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Evaluation of Fracture Toughness for Hybrid Aluminum to Fiber Reinforced Polymer Composite Joints

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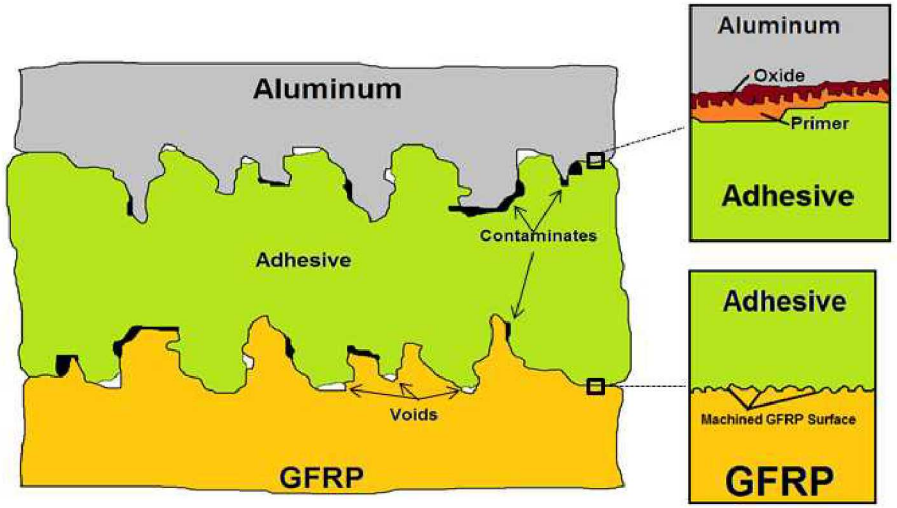
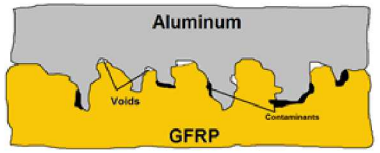
Composite to Aluminum Bonding

- Terms
  - Cobonding – composite is cured in contact with aluminum forming a bond through the matrix curing process
  - Secondary bonding – cured composite is bonded to aluminum in a second step with an infusion resin or paste adhesive forming the bond
- Aluminum bonding issues
  - Oxide layer
  - Anodization
  - Primer
  - Surface cleanliness
- Current standard for good mechanical bonding
  - Phosphoric anodization
  - BR-127 primer
- BR-127 has high VOC and hexavalent chromium
  - Requires advanced filtration for spray application
  - Future environmental regulations may prevent its long term use
  - A replacement surface prep must be found





Primer Selection

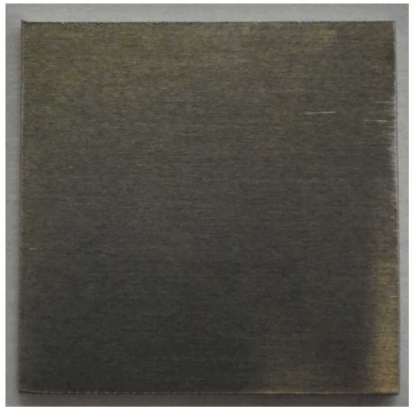
Product	BR® 127	BR® 6700-1	BR® 252	Hysol® 2000
VOC (g/L)	792	0	12	15
Inhibitor	Chromated	Nonchromated	Nonchromated	Nonchromated
Solids (%)	10% ± 1 sprayable	25% sprayable	18% sprayable	10 – 14% sprayable
Density (g/L)	875	1050	1030	1010
Metal Bond Application	Compatible with most 121-177°C curing adhesives	Compatible with most 121-177°C curing adhesives	Compatible with most 121-177°C curing adhesives	Compatible with most 121-177°C curing adhesives
Mechanical Properties	Maximum environmental resistance and durability with bond line Prevents corrosive undercutting	Mechanical properties and corrosion resistance equal to that of solvent-based primer systems	Mechanical properties equal to that of solvent-based primer systems	Excellent resistance to chemicals and water

All selected primers have no Chromium and VOC levels well below the Federal and California limits

Aluminum Anodization

As-received

Cleaned



Phosphoric Acid Anodized

Materials Cleaning and Anodizing Processes

1. Acetone wipe.
2. Oakite®90 alkaline-clean at 93°F for 3 minutes.
3. D.I. water rinse.
4. De-smut in nitric acid bath (40% vol.) at ambient temperature for 5 minutes.
5. D.I. water rinse.
6. Phosphoric acid anodize at 10 V for 25 minutes.
7. D.I. water rinse.
8. N_2 gas-dry.

Oxide thickness measured by calibrated eddy current was 0.135 ± 0.04 mils (3.43 ± 1 um)

Primer Application

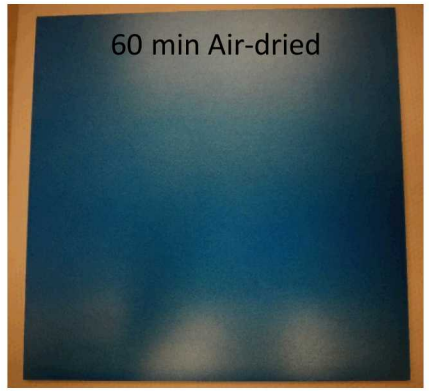
BR® 252

- **2** spray cross coats
- Thickness – **0.24 ± 0.08 mils**
- Recommended – 0.15 – 0.3 mils

BR® 6700-1

- **1** spray cross coat
- Thickness – **0.37 ± 0.1 mils**
- Recommended – 0.15 – 0.3 mils

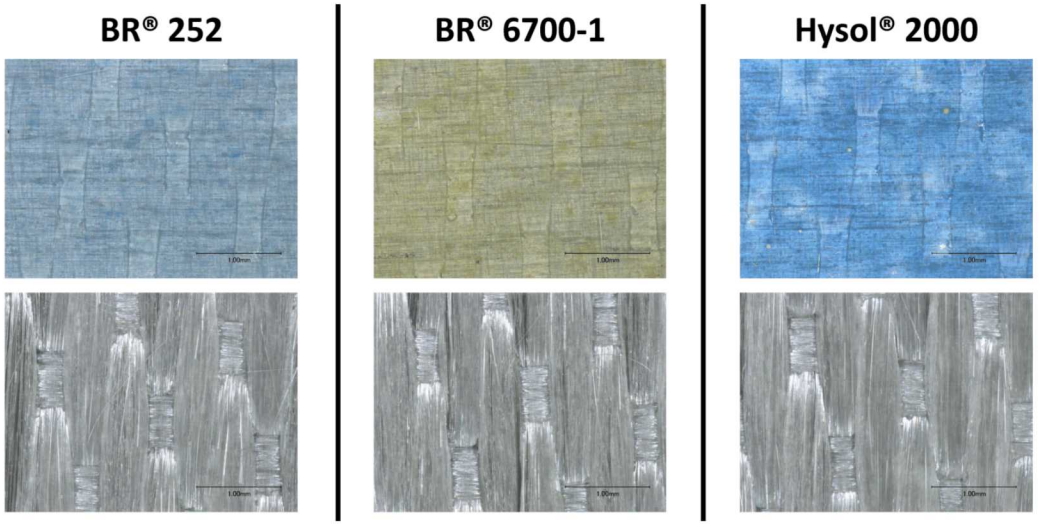
Hysol® 2000



- **4** spray cross coats
- Thickness – **0.27 ± 0.07 mils**
- Recommended – 0.15 – 0.3 mils

Primer Downselect

- Cobonded aluminum to GFRP panels
  - Phosphorically anodized
  - Each of the candidate primers used
- Rapid Adhesion Testing Performed (RAT)
  - Similar to a climbing drum peel
  - Qualitative – determines fracture mode
  - Quick and simple to perform
- All panels failed cohesively within the GFRP
- Hysol 2000 was selected on input from application team



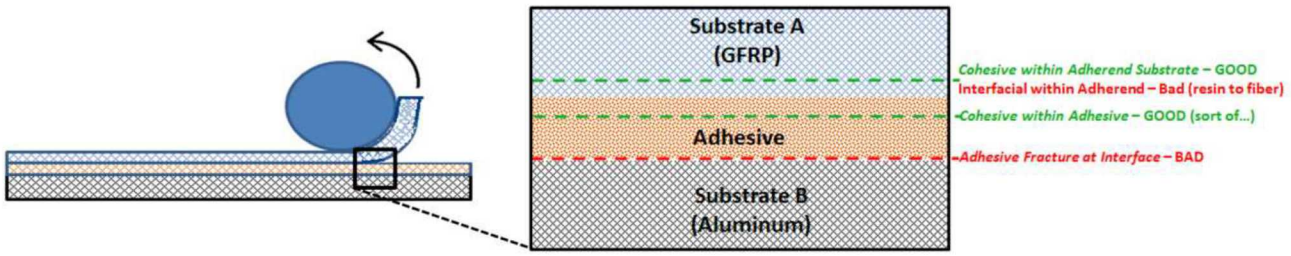
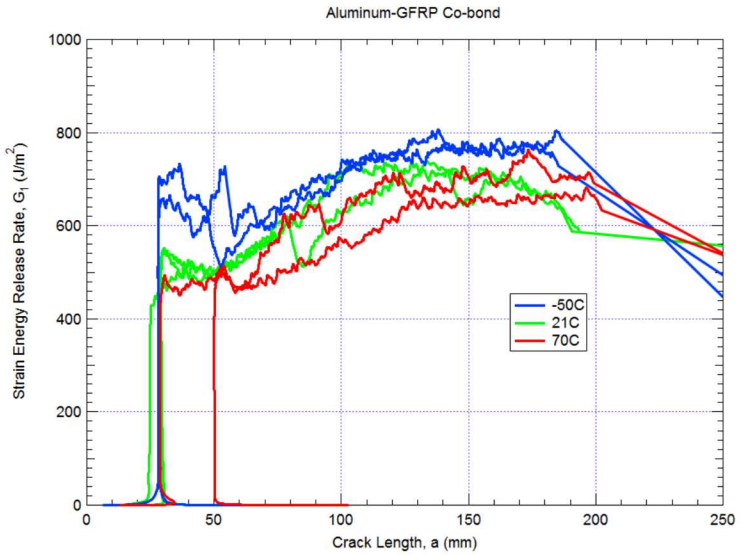


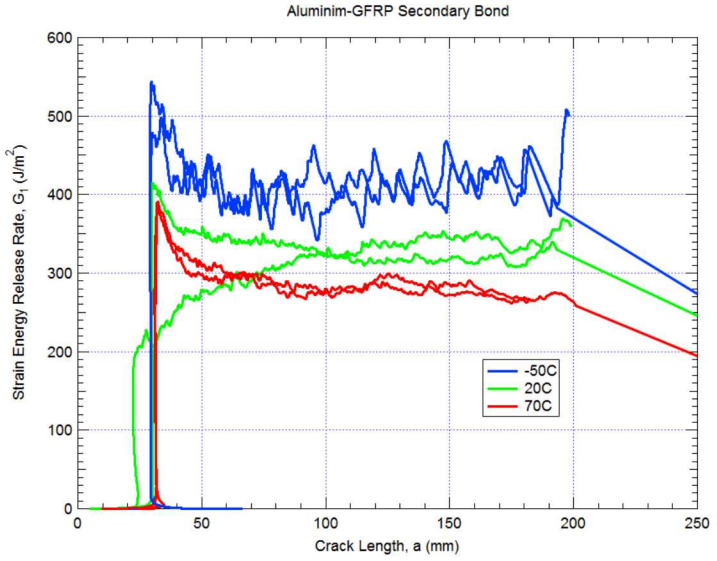
Image adapted from: Tracey, AC, Flinn, BD, et al. *Improving Adhesive Bonding through Surface Characterization: Reverse the Curse of the Nylon Peel Ply?* JAMS/AMTAS Review (2014)

DCB Testing

- Specimens
  - Aluminum 6061-T6/GFRP$[0_7]_s$ – cobonded
  - Aluminum 6061-T6/GFRP$[0_7]_s$ – secondary bonded with infusion resin (INF114/HT251)
- Instron 5989 electromechanical test frame
- Constant displacement (1mm/min)
- Tested across wide temperature range
  - -50°C
  - 21°C
  - 70°C
- Strain energy release rate calculated using beam theory

DCB Results



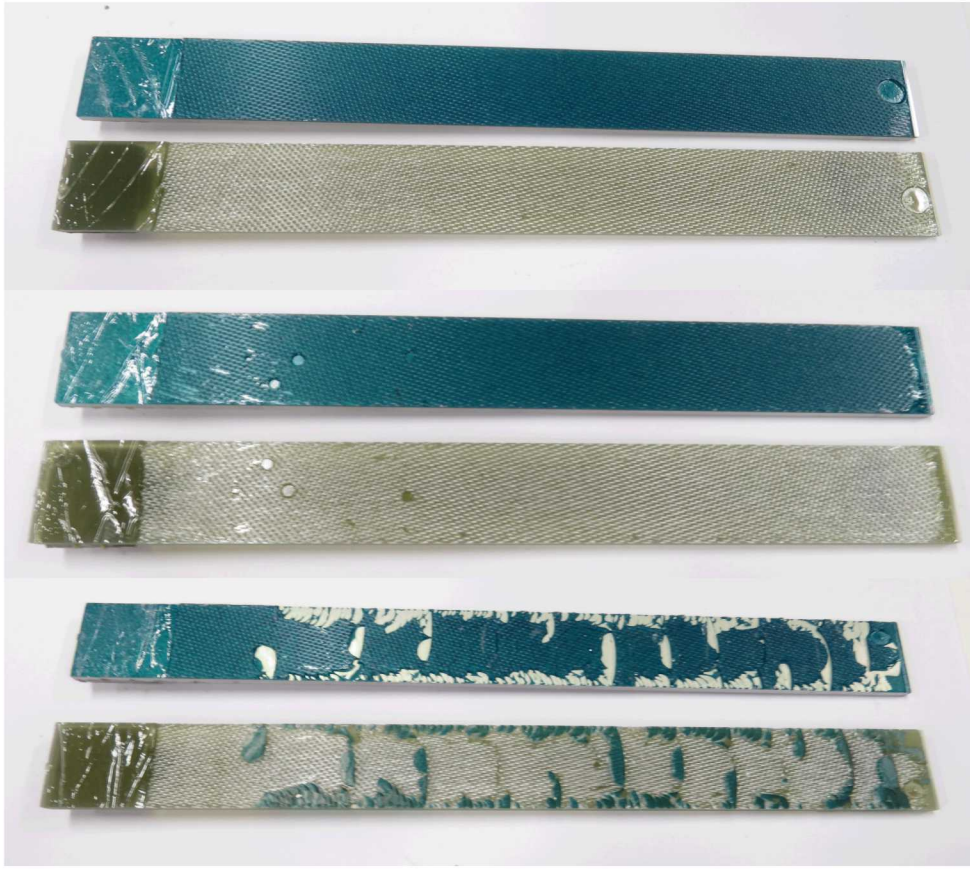


Typical Cobond Failure

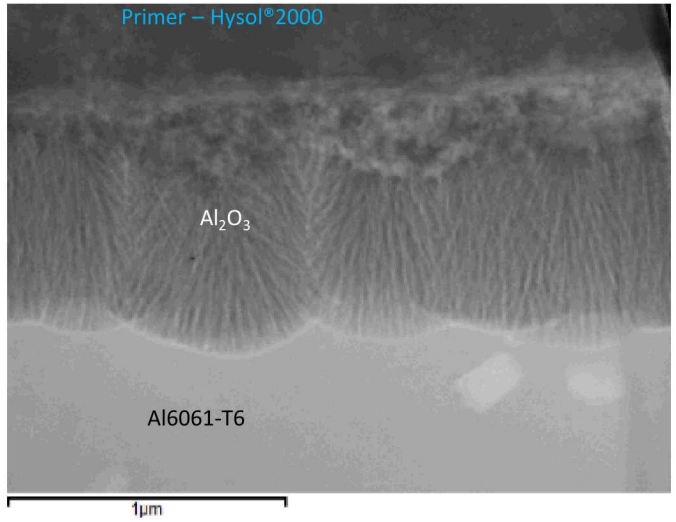
70°C

21°C

-50°C



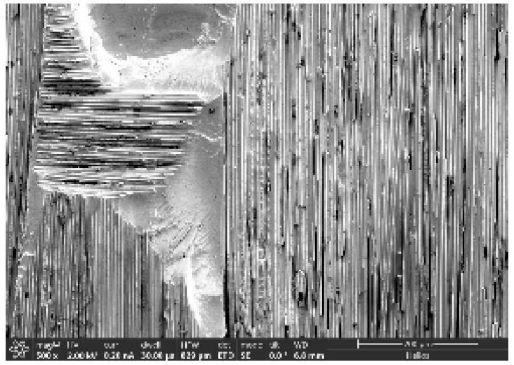
Fracture Surfaces



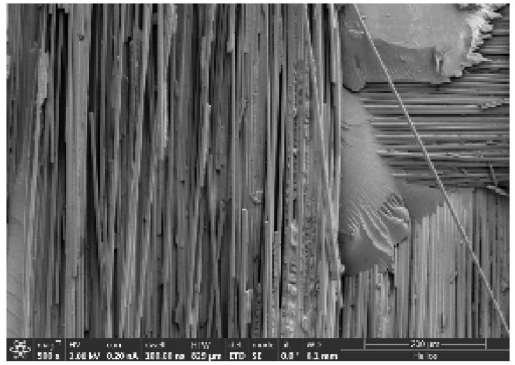
Interface Cross-section

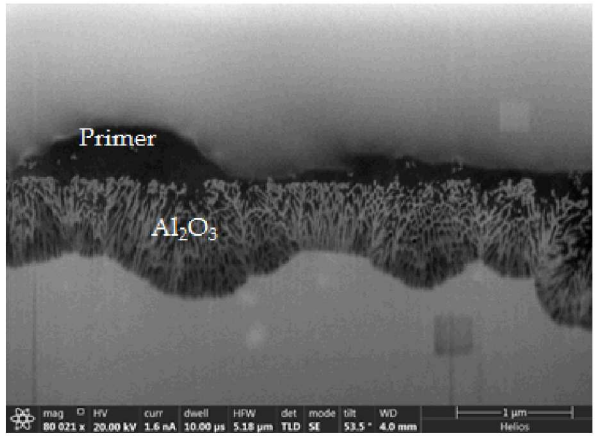
3362 resin to fiber interfacial fracture

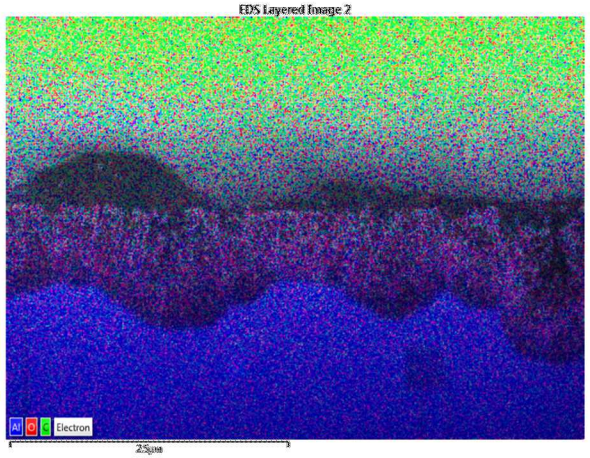
Al side of fracture



GFRP side of fracture

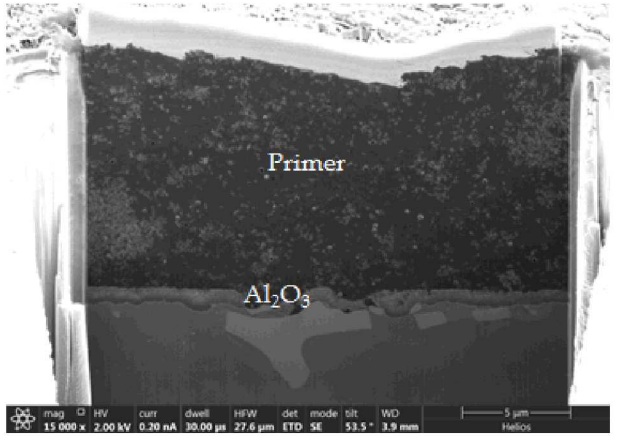




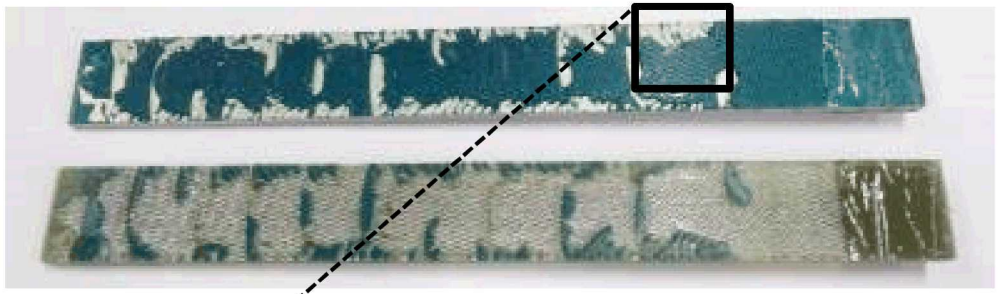


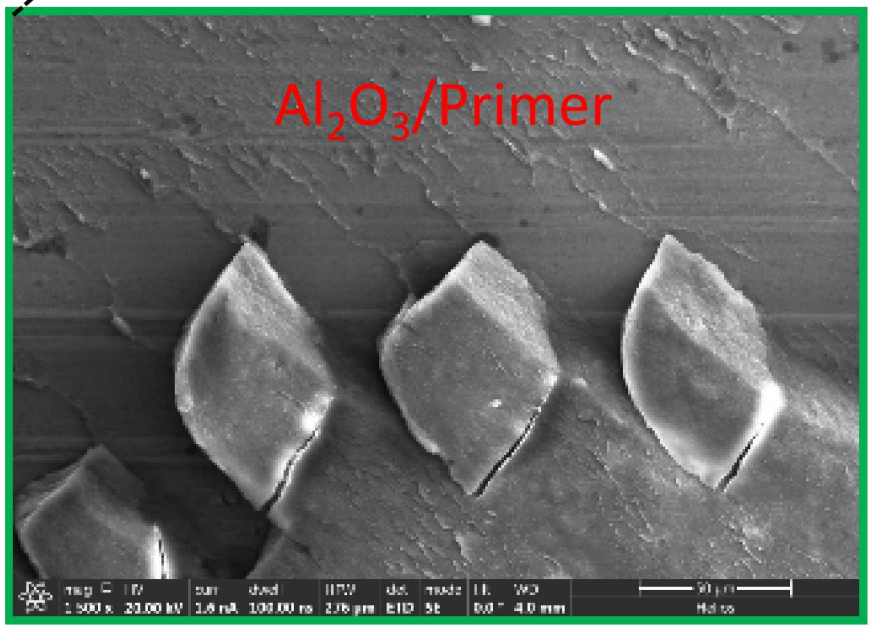
Cohesive fracture within primer at Al_2O_3 interface (left)

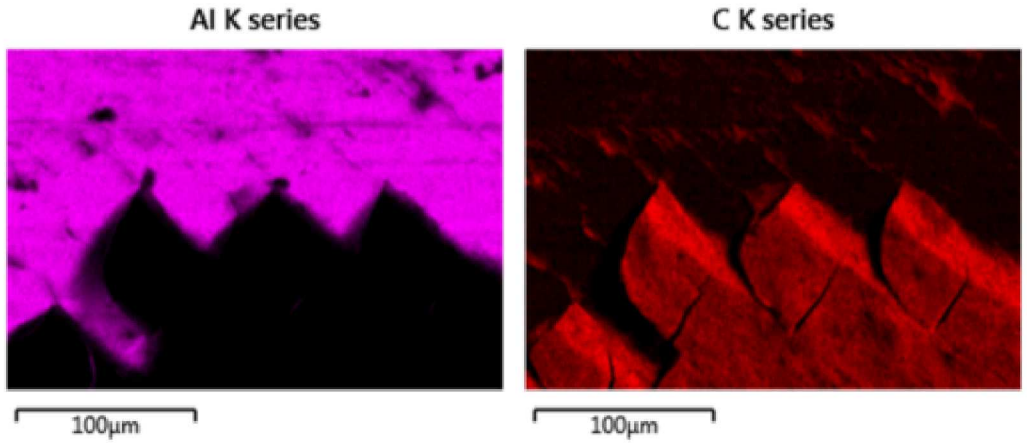
Interfacial fracture along primer to adhesive (right)

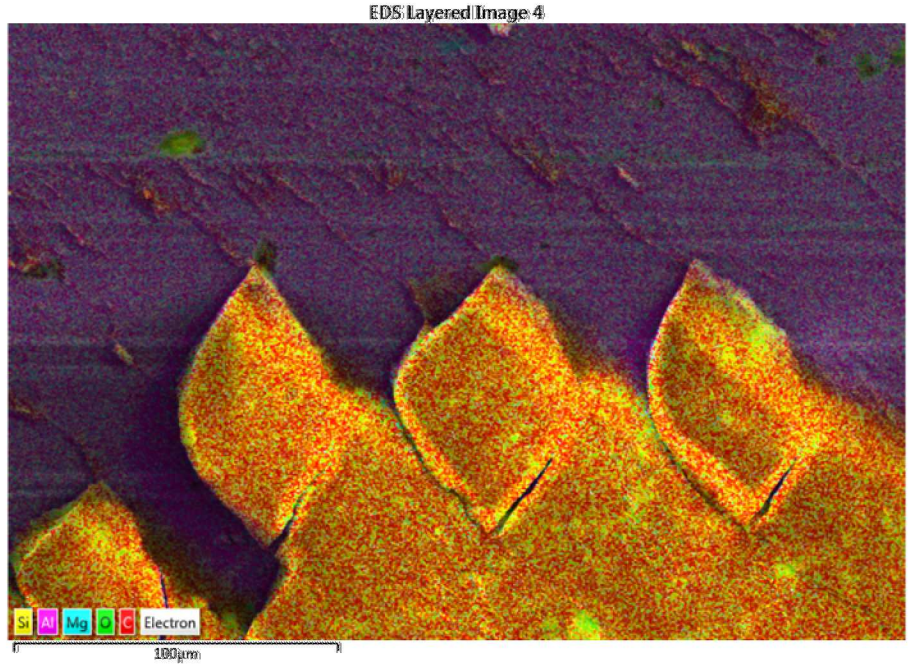


Aluminum/Primer Failure









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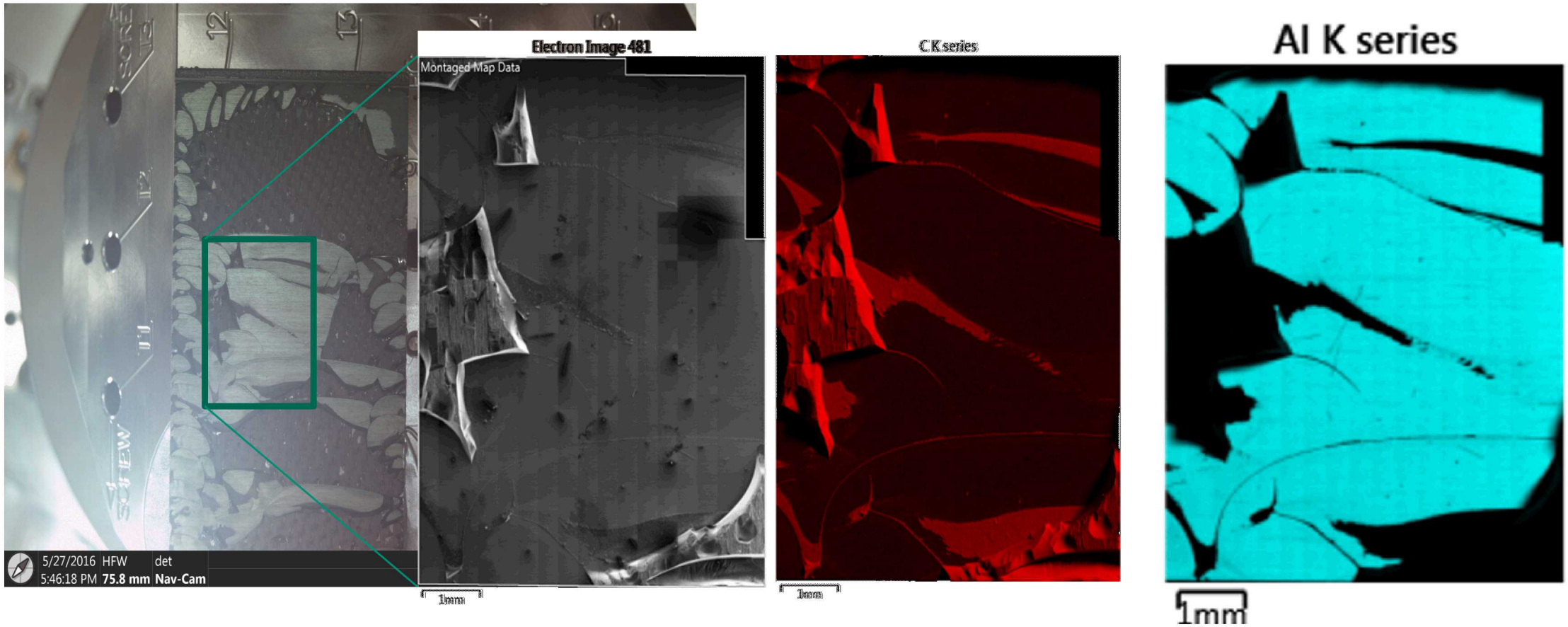

Summary

- Hysol 2000 primer provides adequate bond strength
- Primer/oxide failure for secondary bond at cold temp
  - Potentially due to CTE mismatch
  - Toughness results show higher strength than room or high temp
- Cobonded specimens
  - Adherend failure
  - Bonded joint is not the weak link
- Future work
  - Glass fiber-matrix interface appears to be weak link
  - Fiber sizing
  - Matrix-fiber compatibility
  - Composite surface preparation
    - Plasma cleaning
    - Laser ablation