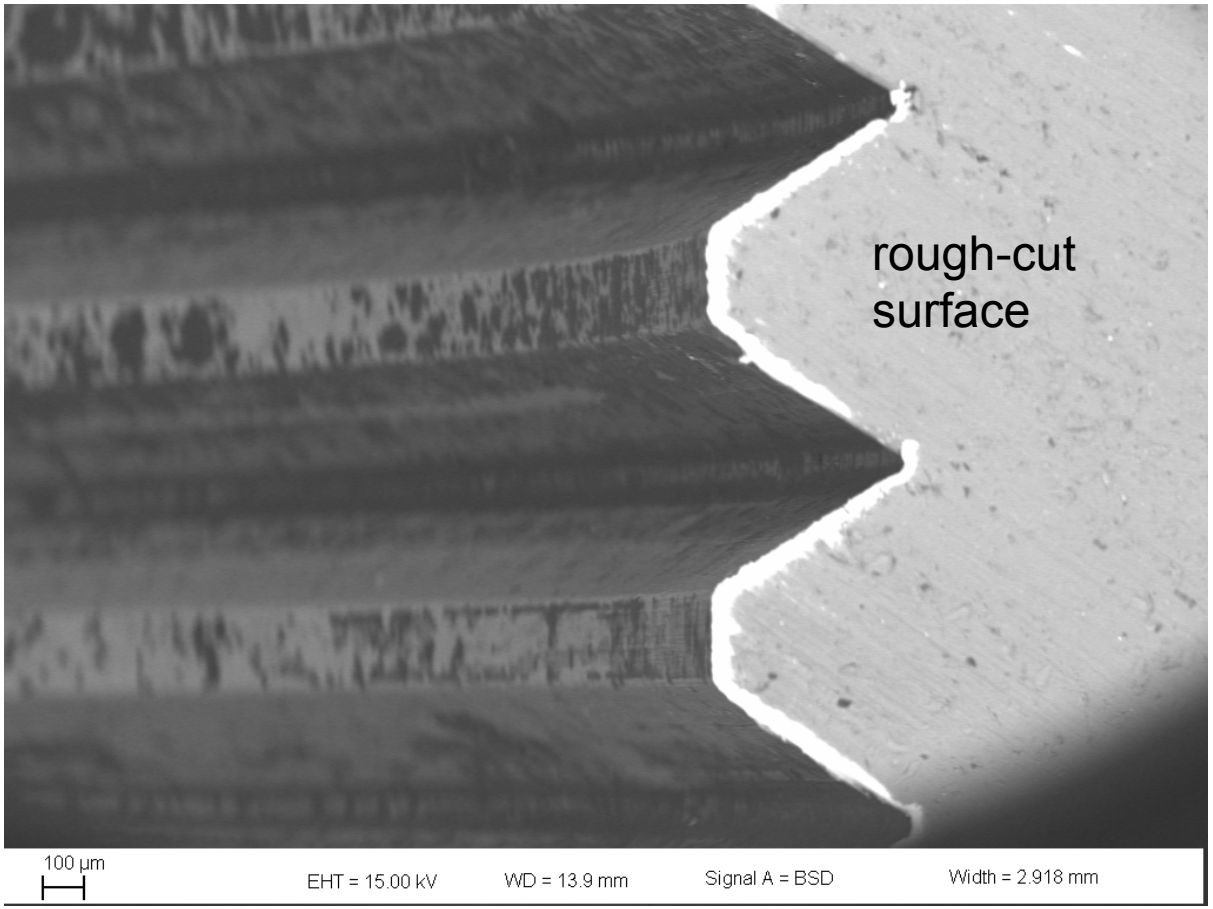
SEM and compositional EDS (Energy Dispersive Spectroscopy) maps… lots of C-O



the text at the bottom left of each image corresponds to the element(s) analyzed in each image, color intensity being a qualitative measure of the concentration of that particular element

Example of a sectioned cap and contamination

This image shows how the caps were sectioned (as-received cap shown here), this one without potting and polishing. Also clearly visible is the C-O contamination.

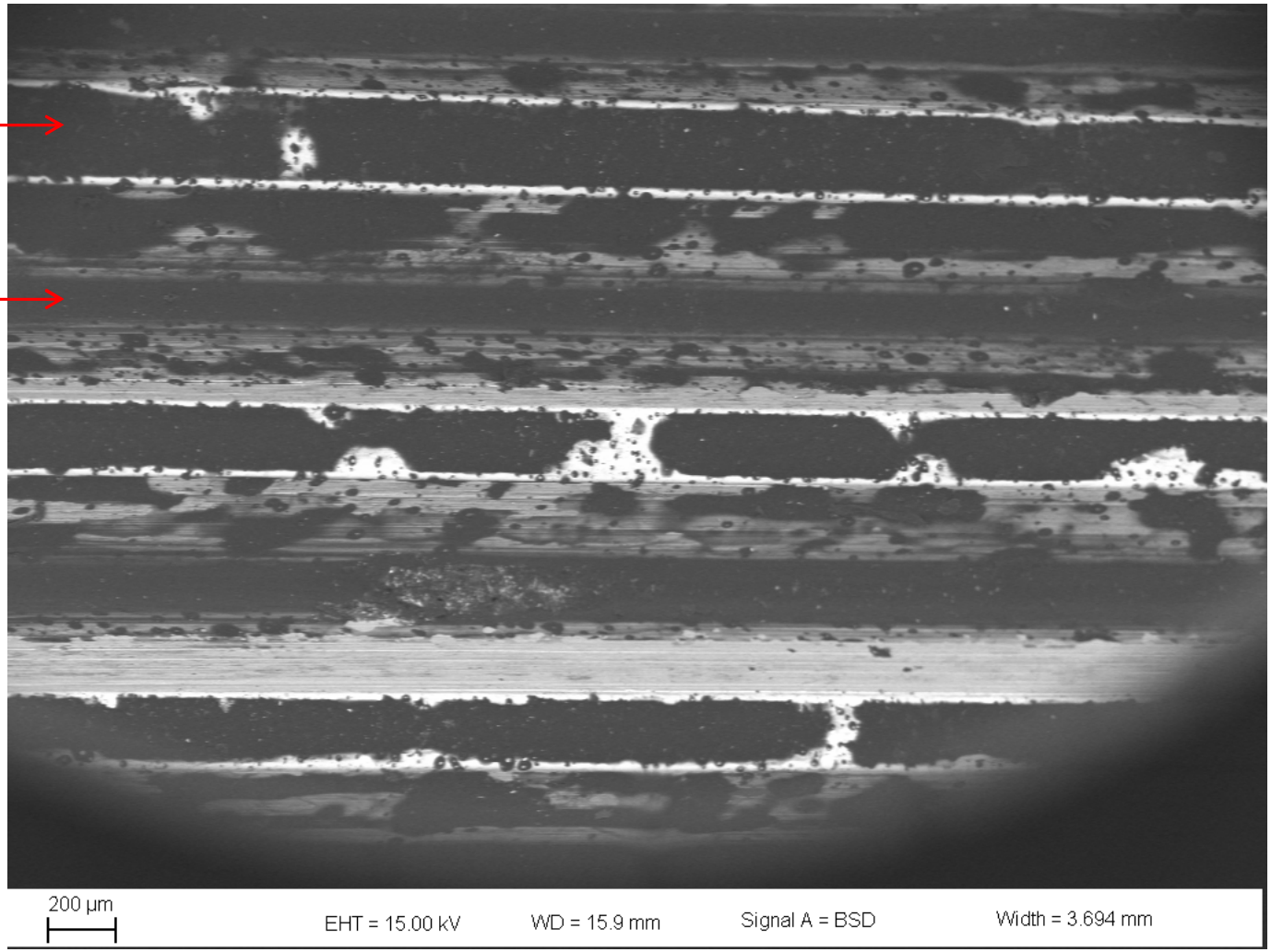


Example of a sectioned cap and contamination

The black stuff all over the inner surface of the cap is the carbonaceous species.

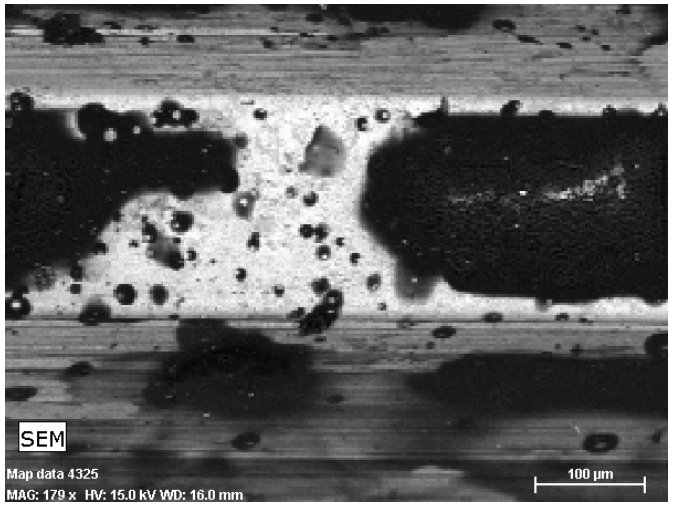
top of thread

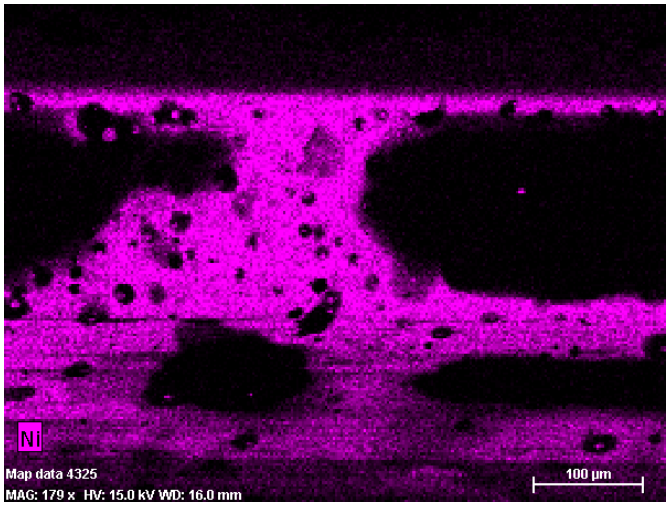
base of thread (trough)

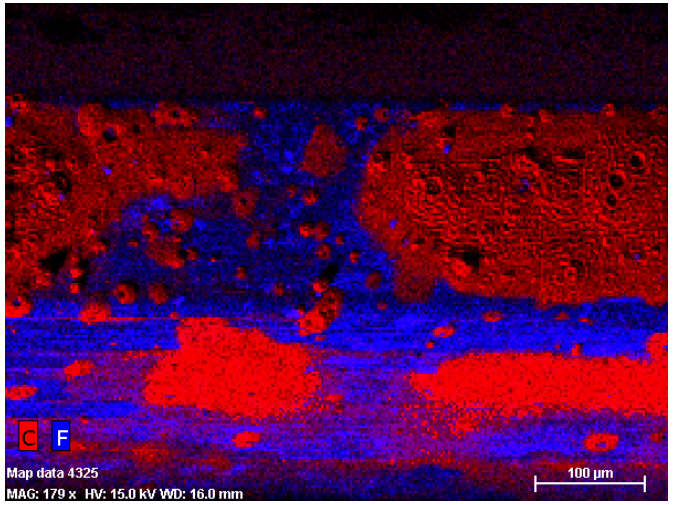


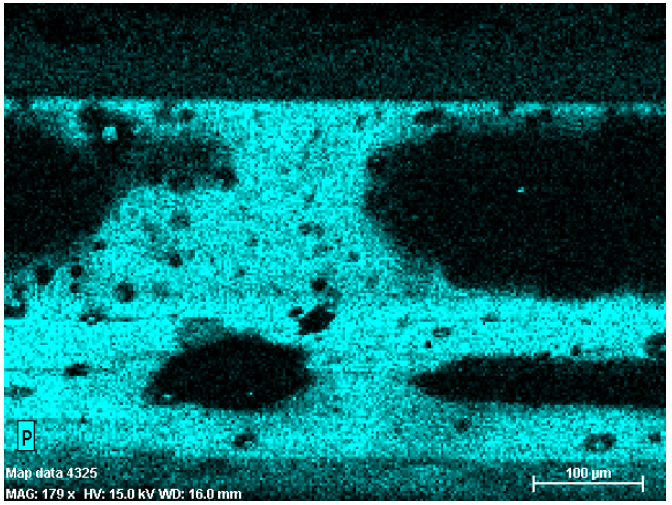
Example of a sectioned cap and contamination

More SEM and EDS maps of the surface of an as-received cap, showing that the fluorine and phosphorus (corresponding to the Ni phosphate and PTFE) are occluded by the carbonaceous contaminant









Next Steps

- Outstanding questions:
  - The damage observed in the photos of the completed Falex (Hohman) tests do not agree, seems more significant, than the damage observed on ball-on-flat tests at Sandia
  - The damage characterized via SEM and EDS on the 1000 cycle sectioned cap showed gross wear (galling); is this due to the “last” cycle damage related to using large torque to remove the cap?
    - We should look at a cap that has seen 100 cycles, and is not seized, but has been worn. We could also section a threaded cap after 100 cycles, and characterize the contact.
  - Origin of the contamination remains TBD.