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EVALUATION OF ALUMINUM SURFACE TREATMENTS FOR EPOXY BONDING APPLICATIONS USING MODE I FRACTURE TESTING

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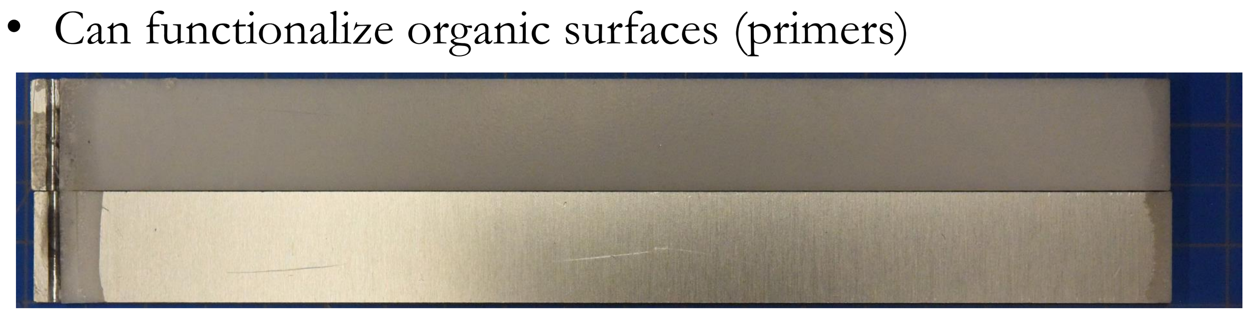
Aluminum Bonding Reliability

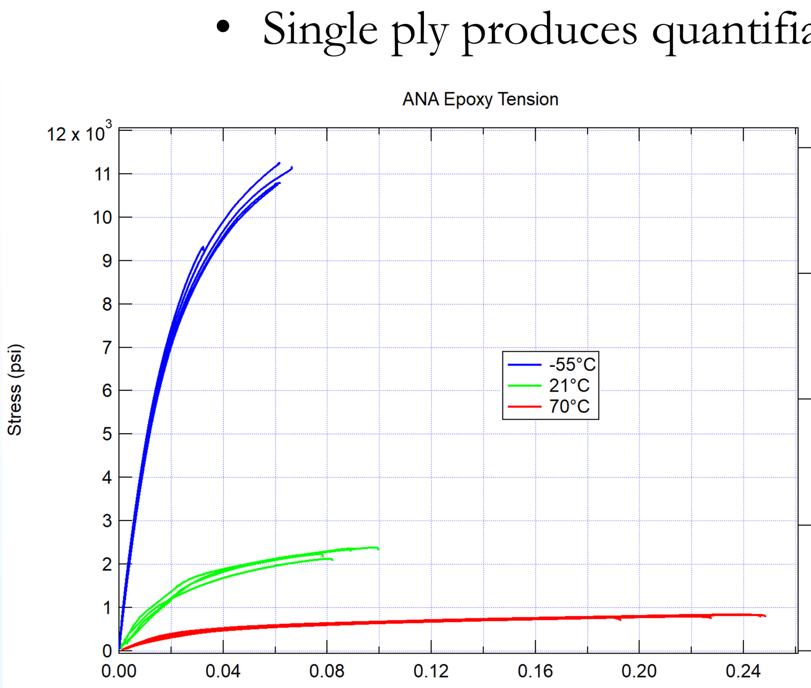
- Necessary for adoption of hybrid polymer/fiber reinforced polymer composite (FRPC)/metal structures
- Wide service temperature range for aerospace structures (-55°C to 70°C)
- Challenging due to natural aluminum oxidation layer
- Requires surface preparation care/evaluation
- Anodizations
  - Chromic Acid Anodization, discontinued due to health concerns
  - Sulfuric Acid Anodization (SAA II)
    - With and without hot water sealing (HWS)
    - Boehmite layer seals pores and prevents water ingress to untreated aluminum
  - Phosphoric Acid Anodization (PAA)
- Primers
  - Chromated primers are discontinued due to health concerns – BR-127
  - Non-chromated primers – BR-6747-NC and EW-5005
- Plasma treatment
  - Can remove organic contaminants
  - Increases surface free energy (SFE) to assist in surface wet-out
  - Can functionalize organic surfaces (primers)



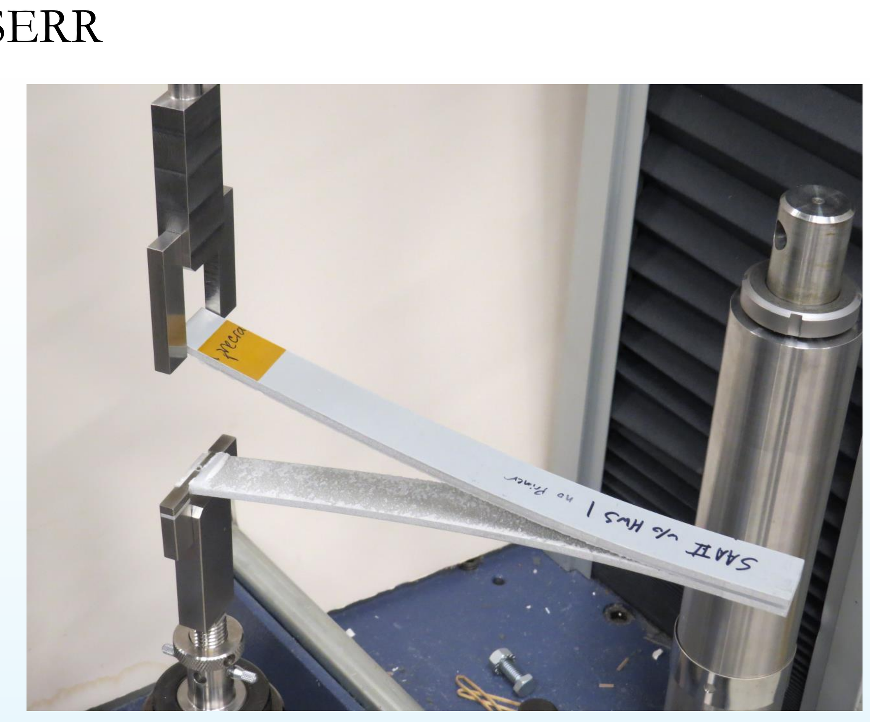
Adhesive failure of 6061-T6/ANA interface for unprimed SAA II w/HWS at -55°C

Testing Methodology

- Double cantilever beam (DCB) testing
  - Determine either interfacial or adhesive strain energy release rate (SERR)
  - Qualitatively determine cohesive or adhesive failure
  - Cohesive failure suggests surface treatment is sufficient
  - Testing performed at -55°C, 21°C, and 70°C
  - Teflon precrack 12.7 μm thick
- Aluminum 6061-T6 3.175mm thick panels were anodized and primed
- Surfaces were plasma treated prior to bonding
  - 5 minute exposure, 100 N_2/25 O_2, 400W, 100mTorr
  - SFE measured using Krüss mobile surface analyzer
- Secondary bond
  - Sandia proprietary low-viscosity, ductile epoxy adhesive (ANA) that is used as a filler to significantly thick bond lines (~1.5mm)
  - Bulk properties for the epoxy vary widely across the temperature range leading to significant changes in the cohesive toughness
  - Initial testing of unprimed SAA II w/HWS showed adhesive failure at sub-ambient temperatures
- Co-bond
  - A single ply of an 8HS weave fabric glass fiber reinforced polymer (GFRP) prepreg is cured between two aluminum adherends
  - GFRP has lower bulk toughness than aluminum/GFRP interface in many cases which would produce a secondary crack front in a full GFRP laminated adherend
  - Single ply produces quantifiable SERR



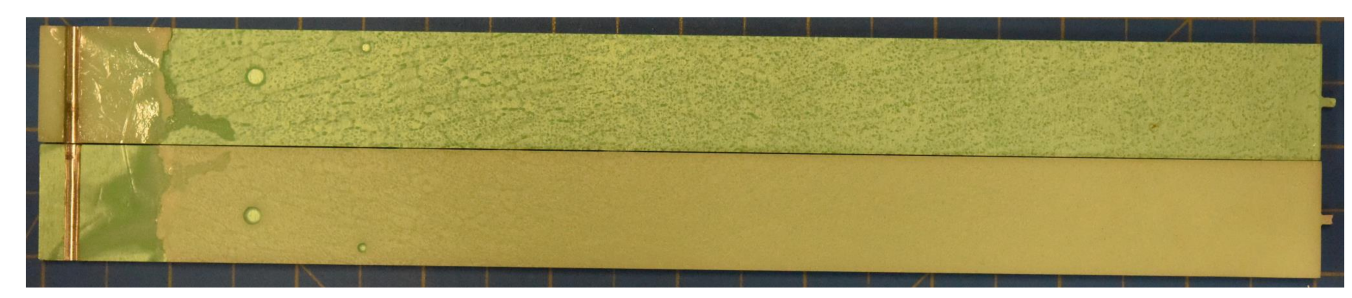
ANA Adhesive Tensile Response



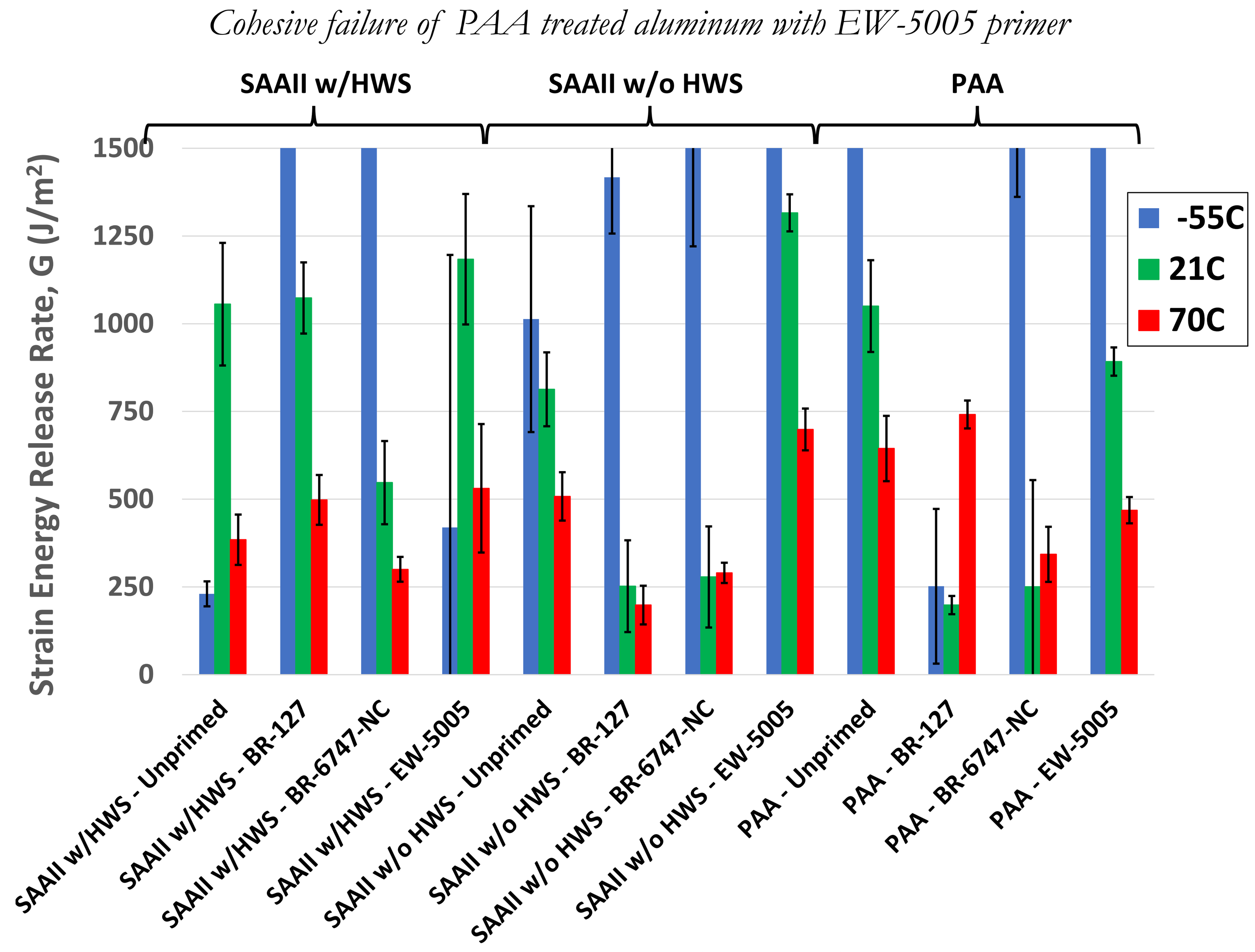
DCB Testing

Secondary Bond Results

- No broad rule of thumb
  - Each anodization had a matched primer that performed sufficiently well in addition to one combination that did not
  - Reinforces the necessity of testing paired adhesive/surface treatments
- ANA is extremely tough at sub-ambient temperatures which caused aluminum adherends to yield
  - Difficult to disentangle plastic work done on adherend with energy dissipated during crack growth
  - Thicker adherends would produce more quantitative data, but that was deemed unnecessary for this study



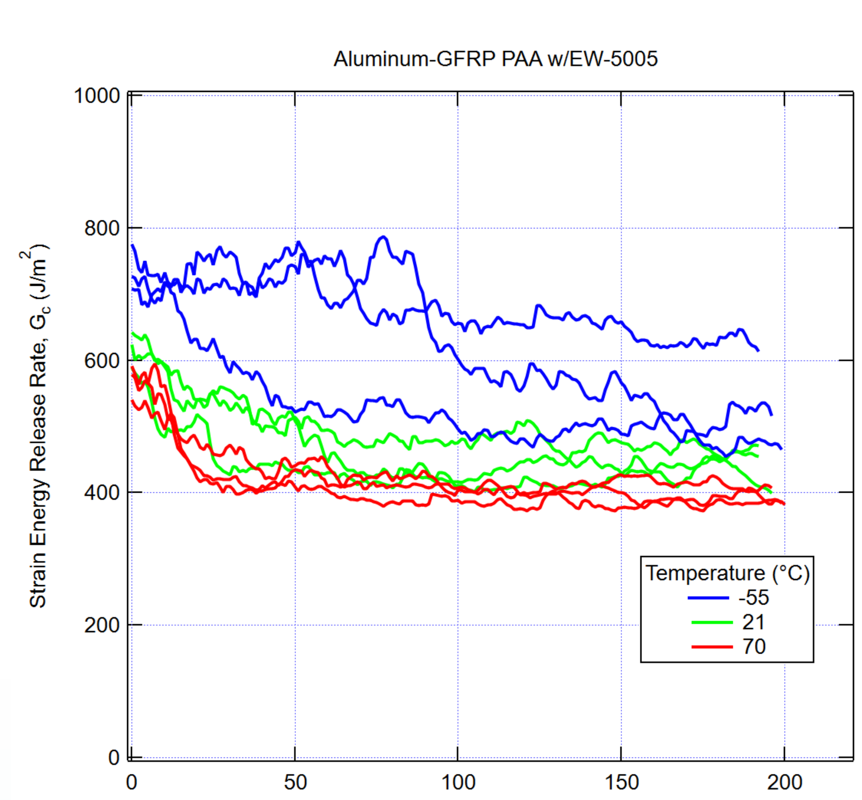
Cohesive failure of PAA treated aluminum with EW-5005 primer



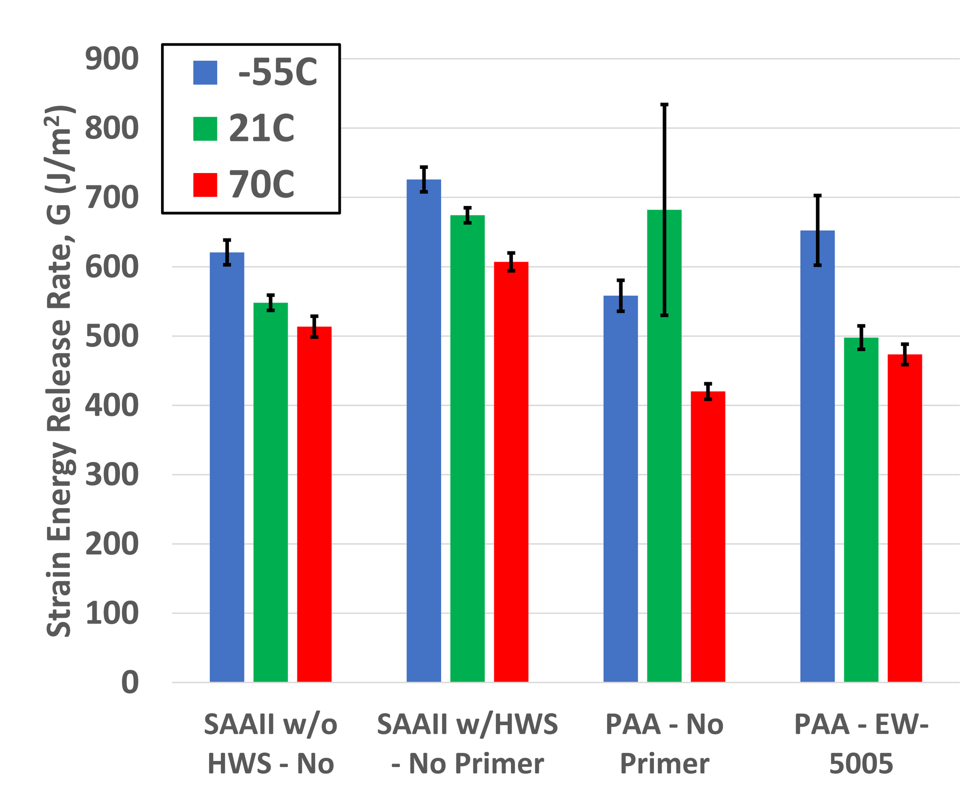
SERR comparisons for secondary bonded interfaces

Co-bond Results

- Down selected to PAA with EW-5005 after secondary bond study
- Compared results to unprimed co-bonded panels with different anodizations
- All failures were cohesive within the prepreg epoxy resin – failure typically at epoxy glass fiber interface
- Small variations in SERR, most likely due to small variations in epoxy pore infiltration/bond line



R-curve for co-bonded GFRP/Aluminum with PAA and EW-5005 primer



SERR comparisons for co-bonded interfaces

Conclusion

- Co-bonding was less sensitive than secondary bonding to surface treatment/environments
- Each adherend/adhesive pair must be evaluated with proper surface preparation
- Initial investment in coupon testing with materials of interest can reveal potential design flaws prior to full scale component environmental testing

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