

Navy Characterization of Covetic Aluminum

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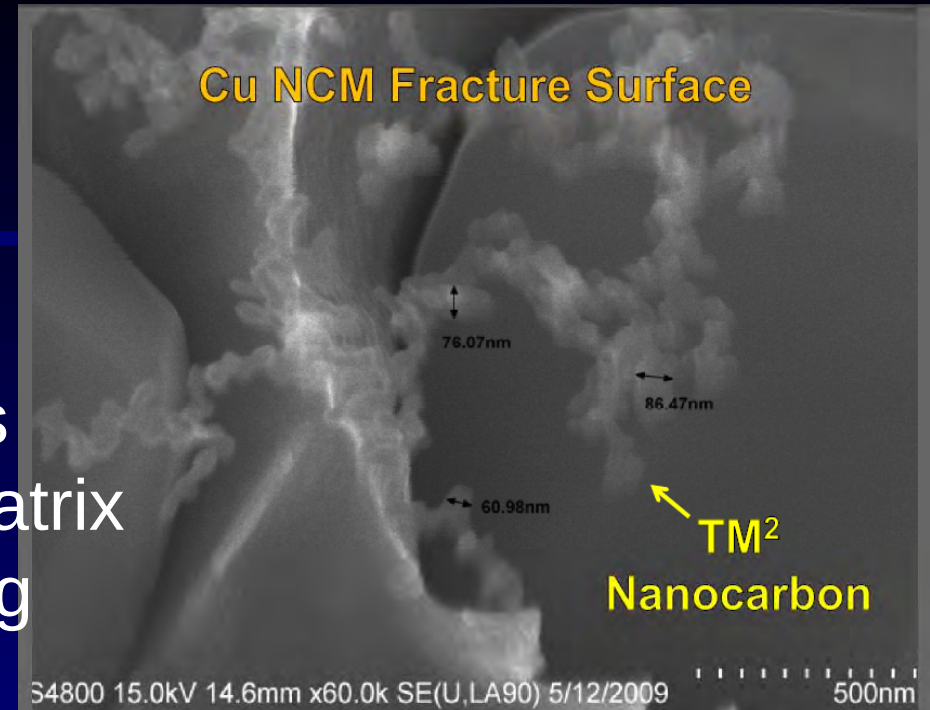
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Summary

- There is a new class of materials: Covetic
 - Third Millennium Metals, LLC; 12-yr development
 - Nanoscale carbon phase, 3-10 wt. %
 - Chemically bound to metal in a way we still need to understand; probably a new nano-effect
 - Increased thermal conductivity, Al and Cu
- NSWCCD has verified some of the claims
 - Increased strength for same work hardening
 - Increased electrical conductivity in Al
- Possible lightweight aluminum armor—more testing needed

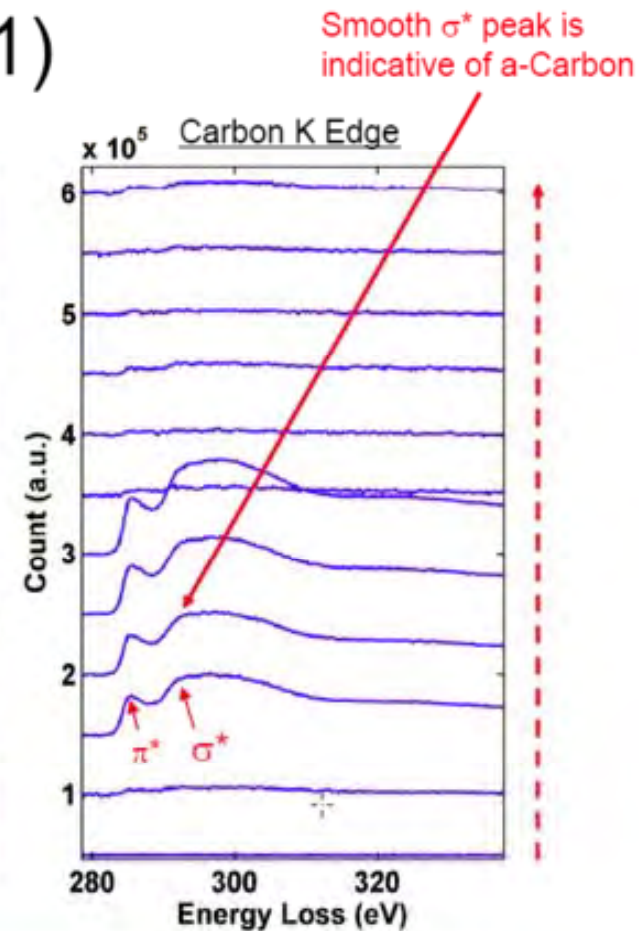
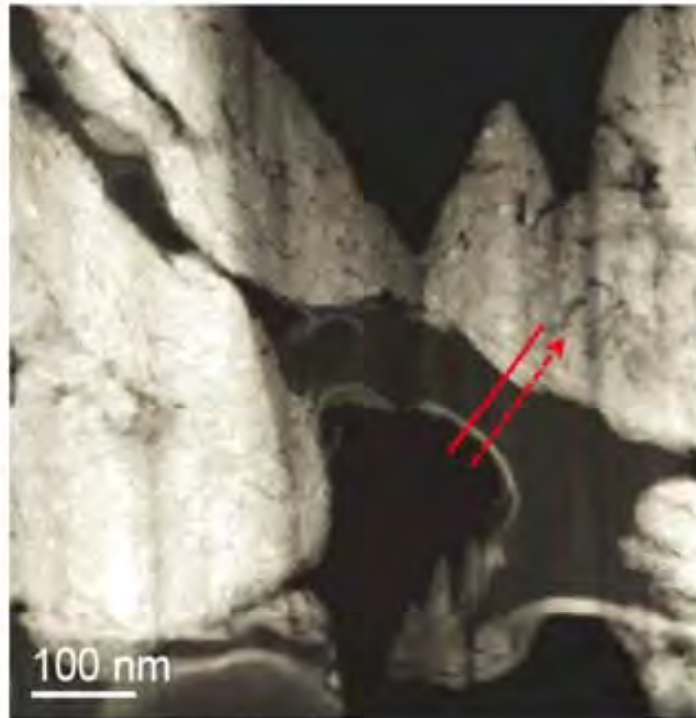
SEM

- In copper, we see
 - Approx. 50 nm particle chains
 - Chemically bound to metal matrix
 - Remains intact upon remelting
- In aluminum, we also see nanoscale carbon
 - But due to beam alignment issues we do not have good images yet



Electronic State of Carbon--Muller, Cornell

Big Void with Carbon Coated (ROI #1)



Voids between grains are coated with sp^2 amorphous carbon.

6061 Chemical Analysis (wt. %)

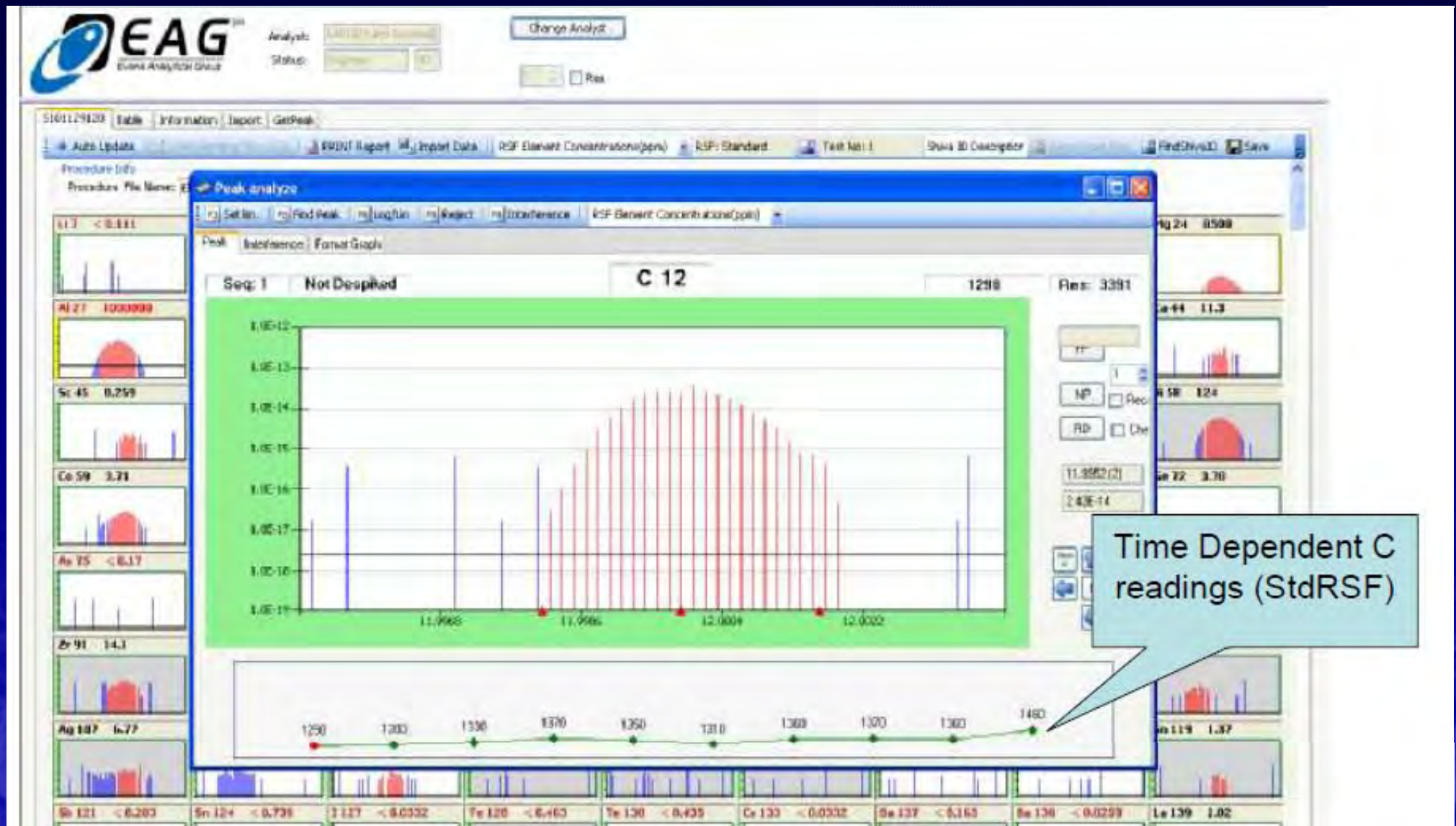
Carbon via LECO combustion method gives only 0.300% carbon inclusions.

The remaining 2.7% is NOT DETECTED.

	6061-0	H-49 Covetic	ASTM B211
C	0.003	0.300	0.05 max
Si	0.72	0.71	0.4 – 0.8
Fe	0.25	0.24	0.7 max
Cu	0.18	0.18	0.15 – 0.40
Mn	0.061	0.064	0.15 max
Mg	0.99	1.03	0.8 – 1.2
Cr	0.054	0.057	0.04 – 0.35
Zn	0.080	0.084	0.25 max
Ti	0.088	0.099	0.15 max
V	0.0072	0.0074	0.05 max

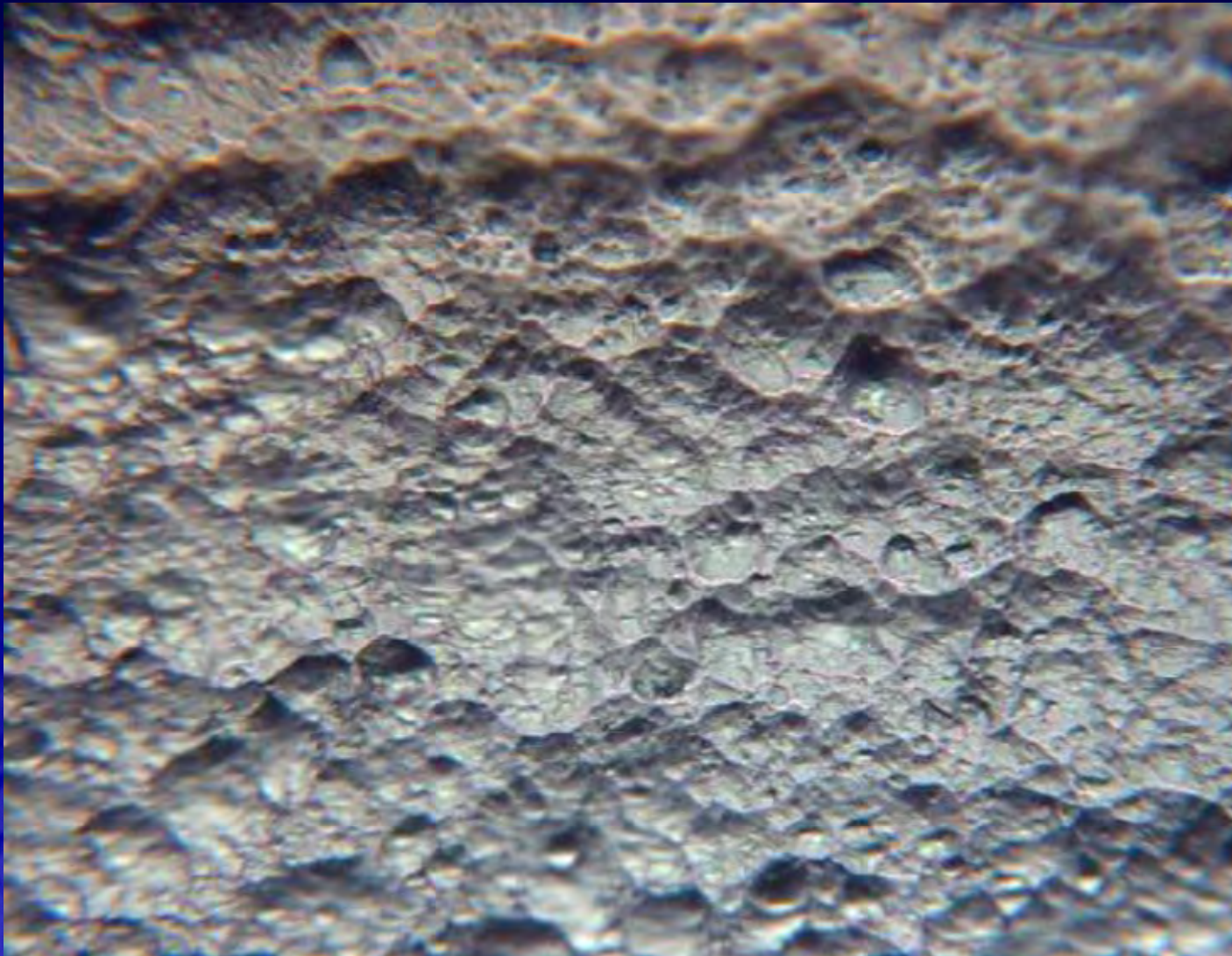
GDMS

Carbon via GDMS gives 0.22 wt%.
However, measured level goes up
over time during sputtering.



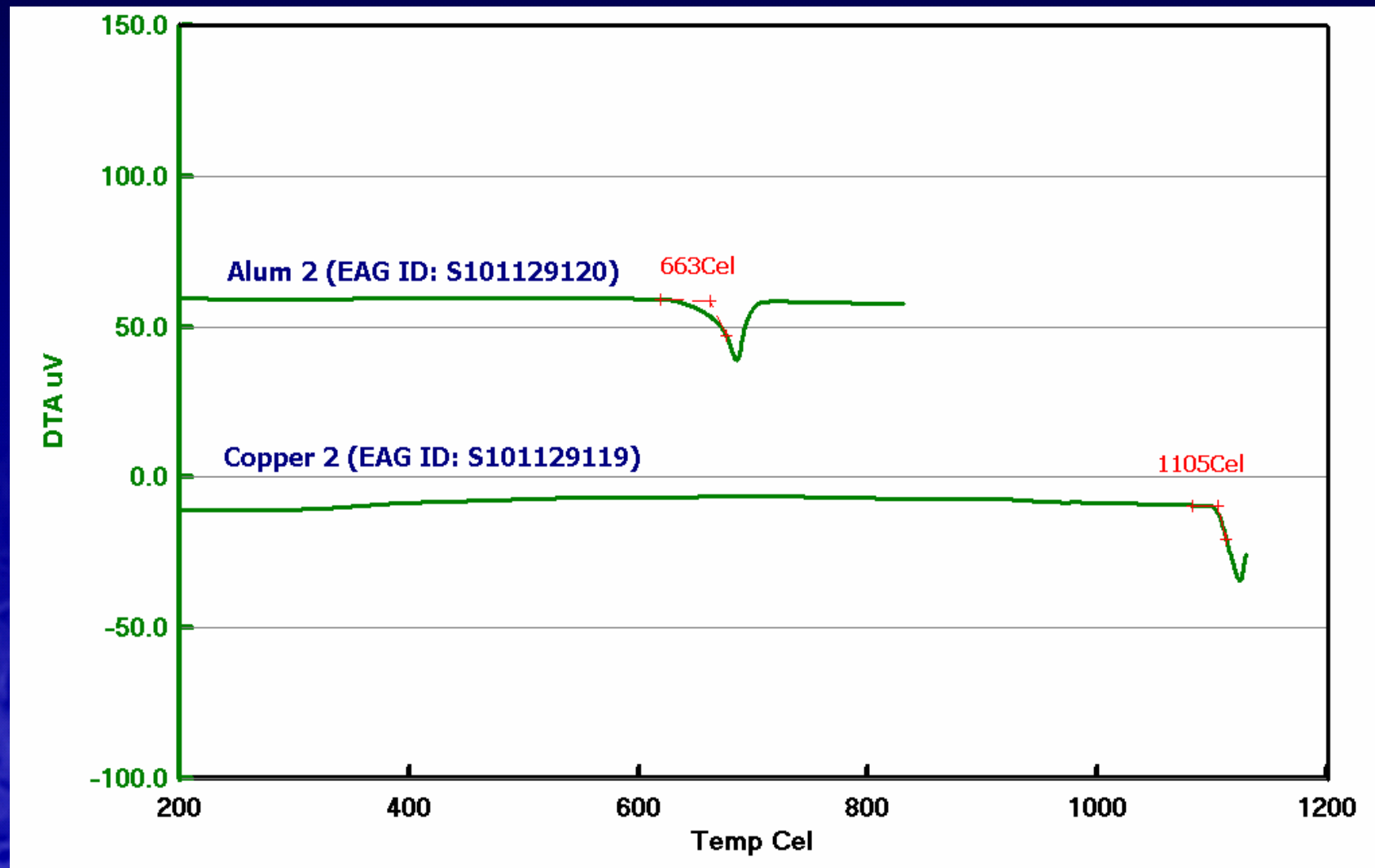
GDMS

“These are indeed very interesting samples. It is evident that both of these samples are sputtering fairly uniform[ly] under normal glow-discharge conditions. However, the texture of the bottom of the plasma craters is very different as compared to ordinary Al and/or Cu samples.” --Karol Putyera, Evans Analytical

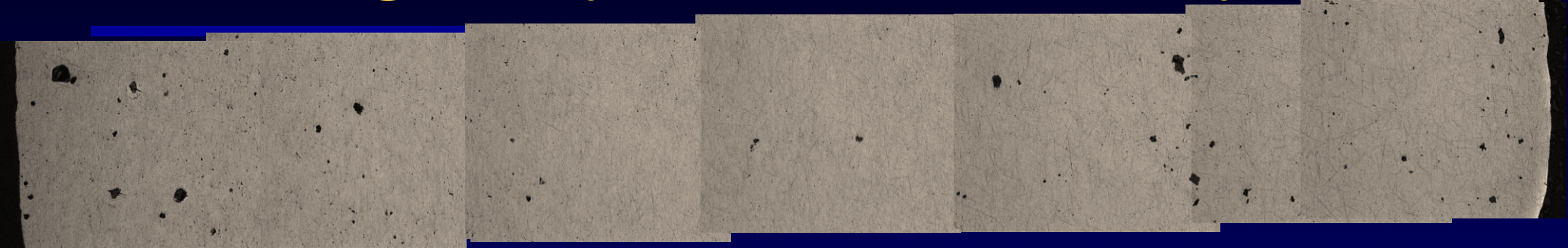


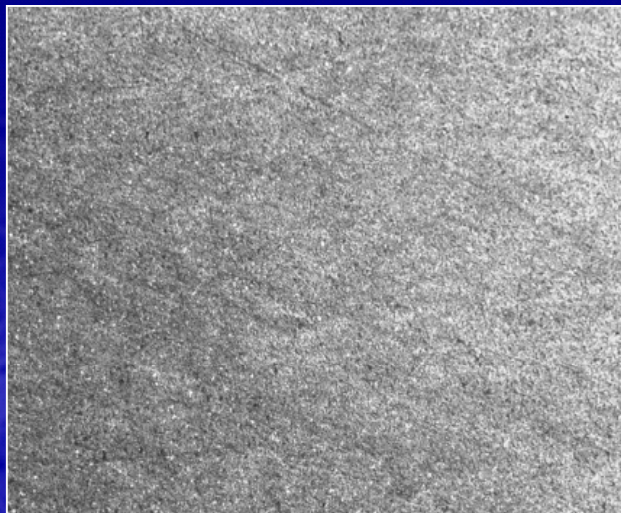
Differential Thermal Analysis

Melting temperature is increased: 663°C vs. 652°C (the liquidus temperature of AA6061).



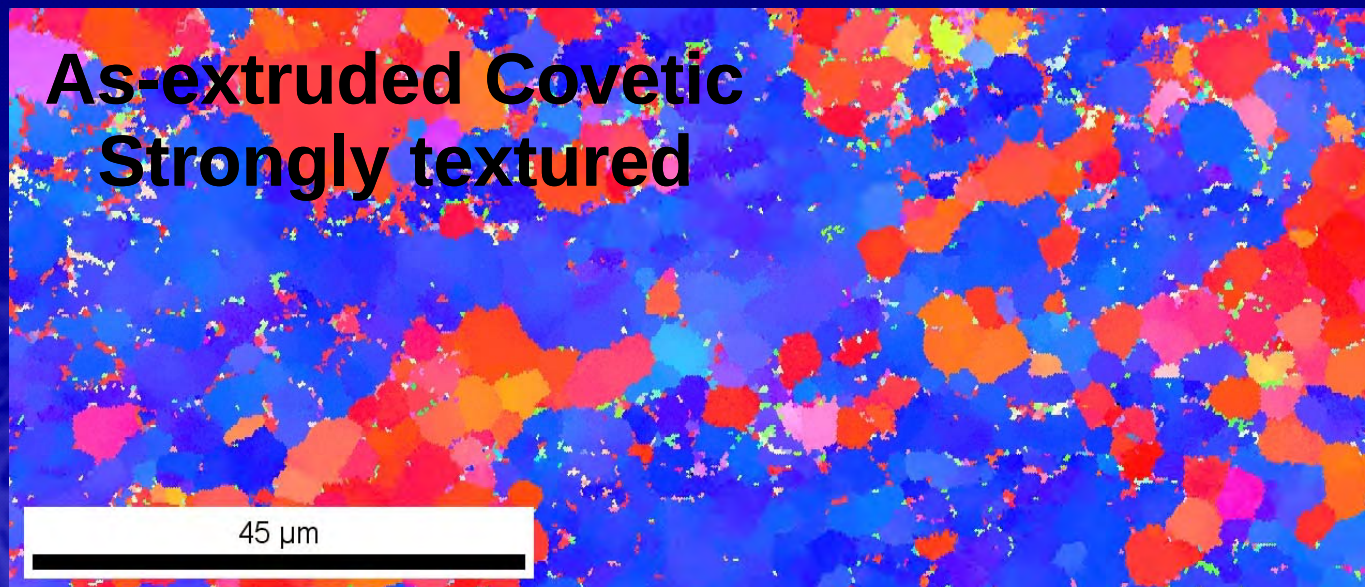
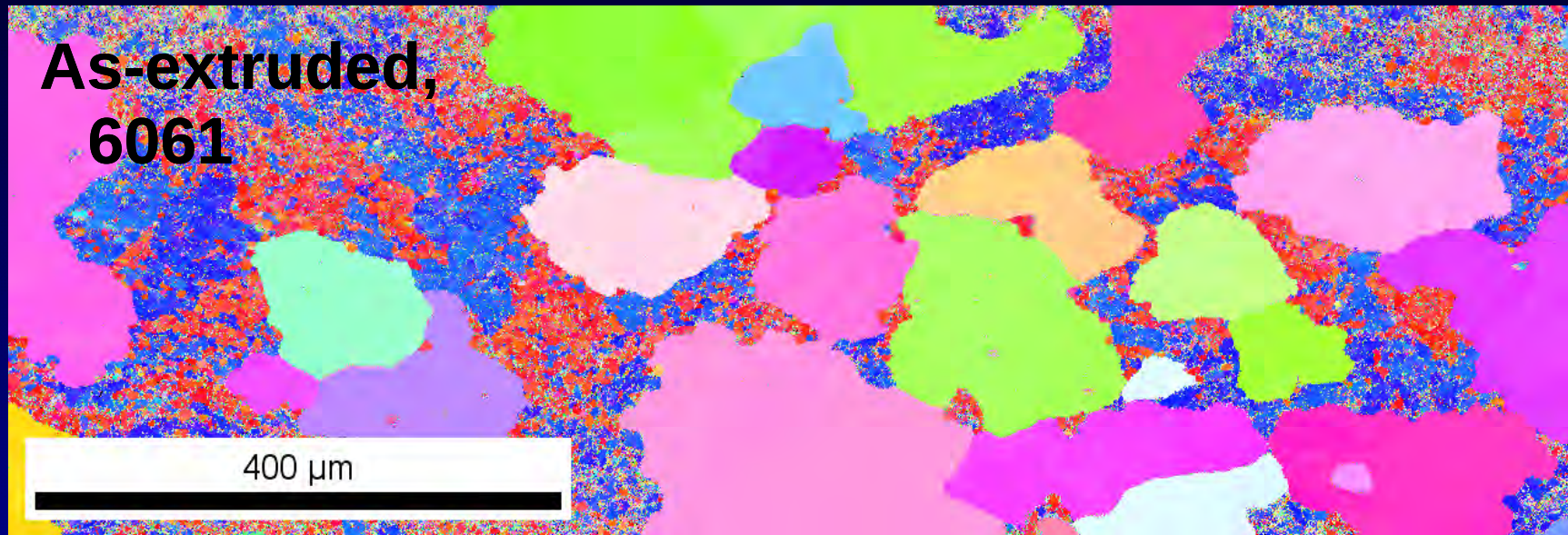
Metallography (Naval Academy)

- 
- A horizontal composite image showing four segments of a metal specimen cross-section. The segments are light gray with a fine, granular texture. There are several dark, irregular spots and inclusions scattered throughout, particularly concentrated towards the outer edges of the segments.
- Composite cross section of H49 covetic aluminum specimen from left to right side
 - Specimen mounted and polished using 3 μm diamond grit
 - 50X magnification.
 - Carbon inclusions present in greater fractions around perimeter of stock material, with larger “spots” towards outer edges.



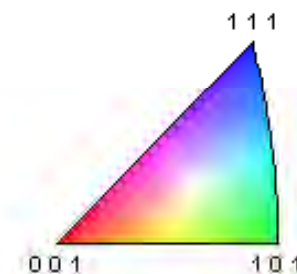
- Typical cross section of comparison 6061
- 50X magnification
- Almost no inclusions noted

Electron Backscatter Diffraction (Wolk): Covetic has much finer grain size



Color Coded Map Type: Inverse Pole Figure [001]

Aluminum



Boundaries: <none>

Density of 6061

Naval Academy, CDR Lloyd Brown

As-extruded material

- Density = 2.647 g/cm³ Covetic 6061
2.683 g/cm³ Normal 6061
- Assuming $\rho_C = 2.25$ g/cm³ and $\rho_{6061} = 2.683$ g/cm³, carbon content = 7 wt%
- But we want to re-measure with ultrapycometer
 - Should only be 3% C
 - Some error is suspected due to surface condition

Electrical Conductivity

Naval Academy

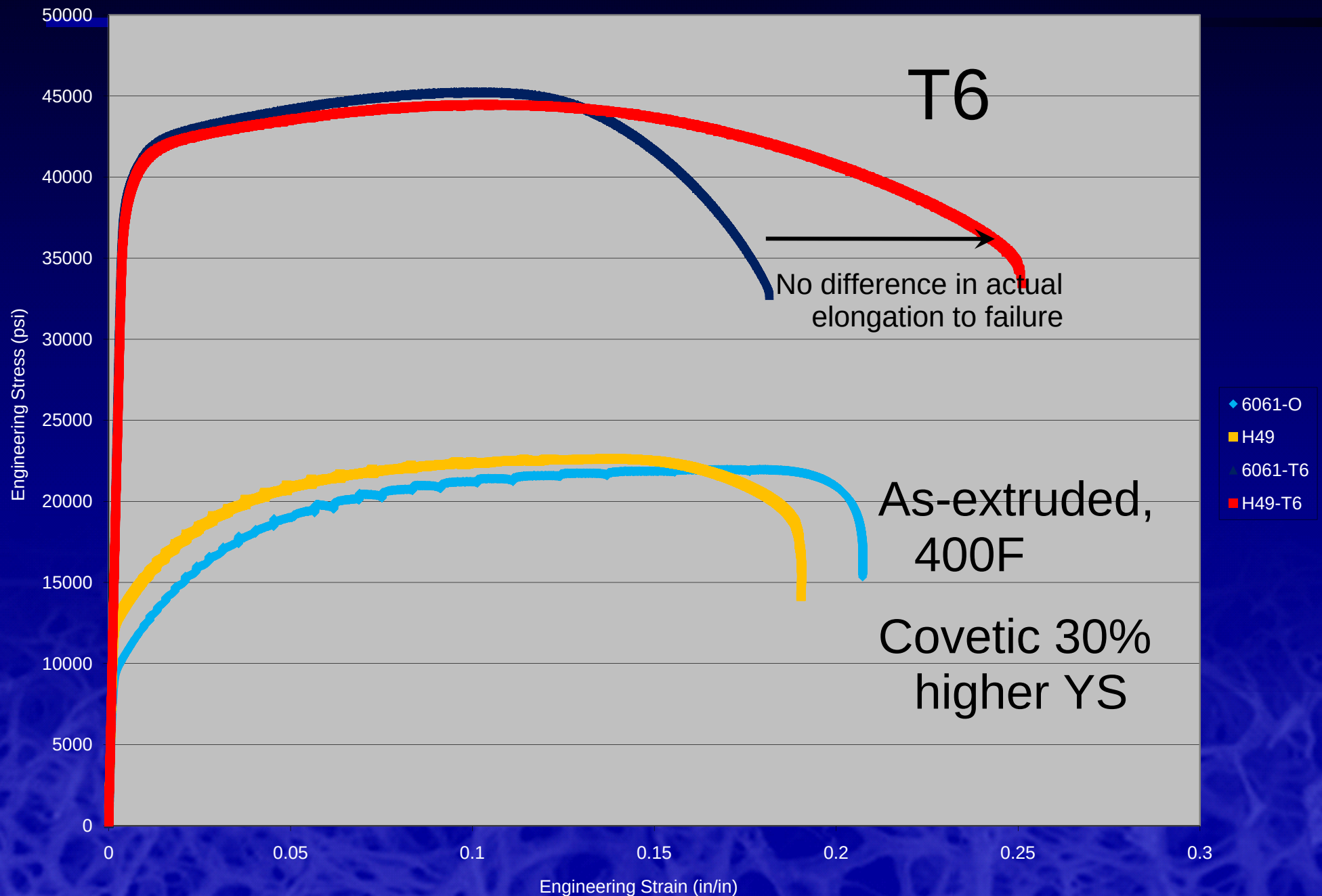
Covetic 47.81% IACS

6061 47.37% IACS



Covetic: 1% Greater electrical conductivity at room temperature

Tensile Curves: No difference in T6 condition



As-Extruded Hardness (CDR Brown)

- Asymmetric distribution for hardness across center for both specimens, not attributable to pores or inclusions.
- Average covetic hardness = HV 47.6
- Average 6061 hardness = HV 38.7

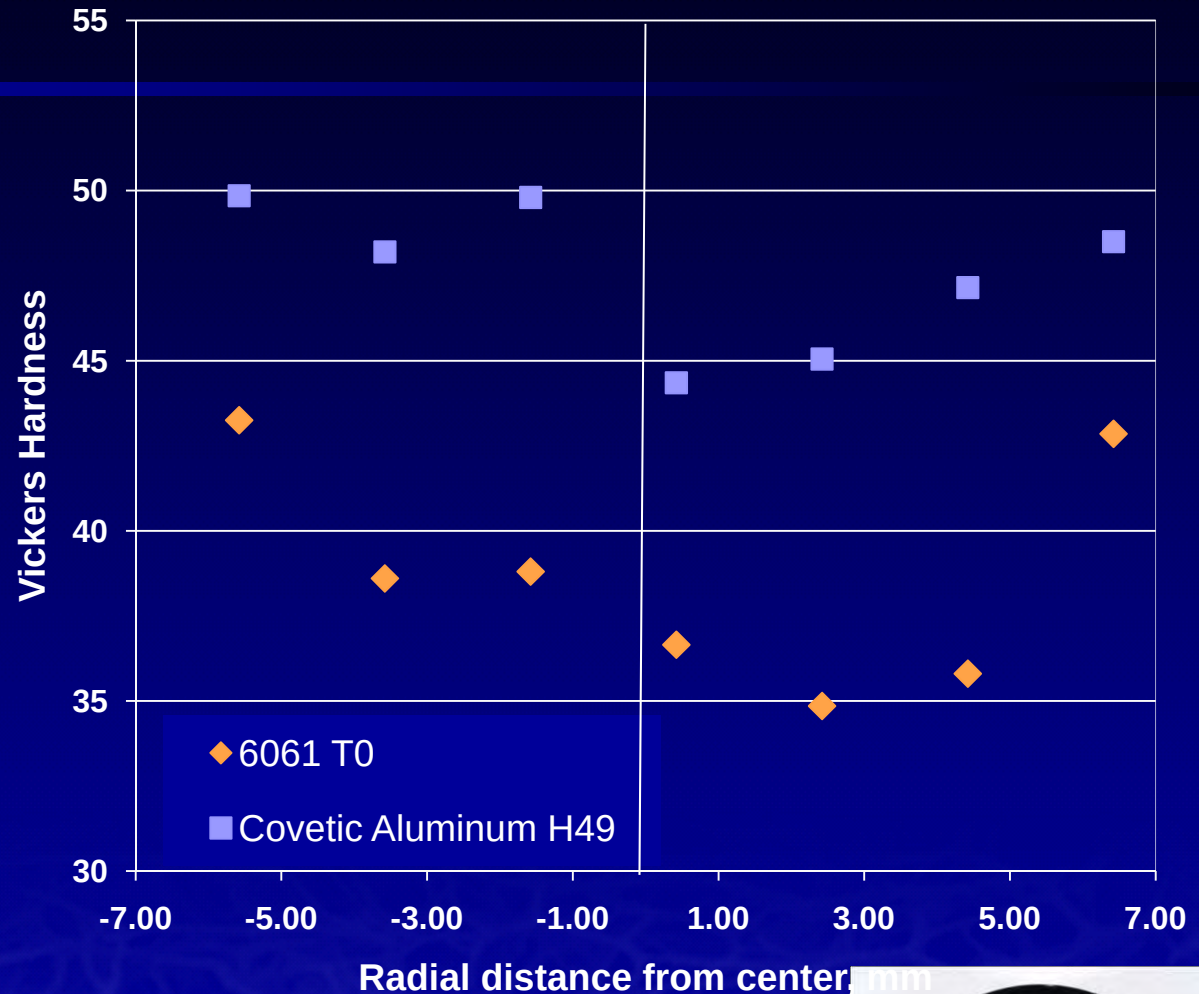
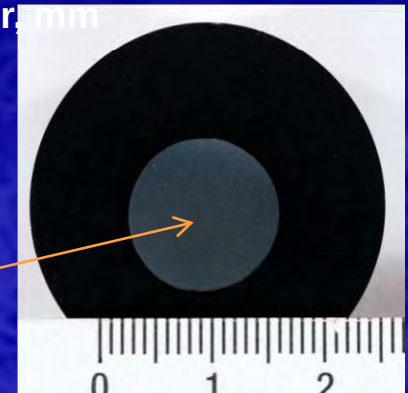
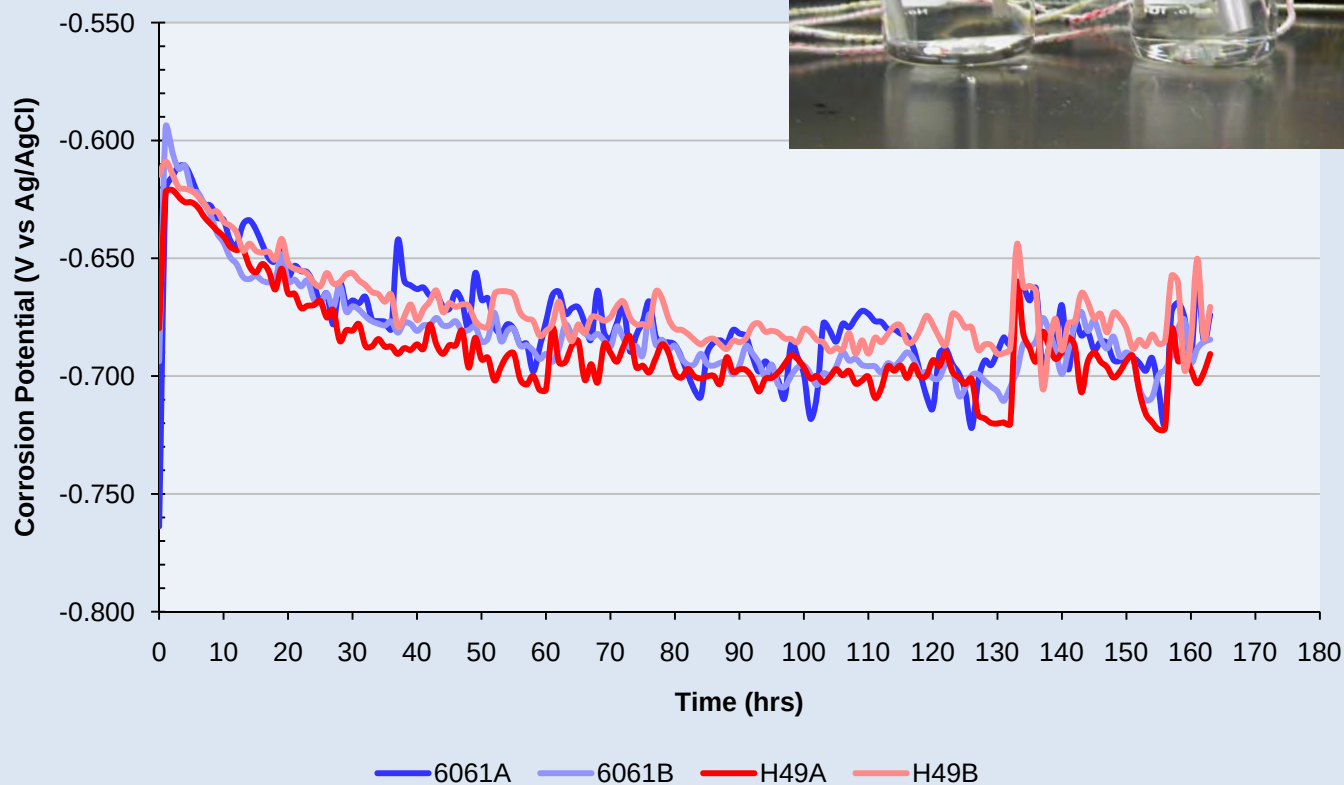
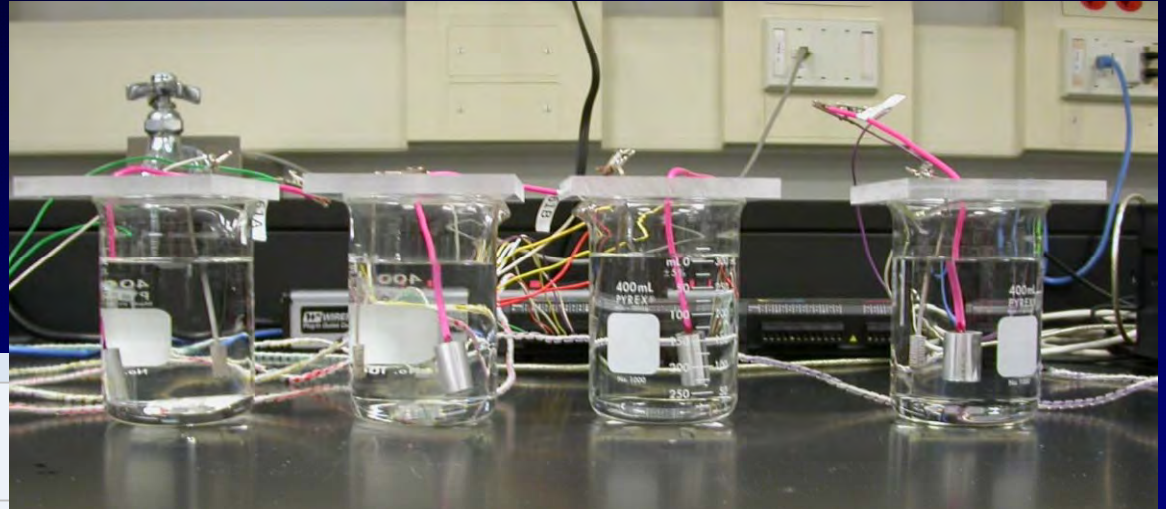


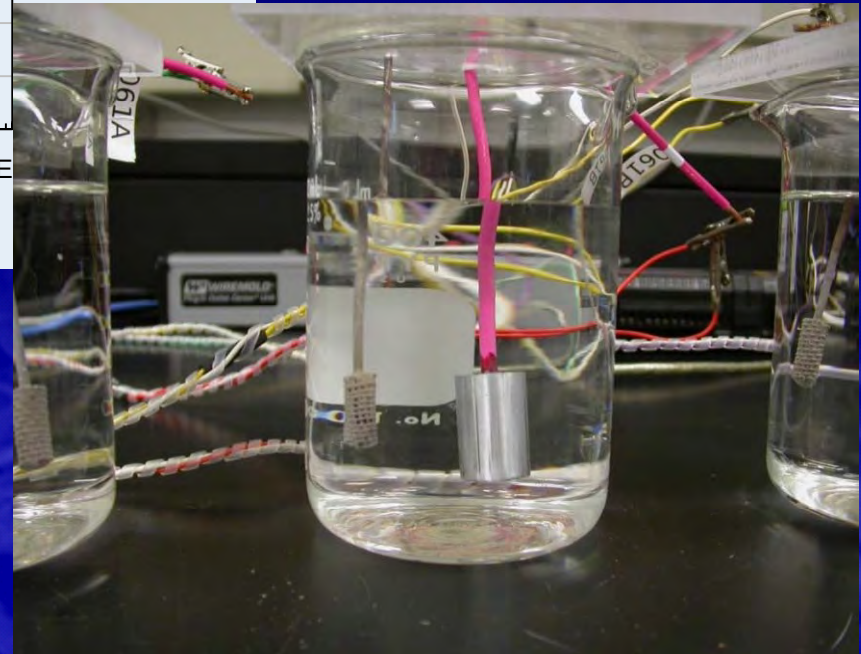
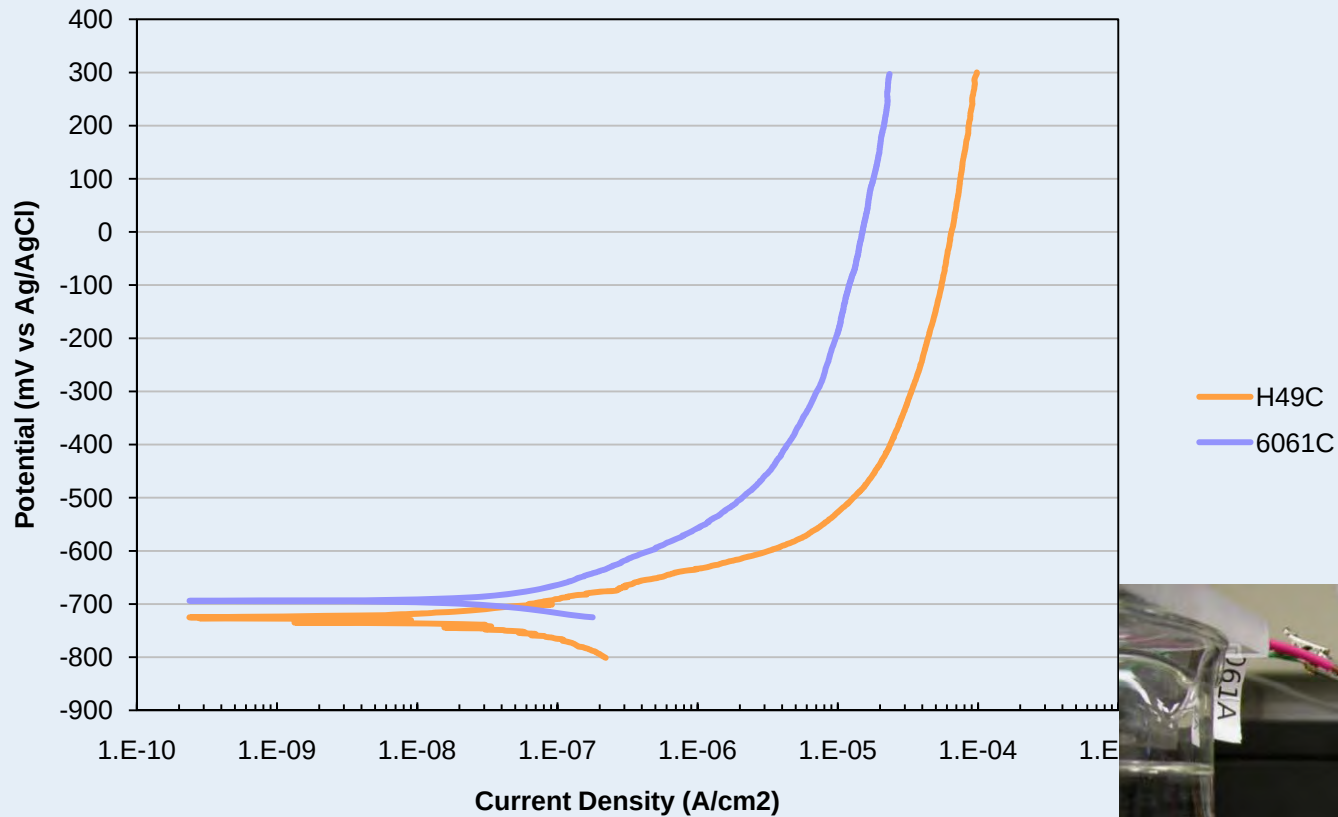
Image of H49 mounted and polished. Hardness values for both H49 and 6061 specimens measured from center.



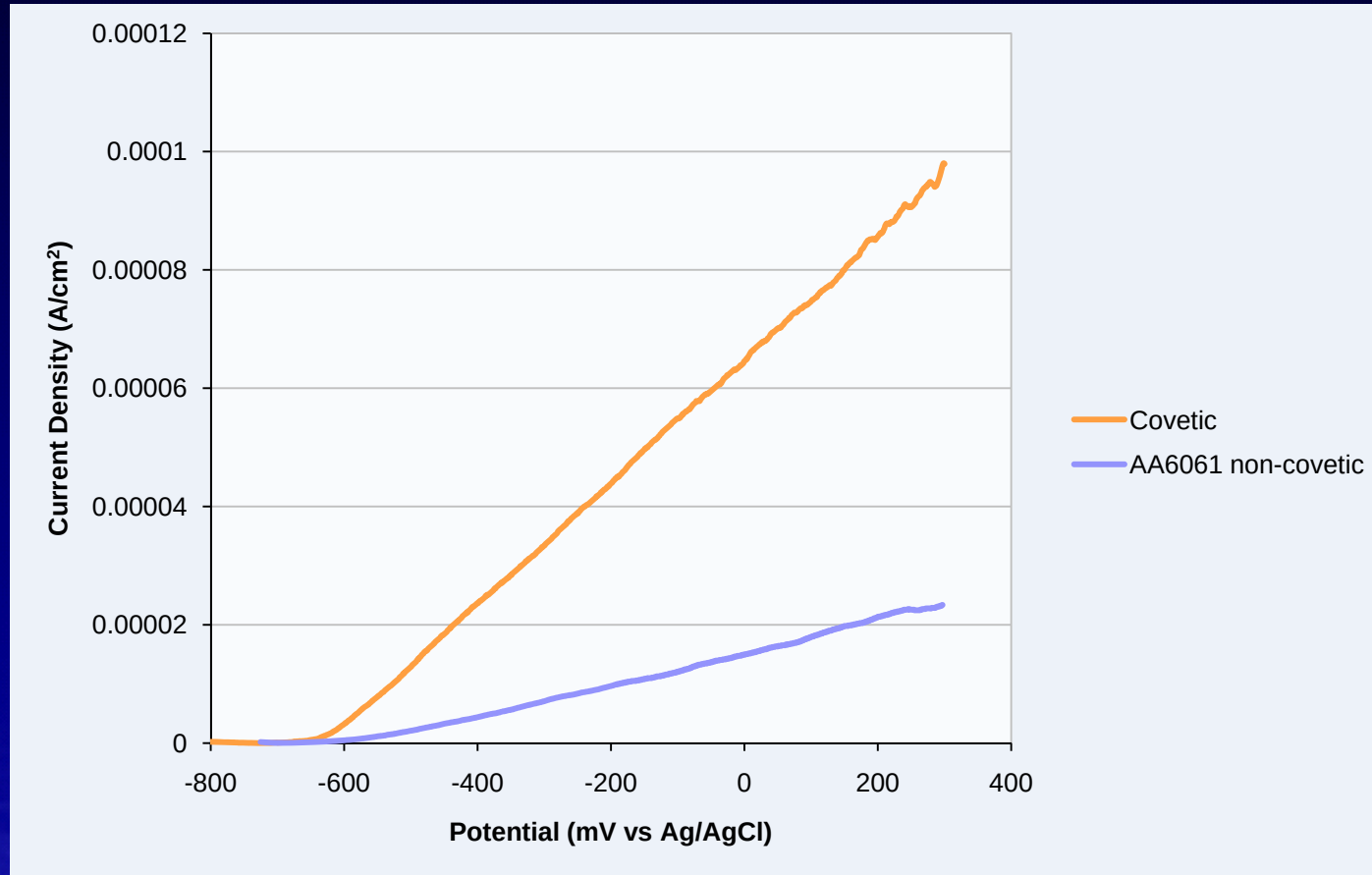
Open Circuit Potential (Seawater): No difference



Anodic Polarization in Seawater



Anodic Polarization in Seawater



Factor of 5 increase in current in artificial seawater: Greater conductivity through the passive film?

Thermal conductivity

- Covetic copper: 1.6X thermal conductivity of Electrolytic Tough Pitch Cu (in cold work direction)
 - Reduced conductivity in orthogonal direction, by 75%
- Normal 90Cu-10Ni: 71 W/m-K
Covetic 90Cu-10Ni: 290 – 460 W/m-K
- Thermal conductivity of aluminum also expected to be much higher (but no data)

Summary

- Nanoscale carbon is not detectable by LECO or GDMS
- Nanoscale carbon raises the melting point of both Al and Cu

Covetic 6061

- Contains several weight % nano-carbon
- Has higher warm-worked strength than normal 6061
- Has significantly finer grainer size and is more strongly textured
- Has 1% higher electrical conductivity
- Probably has much higher thermal conductivity
- May have improved ballistic performance

Note: Annealing and solution treatment wipes out strength differences between cold/warm-worked covetic vs. normal, but covetic material has a slower annealing response so should maintain strength better in moderately elevated temperature applications