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Probing Mechanical Properties of Anodized Coatings on Molten Alloy

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How does Anodized Aluminum Behave at High Temperatures?

- Anodized aluminum is ubiquitous in high technology manufacturing because of advantageous properties
  - low density,
  - high mechanical strength
  - high reflectivity
  - good conductivity
  - relatively low cost
- Good corrosion resistance
  - Natural oxide surface coating (1-3nm)
  - Anodized surface coating (5-30µm)

Aluminum is one of the most studied metals, but what happens to these anodized components at high temperatures?

Fire Danger for Aircraft

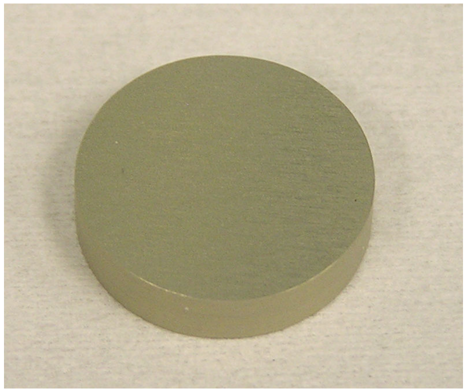
- Aluminum alloys are used for key structural components including the aircraft skin -
- Even after the alloy melts, the anodized coating can continue to retain the liquid metal
- When does the anodized layer fail?

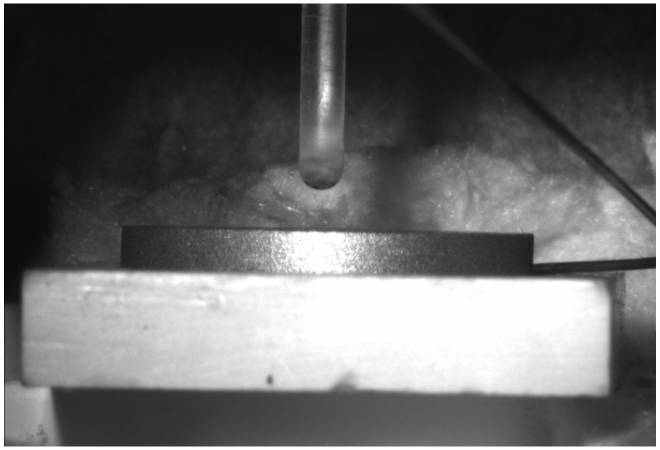
Interfacial Property Measurement of High Temperature Metals

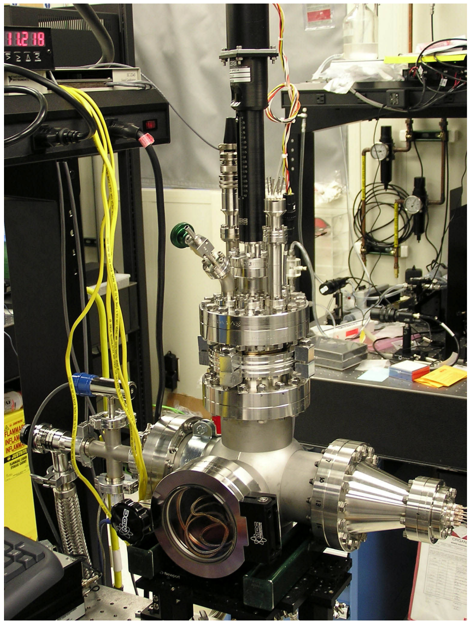
- Our goal is to understand the mechanical properties of the anodized surface coating at temperatures above the melting point of the aluminum alloy
- 7075 Aluminum alloy
  - aluminum +85%
  - zinc 5-6%
  - magnesium 2-3%
  - copper 1-2%
  - Traces of chromium, silicon, manganese
  - solidus of 477°C / liquidus of 635°C
- Study effects of temperature, surface coating and atmosphere
- Micro-indentation technique to probe mechanical response to deformation and failure

Outline and basic look at testing

- Perform indentation experiments on anodized aluminum buttons (1.9cm D by 0.64cm thick)
- Examine the effect of:
  - Temperature
  - Ambient atmosphere
    - Air
    - Nitrogen / Argon
  - Surface finish

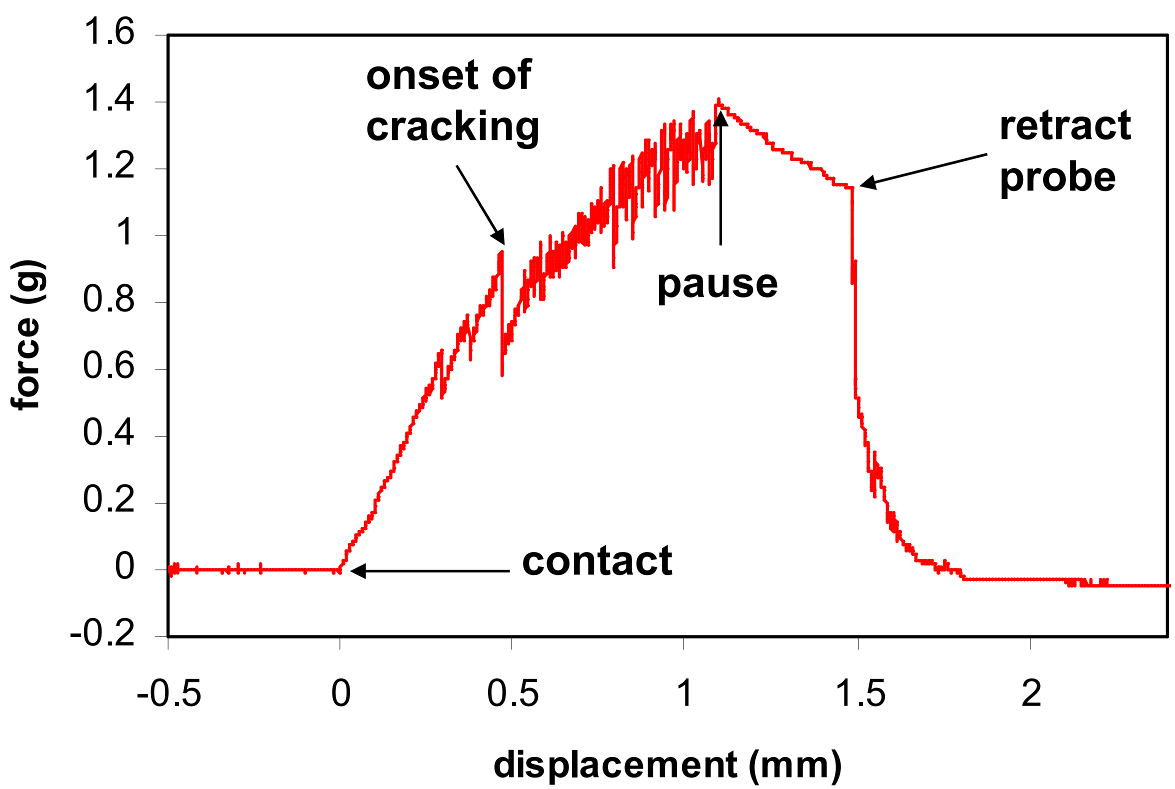


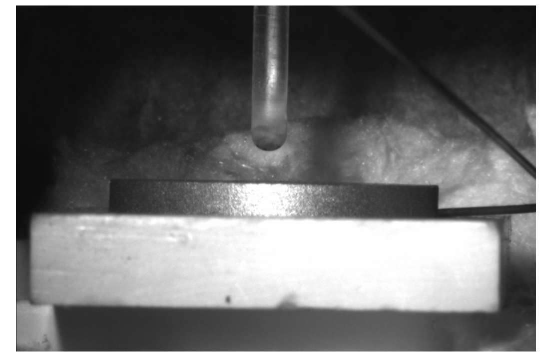


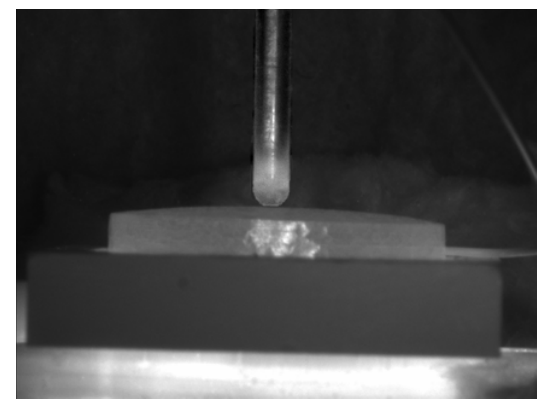


Typical Test Results

- **Test of strength of a sand blasted aluminum surface in nitrogen atmosphere at 615 C**





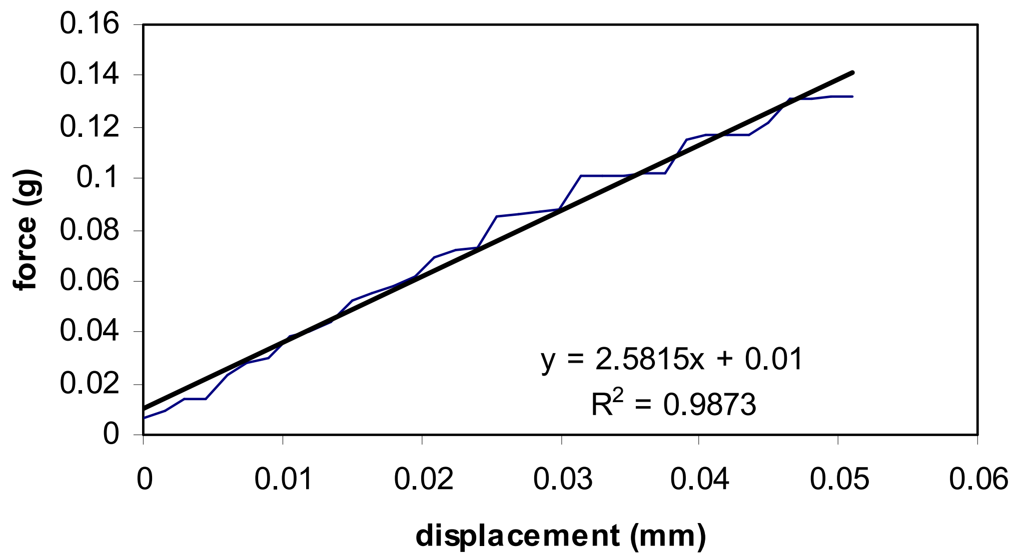


radius of curvature of probe tip R = 1mm → displacement = strain

Effective Young's Modulus

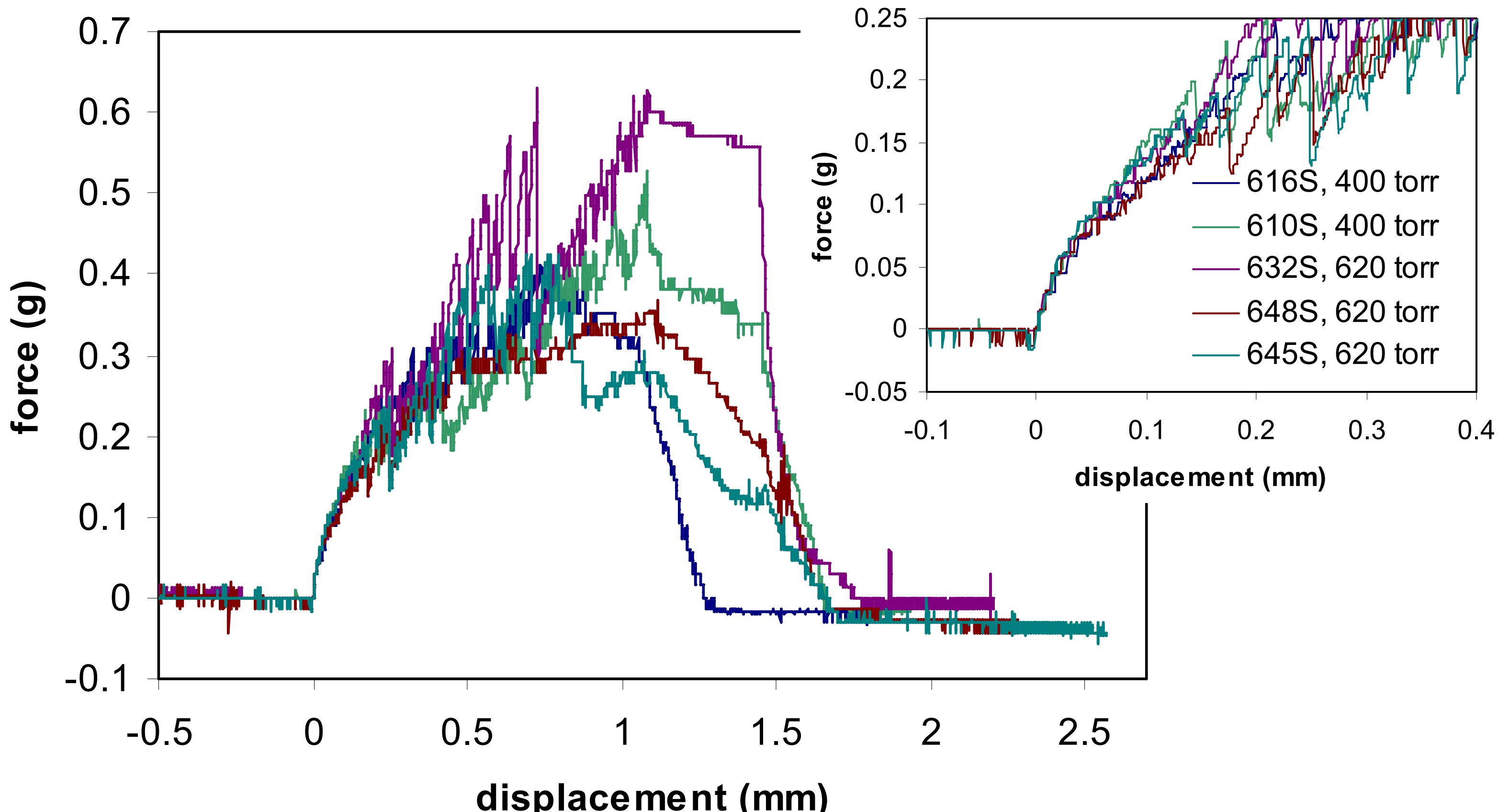
$$E = \frac{stress}{strain} = \frac{force\,/\,contact\ area}{displacement\,/\,probe\ radius} \propto \frac{F}{d\,R}$$

- **the contact area is proportional to the probe radius *R* squared.**
- **the deformed region scales with the size of the probe**
- **calculate over first 50µm displacement**



Temperature Dependence

- **Anodized layer strength in Nitrogen atmosphere**
- **Achieve excellent repeatability in small deformation regime**



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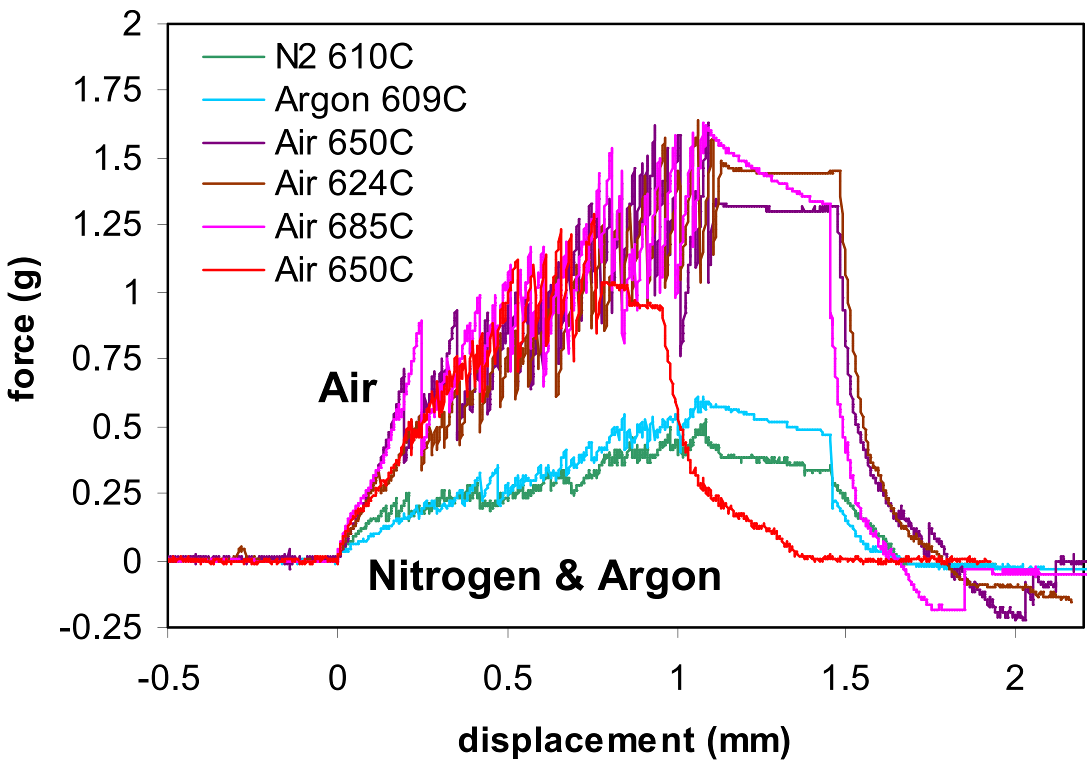
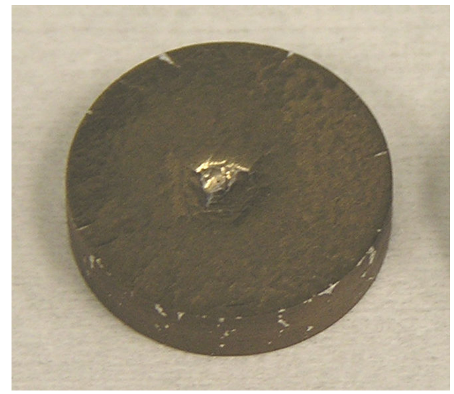
Effect of Ambient Atmosphere

- Samples tested in nitrogen or argon atmosphere are weaker
- At high temperature, the anodized surface coating appears to react in air





tested in N_2

tested in air

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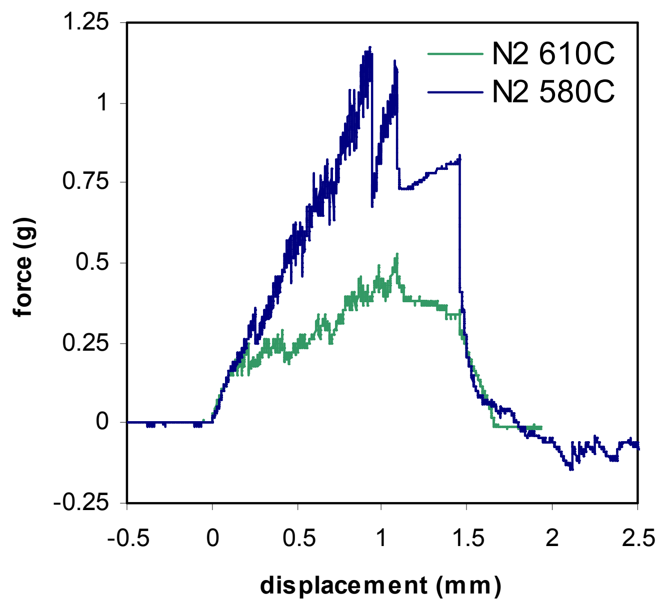
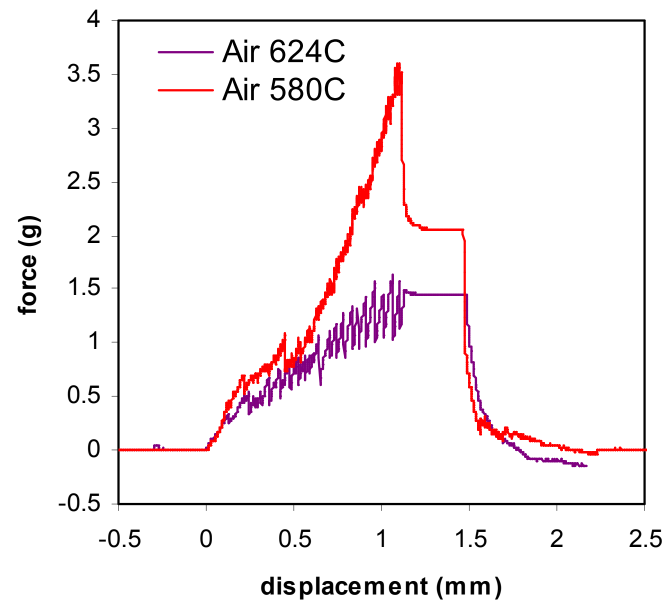
Mushy Zone Below Liquidus Temperature

- **Dependence of mechanical strength below liquidus temperature for (a) nitrogen and (b) air atmospheres shows evidence of liquid-like behavior**

nitrogen

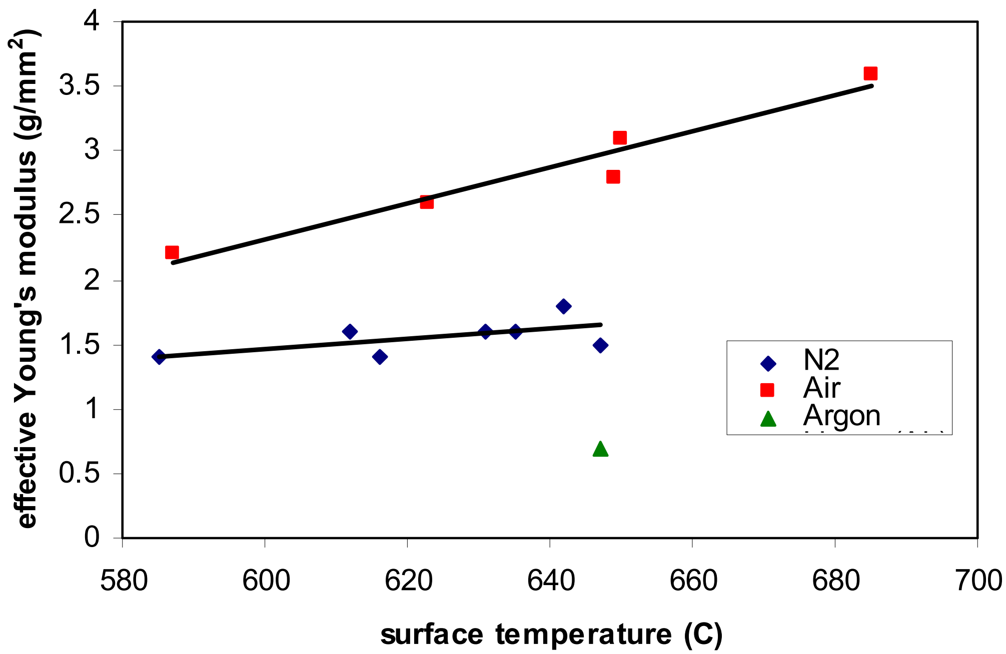


air



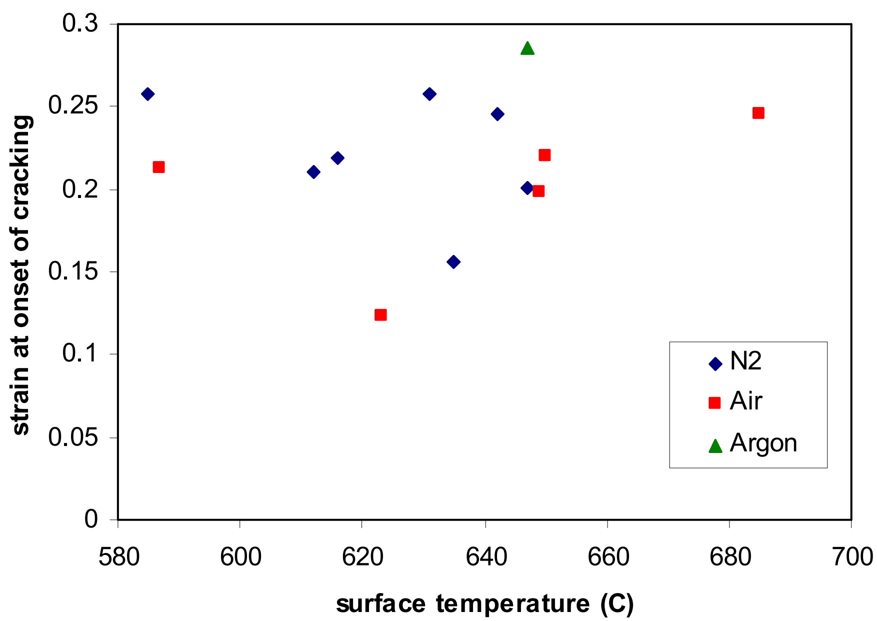
Effective Young's Modulus

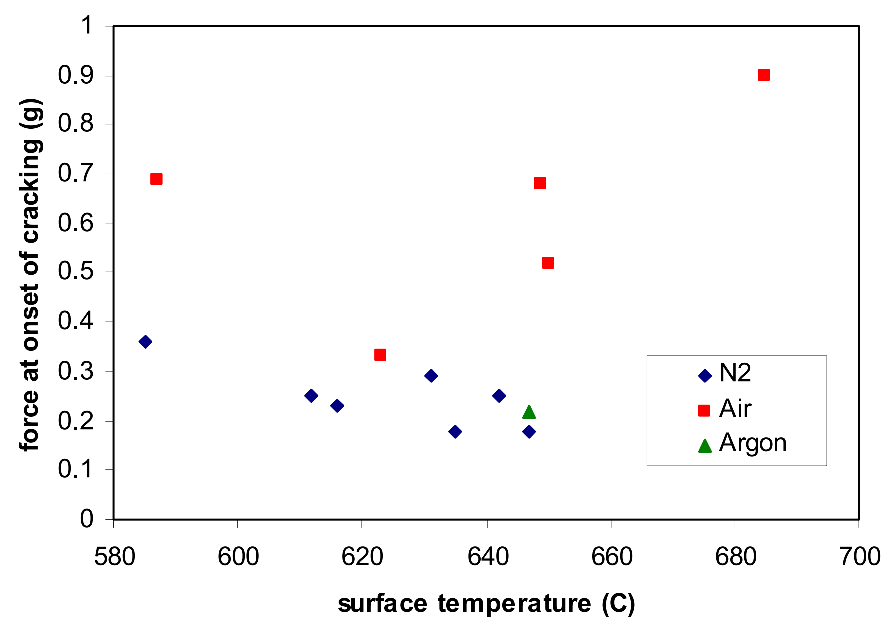
- **Coatings tested in air are much stronger than coatings tested in an inert atmosphere and also seem to have a stronger temperature dependence.**



Failure of the Anodized Coating

- All of the coatings fail at a similar strain ~0.2, but the force at failure is higher in air atmosphere due to higher Young's modulus





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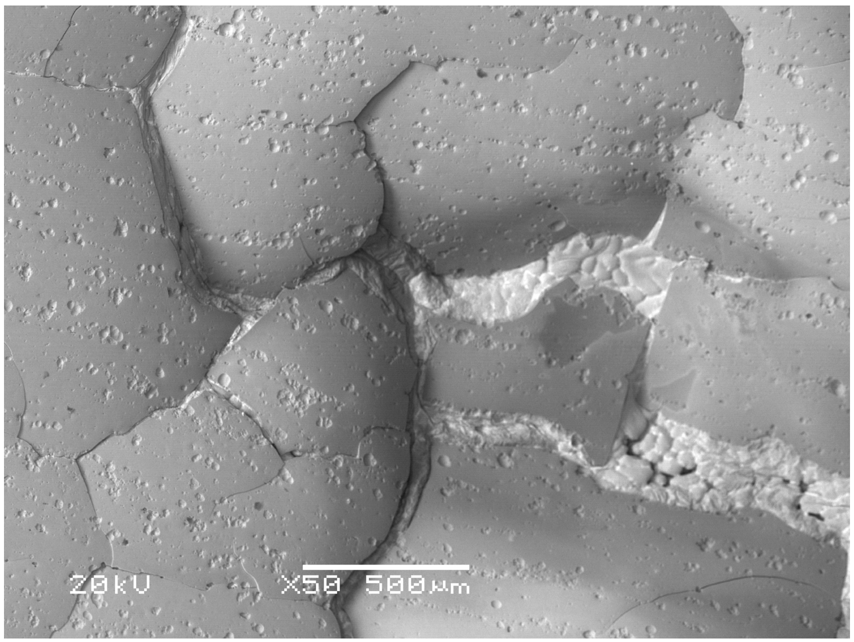
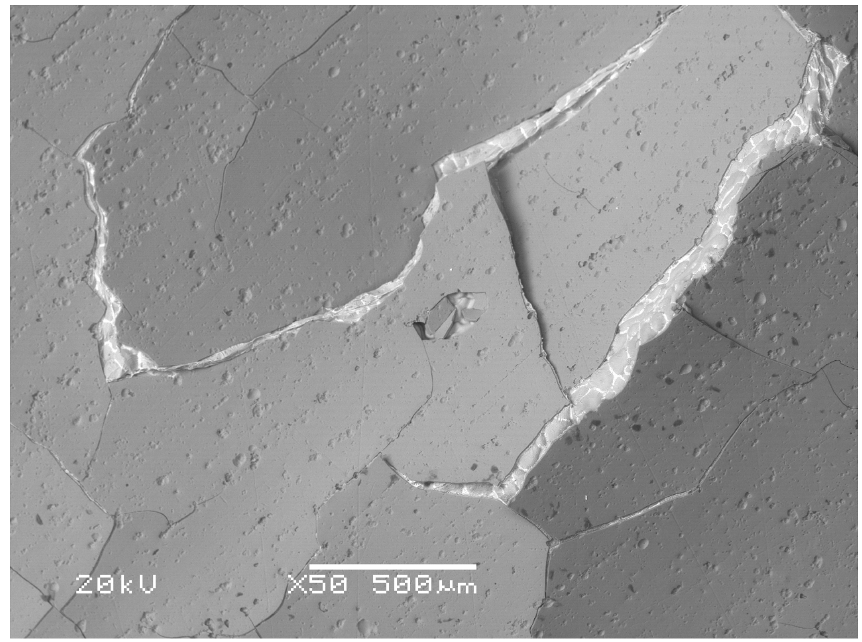
SEM Analysis of Aluminum Samples

Impact point from Nitrogen sample



Impact point from Air sample

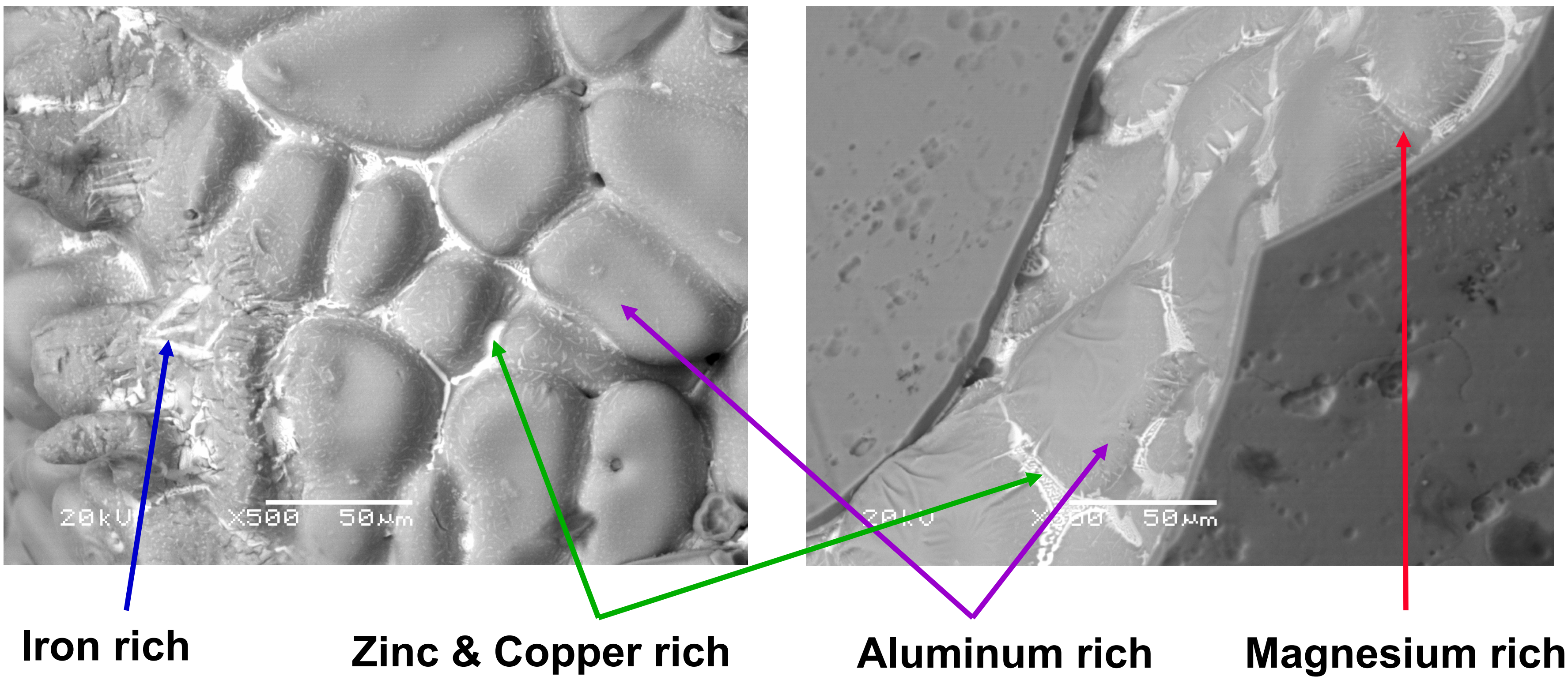


- Sample tested in air shows a more brittle cracking of the anodized layer compared to sample tested in Nitrogen

SEM Analysis of Exposed Crack

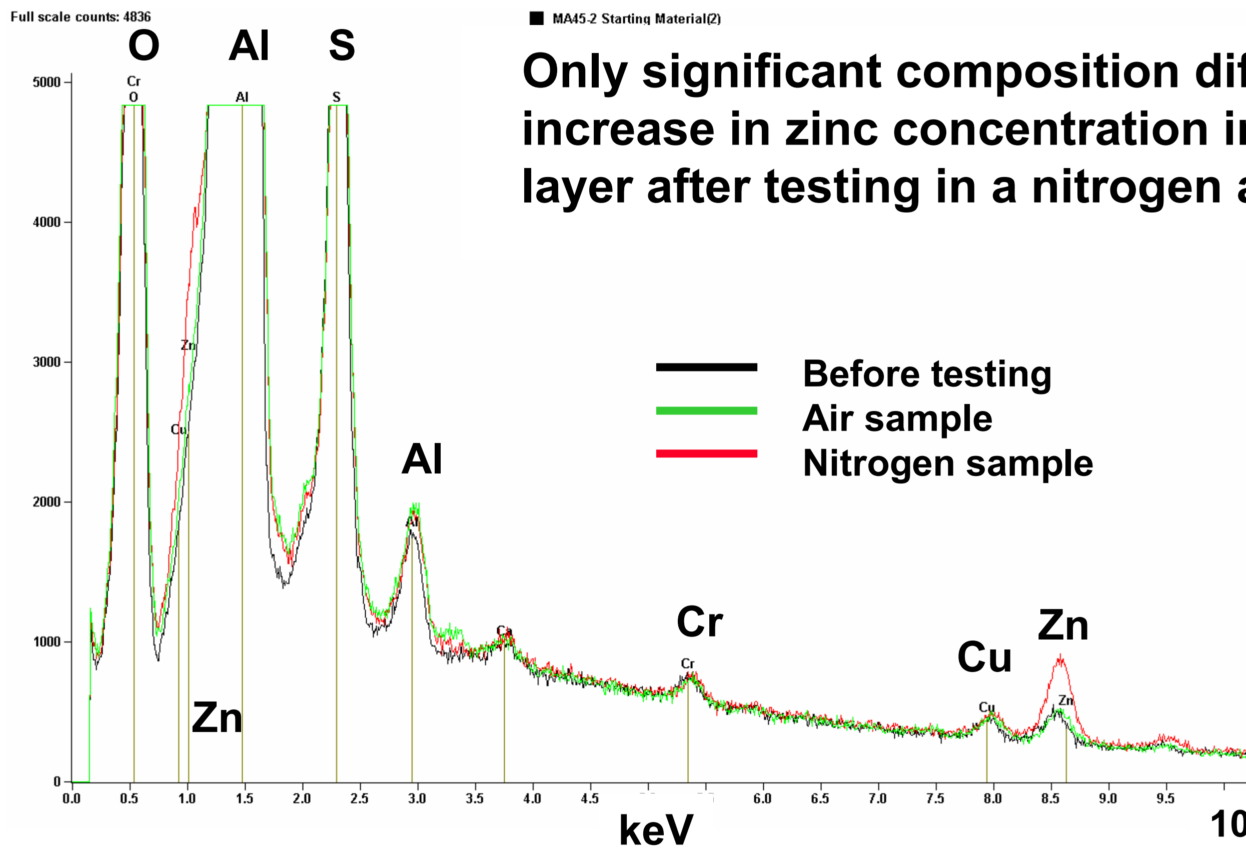
Close-up of exposed alloy from Nitrogen sample

Close-up of exposed alloy from Air sample



Chemical Analysis of Anodized layer by EDS

Only significant composition difference is an increase in zinc concentration in the anodized layer after testing in a nitrogen atmosphere



EDS samples a region 2-3 microns deep at the surface

Native oxide films are 1-3nm

EDS may not be sensitive enough to detect such a thin layer

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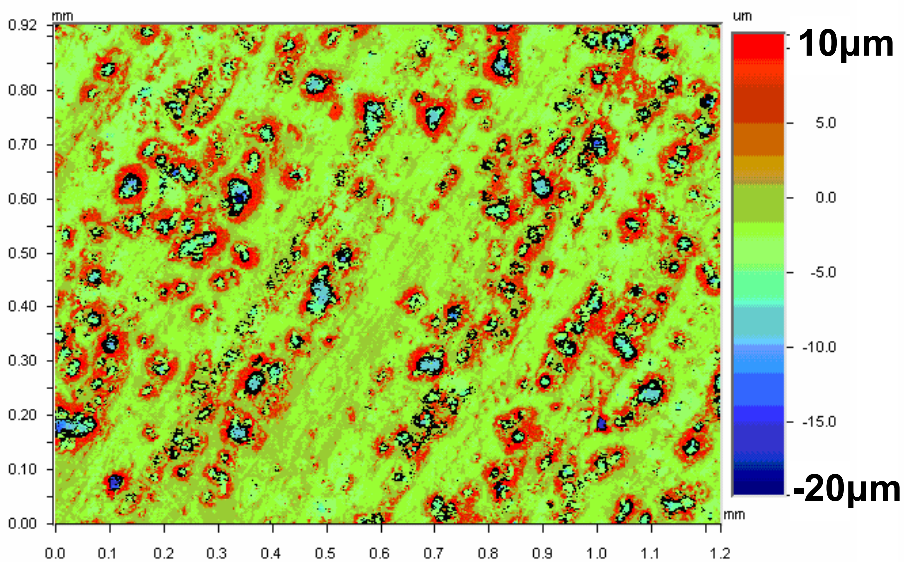
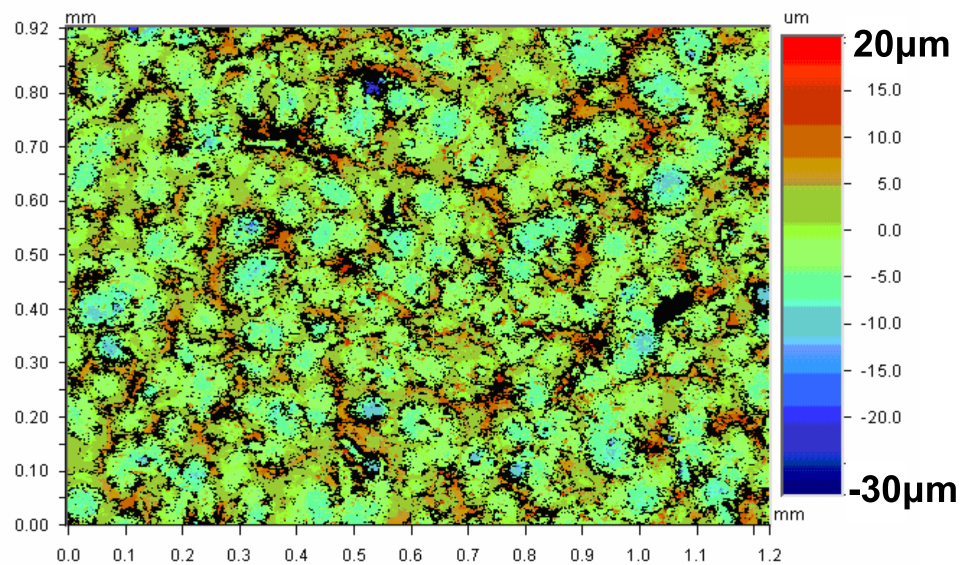
Effect of Surface Finishes

- Two surface finishes were applied prior to anodization
  - Diamond turned optical quality polish
  - Sandblasted with 80 grit AlOx powder
- Anodization is a conformal coating process



Pitting 50 μm x 30 μm



Craters 100 μm x 40 μm

	R_a	R_z
Button – flat	2.8	27
Button – sand	3.3	35-42

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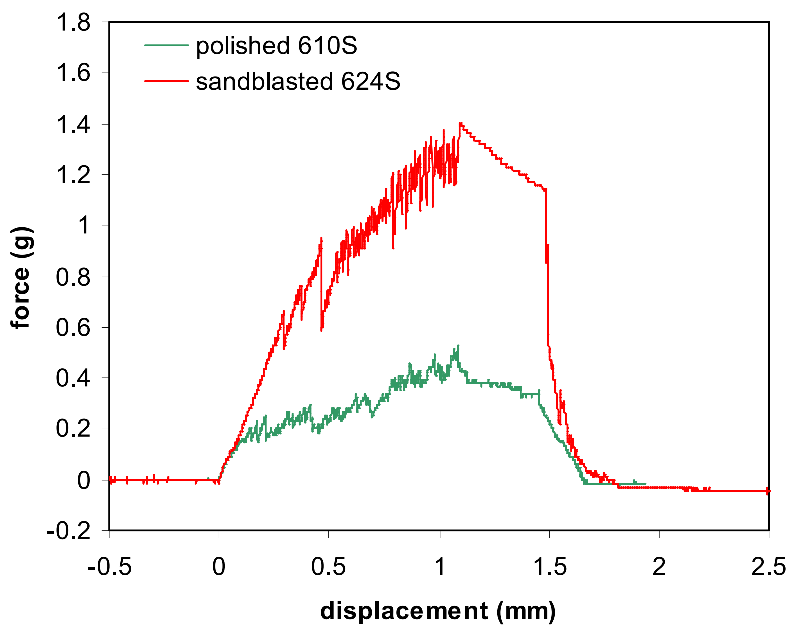
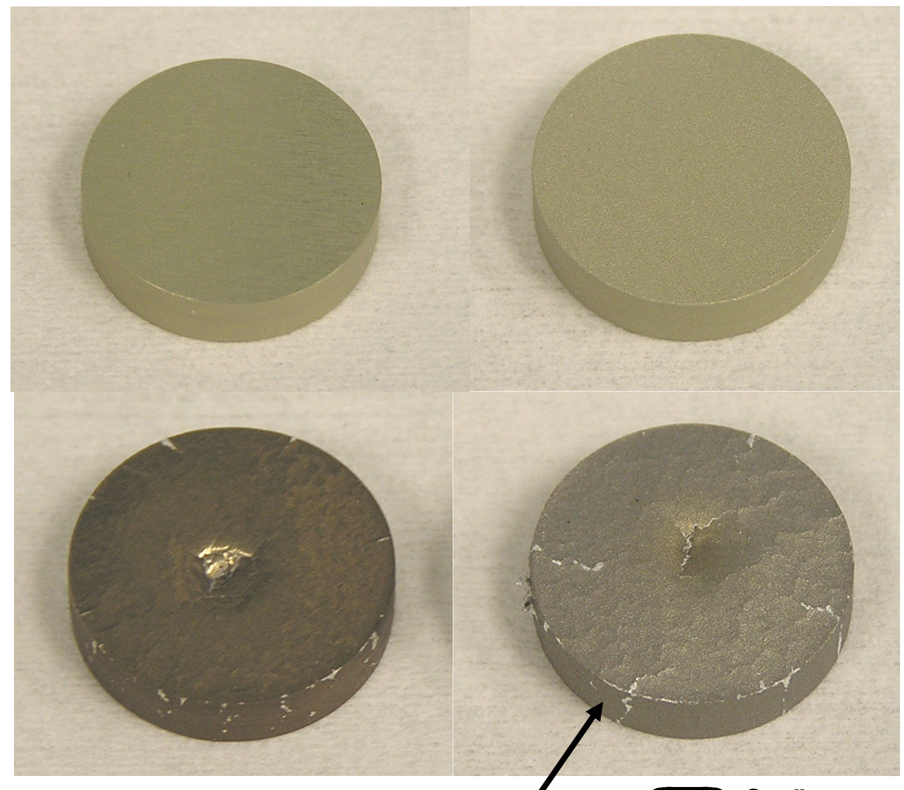
Effect of Surface on Anodized Layer Strength

- **Sand roughened surface is much stronger than regular anodized surface. Small machining marks only a few microns deep do not impact surface strength**

Nitrogen atmosphere

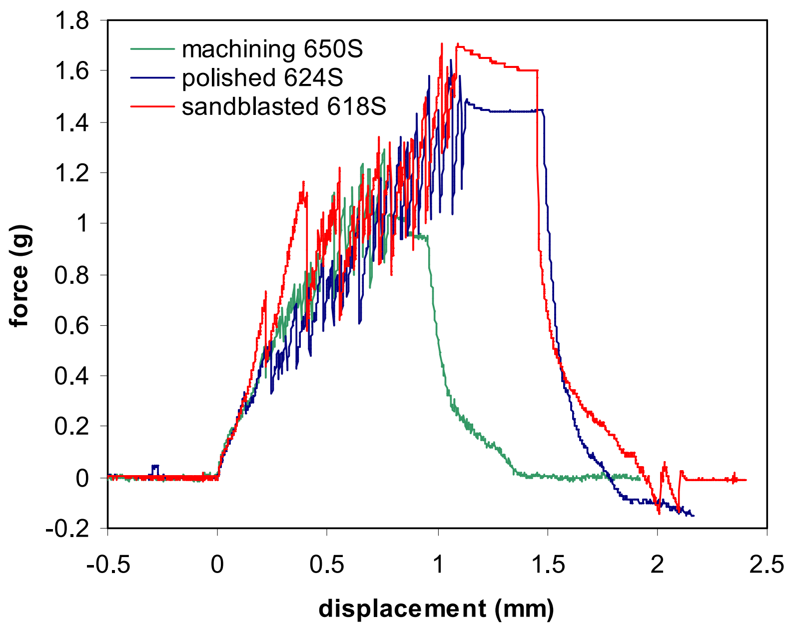


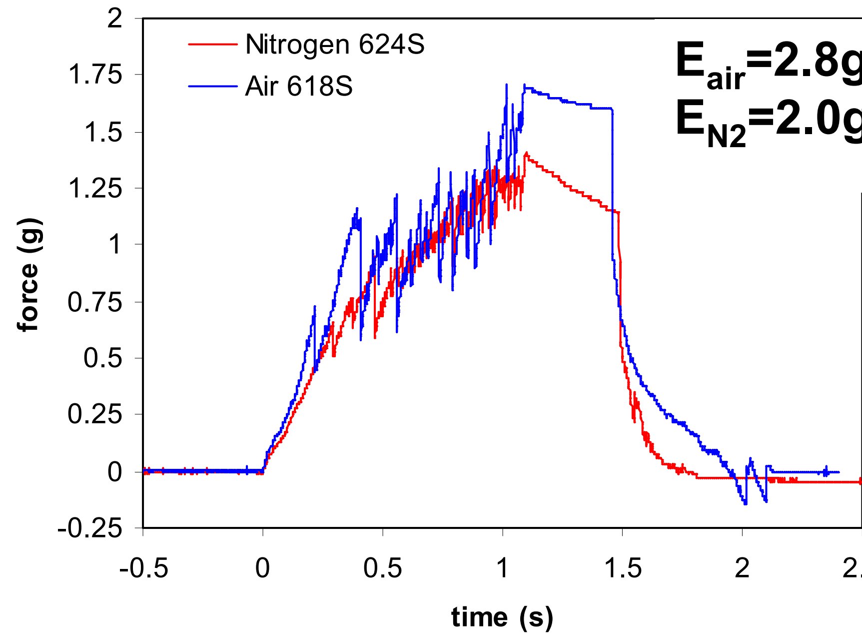


Light color due to exposure to air to measure internal temperature

Atmosphere Dependence

- Surface treatment dependence is not as pronounced in air
- Atmospheric dependence is not as pronounced with sandblasted surface.





E_{air}=2.8g/mm²

E_{N2}=2.0g/mm2

Summary

- Demonstrated new controlled pressure / atmosphere capability to measure interfacial material properties
- Examined mechanical properties of anodized coating at high temperatures where the aluminum alloy is molten
- Coatings are much stronger in air than inert atmospheres and require a larger force to break the coating
- SEM analysis shows correlated morphology difference in the anodized layer, but no chemical differences detected
- Sandblasting effectively increases the strength of the anodized layer in a nitrogen atmospheres