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Composite Erosion Protection Films

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Ryan Marx | October 2014

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Outline:

Erosion of aircraft components

Types of erosion protection

Co-curable Erosion Films (CEFs)

- Rain erosion resistance
- Grit erosion resistance
- Flow characteristics
  - Rheological characterization
  - Flow during cure
- Peel adhesion to epoxy film adhesive

Erosion of Aircraft Components

- 2 Main types of erosion damage
  - Solid particle erosion (sand, dust, or grit)
  - Rain erosion
  - Fiber reinforced polymeric composites are especially susceptible to erosion damage
    - Impacts cause the matrix resin to crack and debond at fiber interfaces, causing rapid degradation
- Erosion damage to aircraft parts can affect aerodynamics and lead to increased maintenance costs, increased aircraft downtime, and a negative impact on the airworthiness of the aircraft

Types of Erosion Protection

Metallic systems (titanium, nickel, aluminum)

Polymeric systems

- Paints
- Sprayable polyurethane coatings
- Polyurethane Tapes

	Rain Erosion Resistance	Grit Erosion Resistance	Impact Resistance	Weight Consistency	Density	Repairability	Temperature Resistance	UV Resistance	Application / Cure time	Application to complex curvatures	Upfront Cost	Corrosion	VOCs / HAPs	Tapered trailing edge
Metallic systems	+++	+	+++	+++	---	---	+++	+++	+	+	---	-	+++	-
Paints	---	---	---	-	+++	+	+++	+	---	+++	+++	+++	--	+++
Sprayable polyurethane coatings	+	+	+	--	+++	+	++	-	---	+++	++	+++	---	+++
Polyurethane tapes	+	++	+	+++	+++	++	-	++	++	-	++	+++	+++	-
Co-curable Erosion Films	++	++	+	+++	+++	++	++	++	+	-	++	+++	+++	+

Key

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Worst → Best

Co-curable Erosion Films (CEFs)

What are CEFs?

- Erosion resistant polyurethane films with processing temperatures up to 400 °F and service temperatures up to 250 °F
- Able to be co-cured with composite parts or post bonded with structural adhesives (built-in erosion protection)
- Unique flow characteristics
  - Film can be stacked to increase thickness
  - Seams self seal
  - Surface texture exactly matches the tool or caul sheet
  - Does not “melt” and flow like a thermoplastic polyurethane in the 120°C – 180°C range

Advantages over conventional erosion protection systems

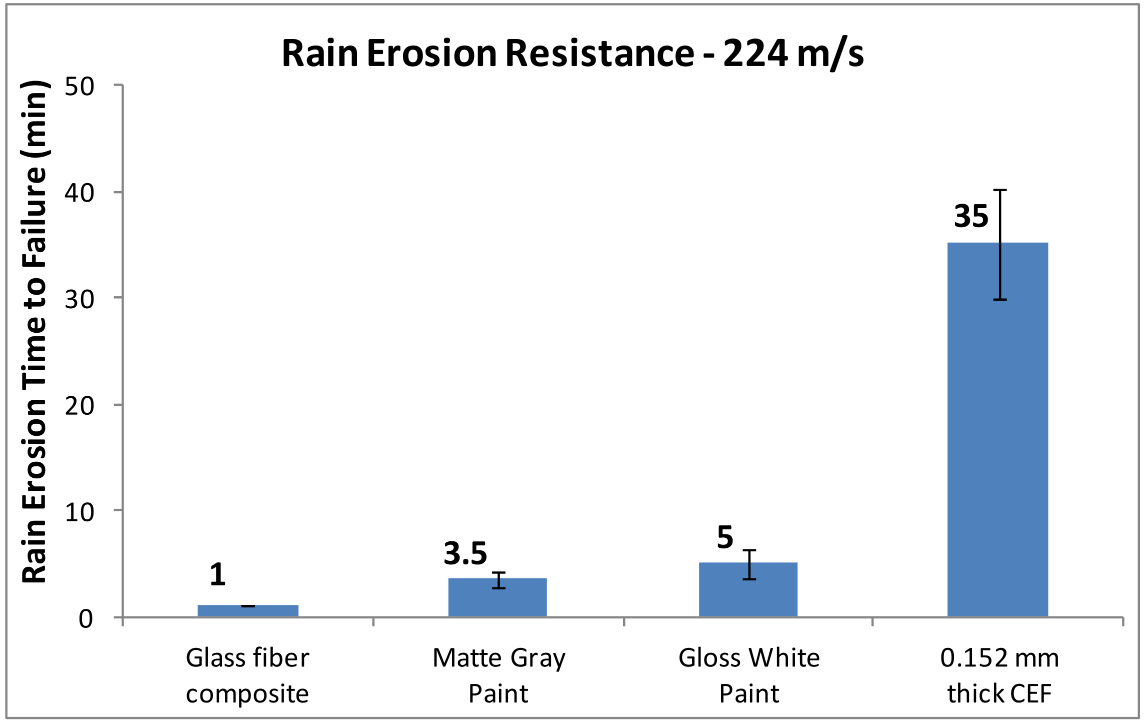
- Relative to metal
  - Lower density, more easily repairable, & decreased cost
- Relative to paint and sprayable urethanes
  - Improved erosion and impact resistance, more consistent thickness and weight, reduced cure time, free of VOCs & HAPs
- Relative to urethane tapes
  - Improved rain erosion resistance, increased temperature capability, increased adhesion

Rain Erosion Resistance

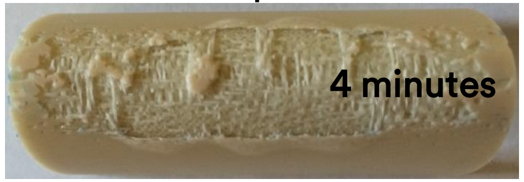
Glass fiber composite airfoils begin eroding within the first minute of testing

Paint provides minimal protection from rain erosion

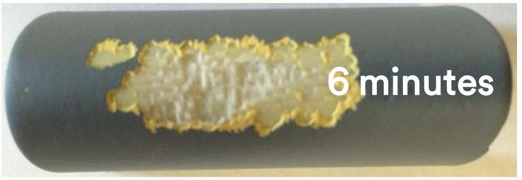
Co-curable erosion film provides about 7x – 10x improvement in rain erosion resistance relative to paint for a comparable thickness



Glass fiber composite



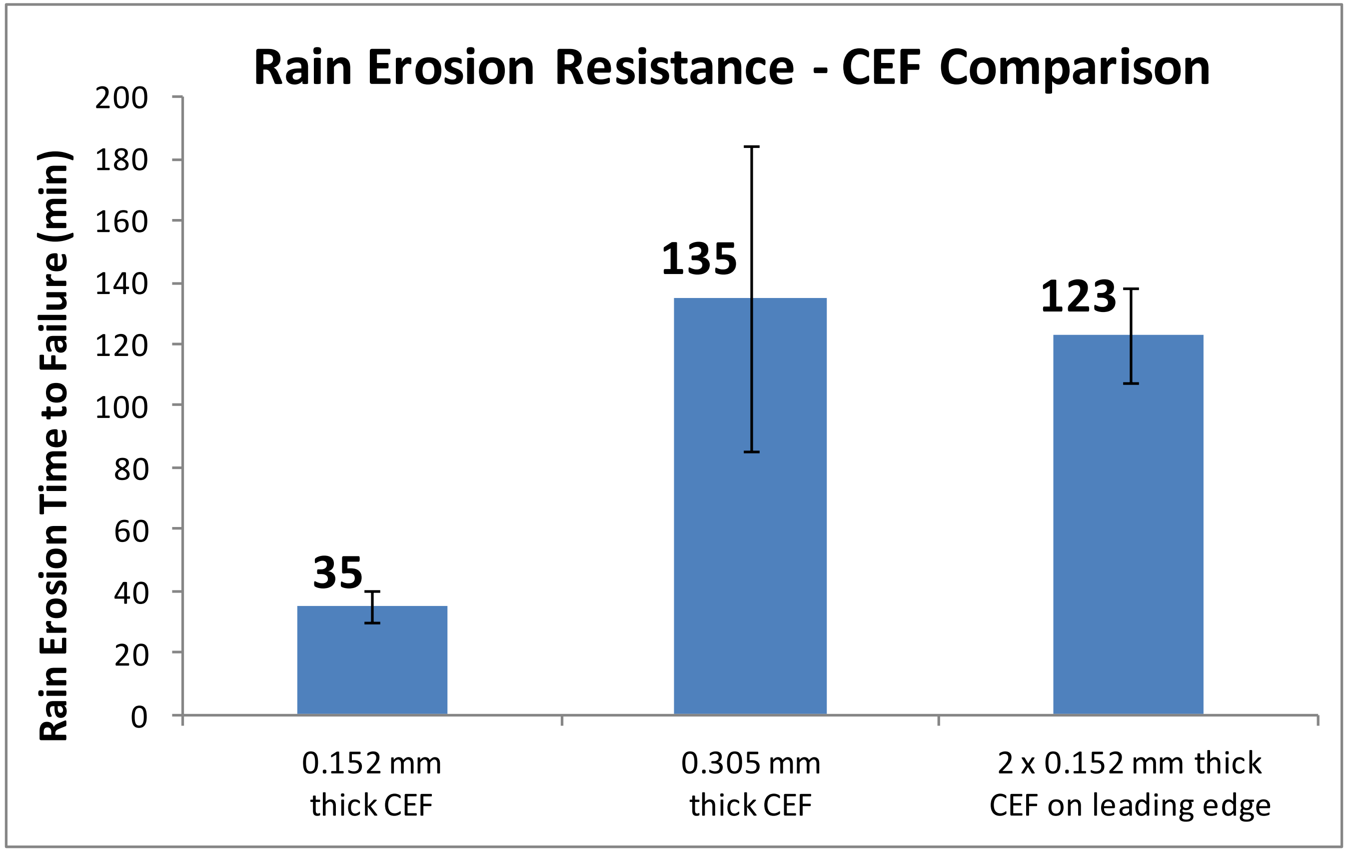
Paint



CEF

Procedure:
Samples tested via whirling arm testing at the University of Dayton Research Institute Rain Erosion Test Facility located at Wright Patterson Air Force Base in Dayton, Ohio. Testing was conducted at 224 m/s, 2.54 cm per hour rain fall, with approximately 2 mm diameter rain drops. The composite and paint data are based on a sample size of 2, while the CEF data are based on a sample size of 8. The CEF samples were made by co-curing the CEF with the glass fiber composite airfoil.

Rain Erosion Resistance



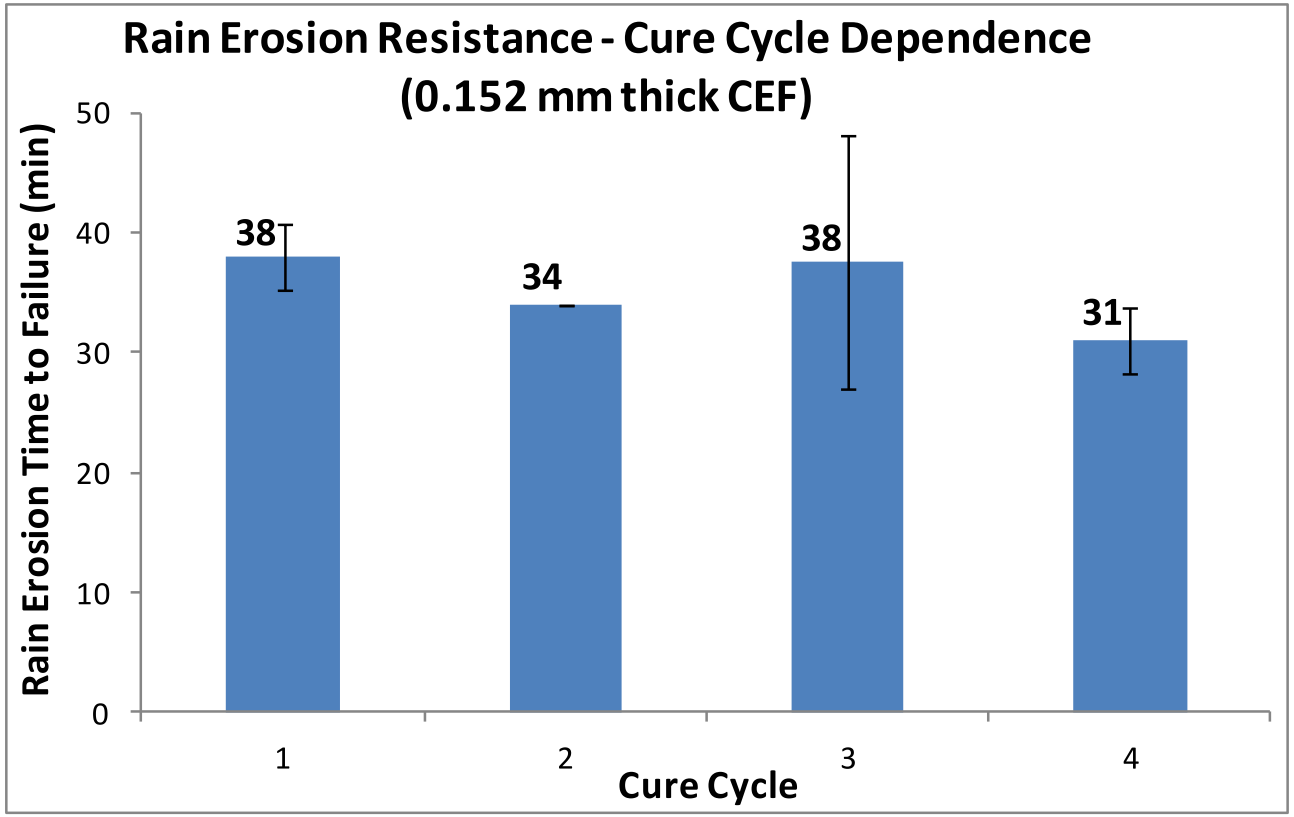
Doubling the thickness of the CEF (0.305 mm vs 0.152 mm) results in ~4x improvement in rain erosion resistance (135 min vs 35 min)

- Performance enhancement is also achieved by stacking 2 layers of 0.152 mm thick CEF directly on the leading edge (overall coating weight increase was 27%)

Procedure:
Samples tested via whirling arm testing at the University of Dayton Research Institute Rain Erosion Test Facility. Testing was conducted at 224 m/s, 2.54 cm per hour rain fall, with approximately 2 mm diameter rain drops. The data are based on a sample size of 2. All samples were produced by co-curing the CEF with the glass fiber composite airfoil.

Rain Erosion Resistance

Rain erosion resistance of the co-curable erosion films is independent of cure cycle

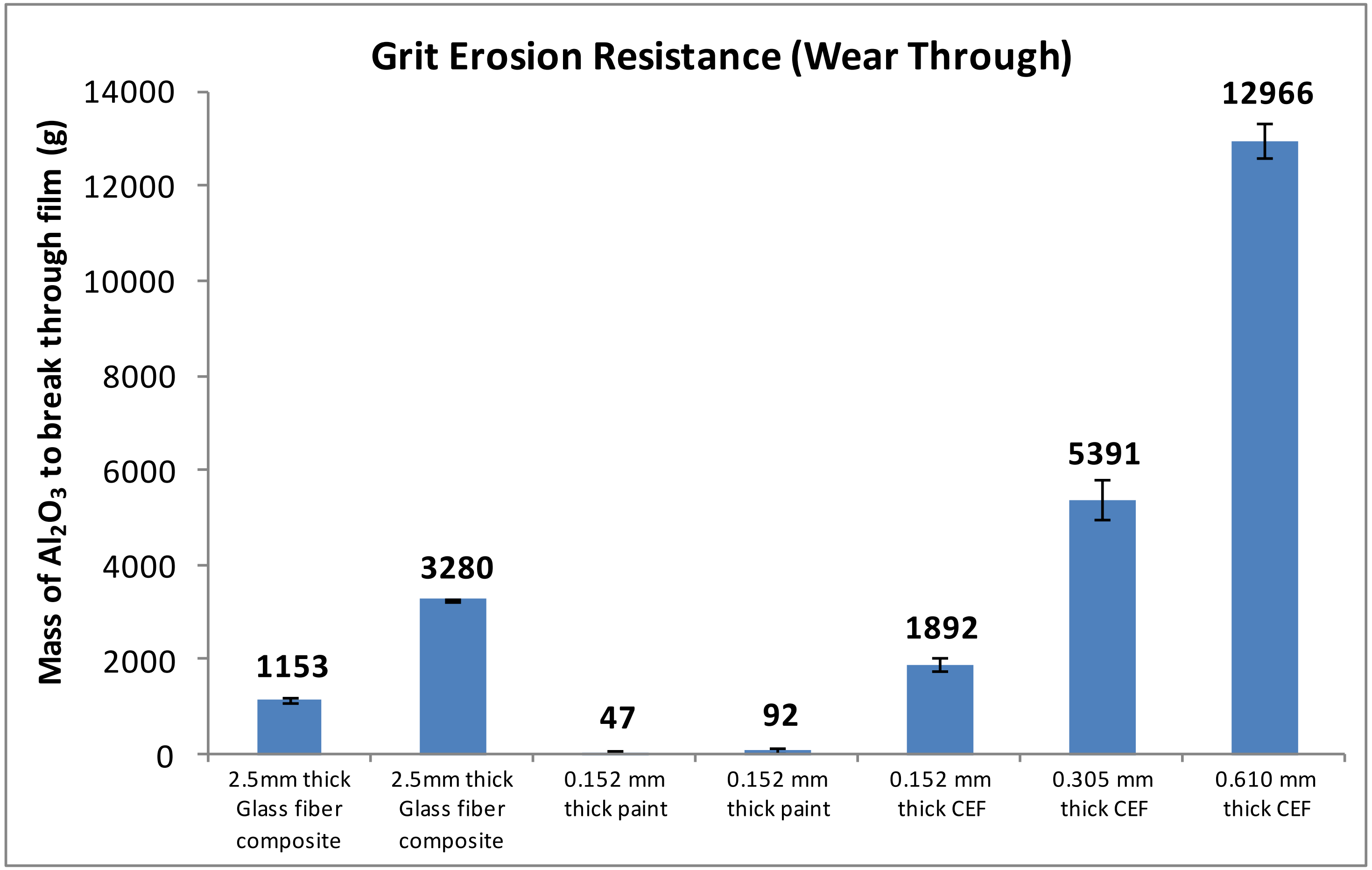


Cure Cycles

1) Vacuum pressure of 91.4 kPa with a 2.8 °C/min ramp to 82 °C, hold for 60 minutes, then a 2.8 °C/min ramp to 121 °C with a hold for an additional 2 hours
2) 0.31 MPa pressure with a 2.8 °C /min ramp to 121 °C and hold for 2 hours
3) 0.62 MPa pressure with a 2.8 °C /min ramp to 121 °C and hold for 2 hours
4) 0.62 MPa pressure with a 2.8 °C /min ramp to 177 °C and hold for 2 hours

Procedure:
Samples tested via whirling arm testing at the University of Dayton Research Institute Rain Erosion Test Facility located at Wright Patterson Air Force Base in Dayton, Ohio. Testing was conducted at 224 m/s, 2.54 cm per hour rain fall, with approximately 2 mm diameter rain drops. The data are based on a sample size of 2. All samples were produced by co-curing the CEF with the glass fiber composite airfoil.

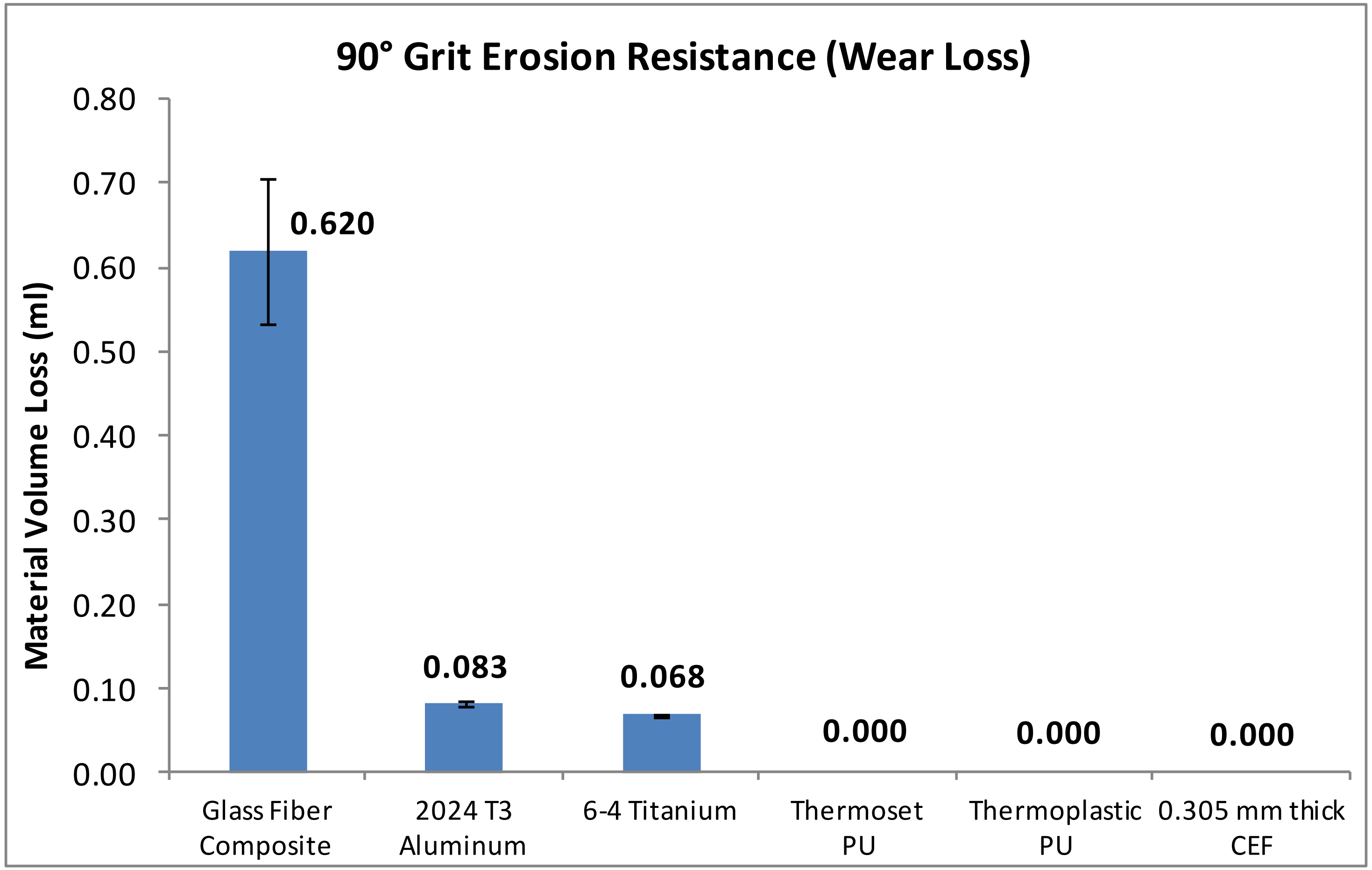
Grit Erosion Resistance



Co-curable erosion films provide a much higher level of resistance to grit erosion (90° and 30°) than glass fiber epoxy composite or paint

Procedure:
Samples tested in a modified grit blaster at 70 psi, 3 inch distance, using 46 grit Al_2O_3. 90° erosion data is not provided for the CEFs because the effect was minimal.

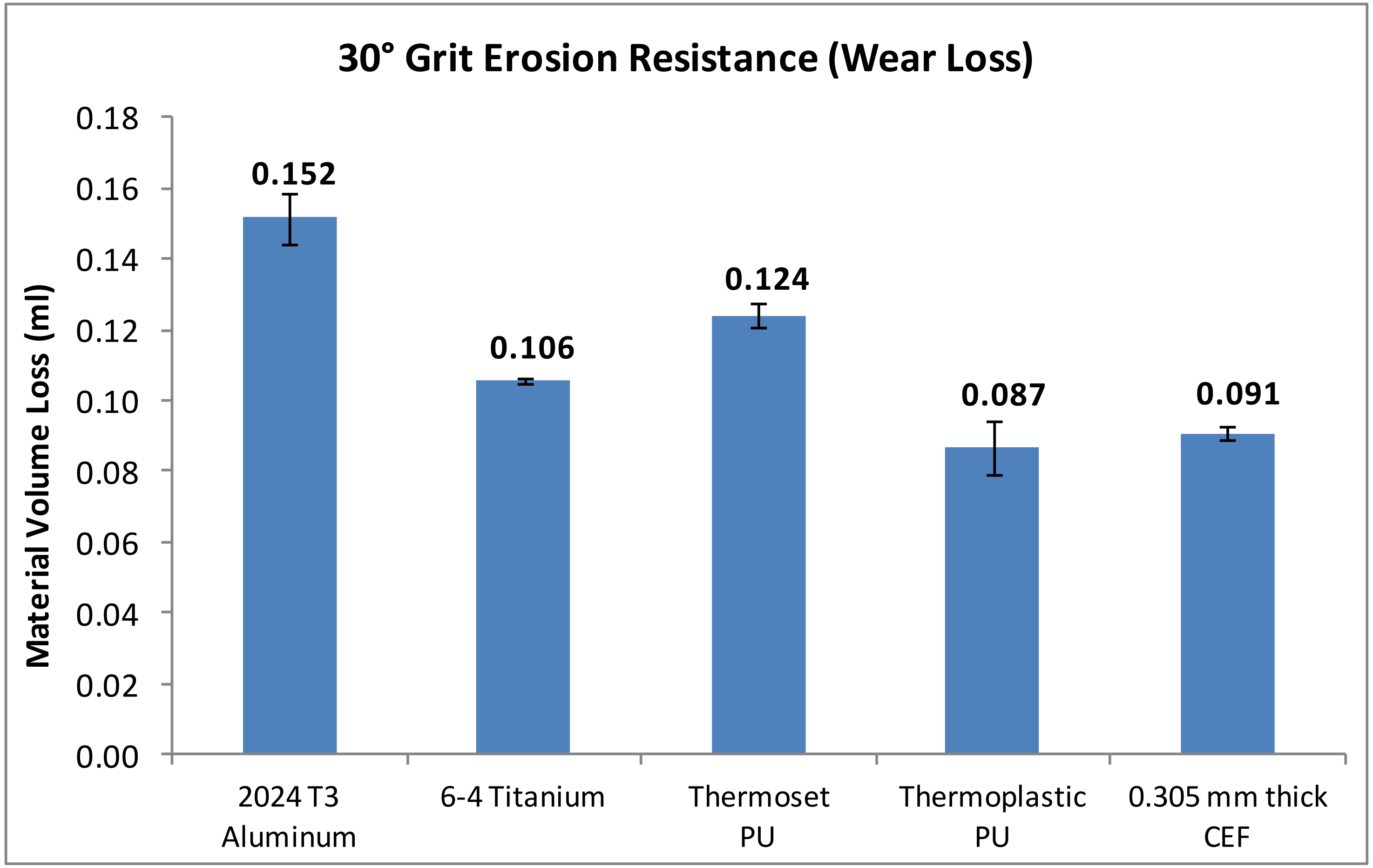
Grit Erosion Resistance



Co-curable erosion films show minimal to no erosion loss at a 90° angle

Procedure:
Samples tested in a modified grit blaster at 70 psi, 3 inch distance, using 4 kg of 46 grit Al_2O_3. The mass loss was measured and converted to a volume loss with known specific gravities.

Grit Erosion Resistance

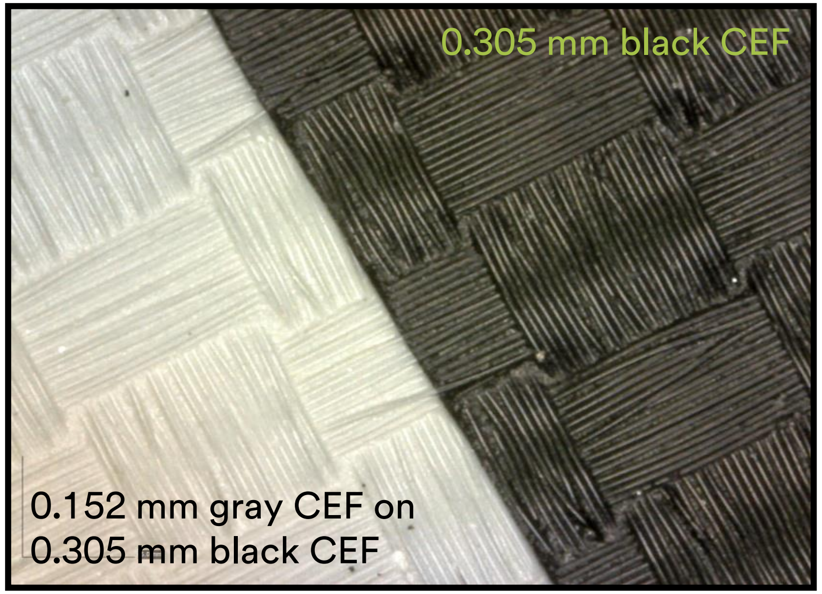


At a 30° angle, the CEF shows similar erosion resistance as a thermoplastic polyurethane and better than aluminum, titanium, or a thermoset polyurethane

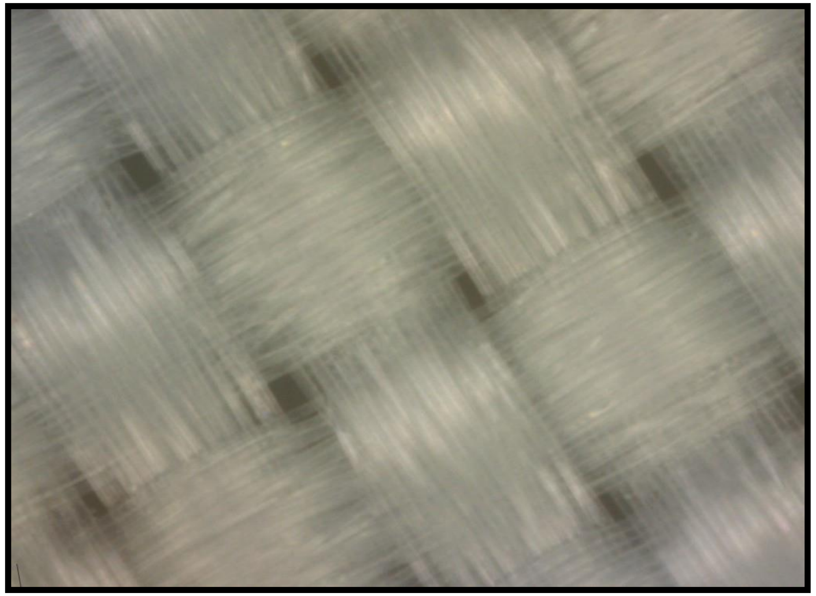
Procedure:
Samples tested in a modified grit blaster at 70 psi, 3 inch distance, using 4 kg of 46 grit Al_2O_3. The mass loss was measured and converted to a volume loss with known specific gravities.

Flow Characteristics

Co-curable erosion films exhibit enough flow during a cure to effectively take on the surface texture of the tool or caul sheet and have seamless transitions, yet boundary fidelity is maintained



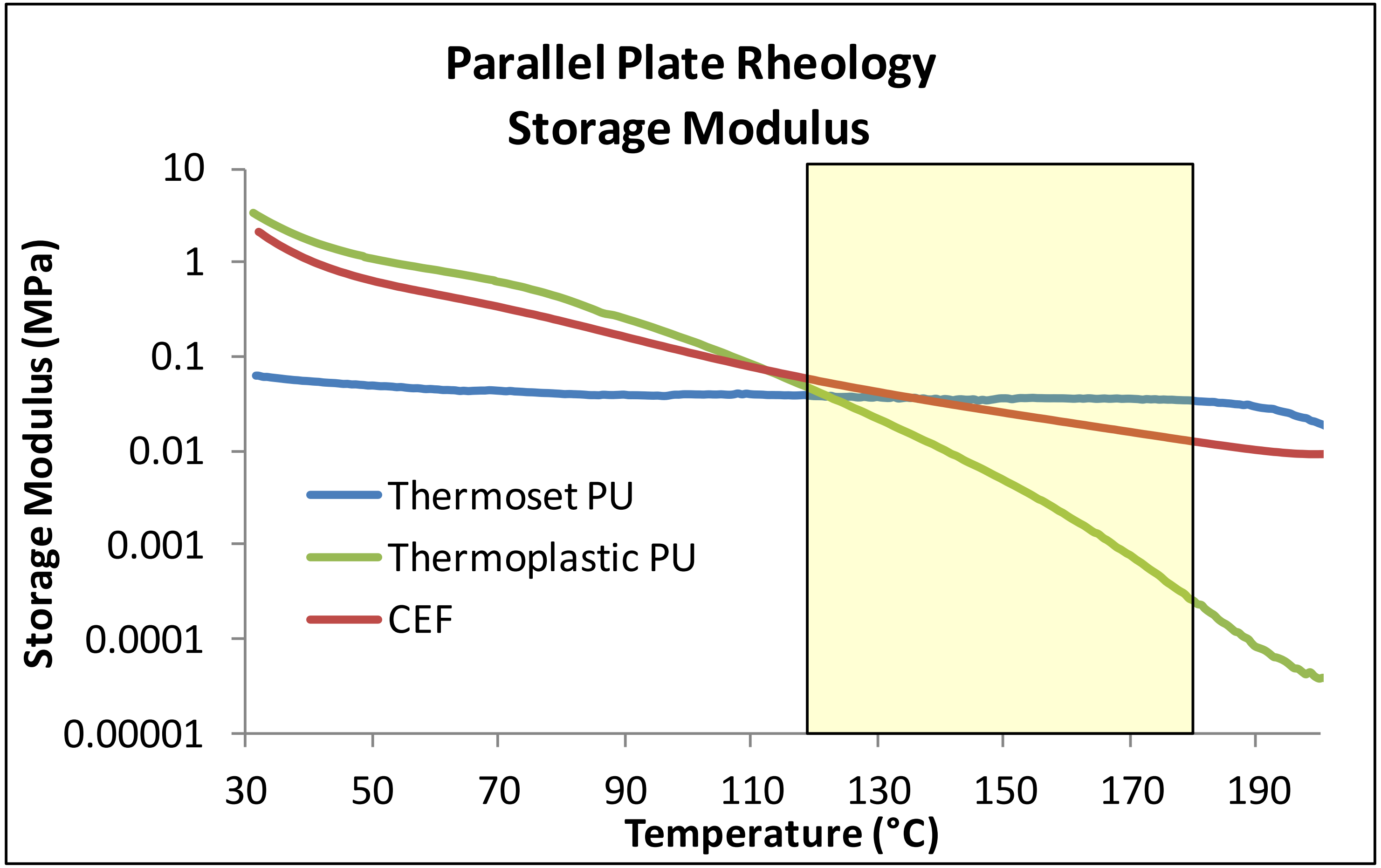
CEFs bonded to composite panel with 121 °C cure cycle with nylon peel ply on surface that was removed after cure



Nylon Peel Ply

Gray 0.152 mm 3M CEF co-cured on 0.305 mm black CEF with carbon fiber composite at 177 °C cure

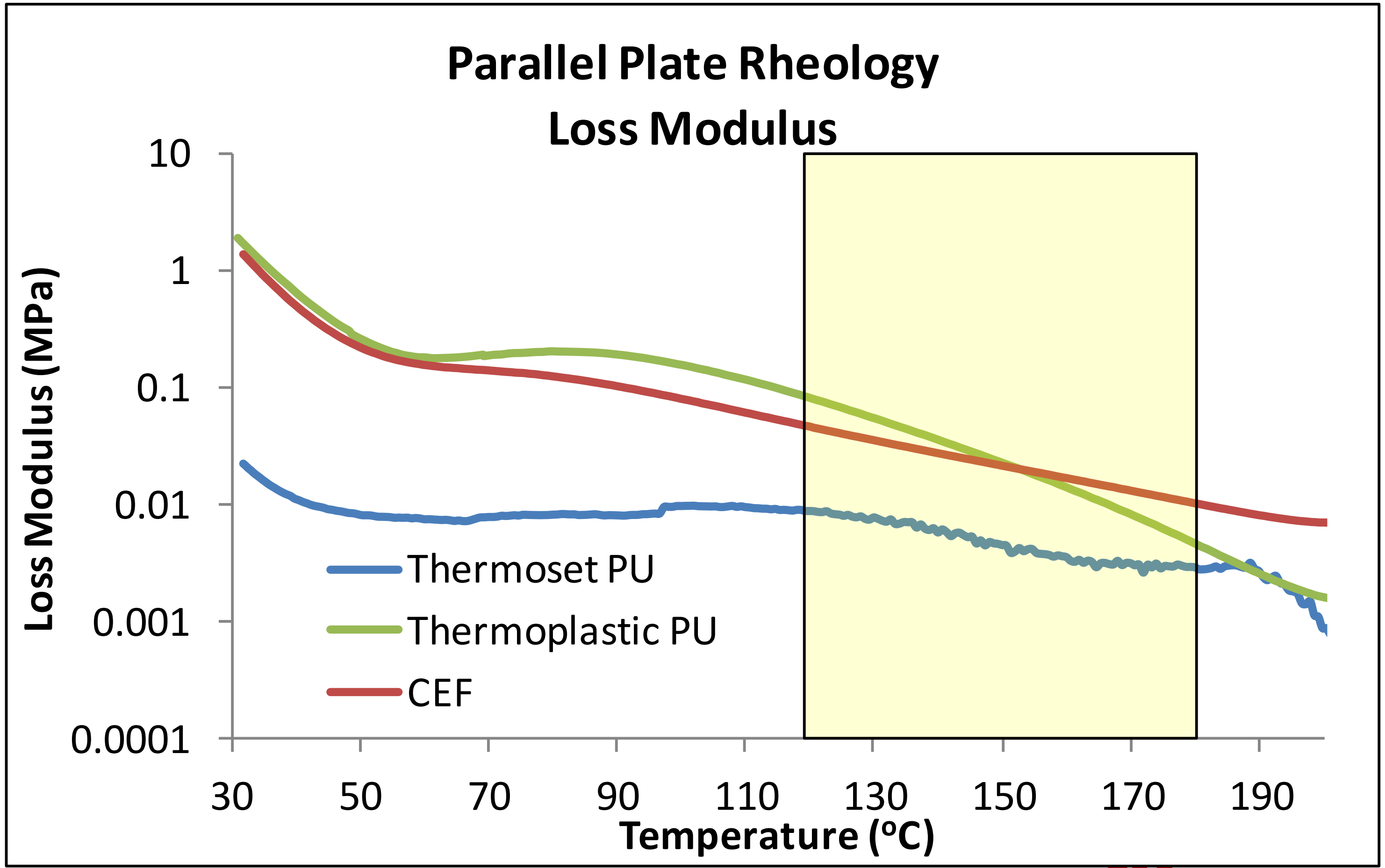
Rheological Characterization



- The thermoplastic PU and the CEF begin to differ around 110 °C as the thermoplastic PU begins to melt
- The thermoset PU and the CEF have a similar storage modulus (elastic nature) over the 120 °C to 180 °C region.

Procedure:
Parallel plate rheology was performed using an ARES G2 Rheometer from TA Instruments. The rheology was measured with a frequency of 1 Hz and a strain of 2.0%. The samples were heated to 205 °C and then cooled at a rate of 2 °C per minute to 30 °C while taking measurements.

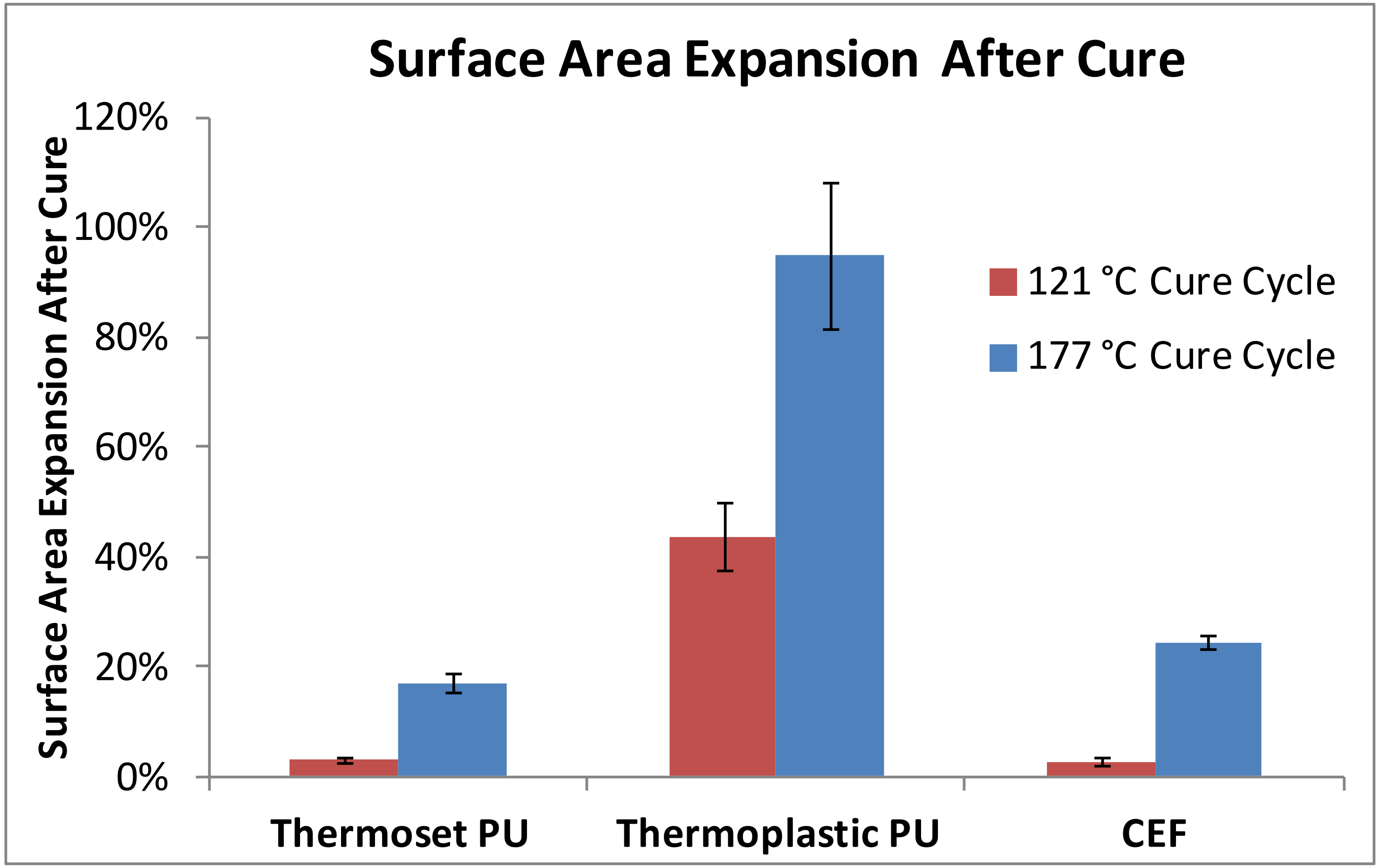
Rheological Characterization



- The thermoset PU displays a lower loss modulus than either the CEF or thermoplastic PU over the 120 °C to 180 °C range.
- The thermoplastic PU and the CEF display a similar loss modulus (viscous nature) over the 120 °C to 180 °C range.

Procedure:
Parallel plate rheology was performed using an ARES G2 Rheometer from TA Instruments. The rheology was measured with a frequency of 1 Hz and a strain of 2.0%. The samples were heated to 205 °C and then cooled at a rate of 2 °C per minute to 30 °C while taking measurements.

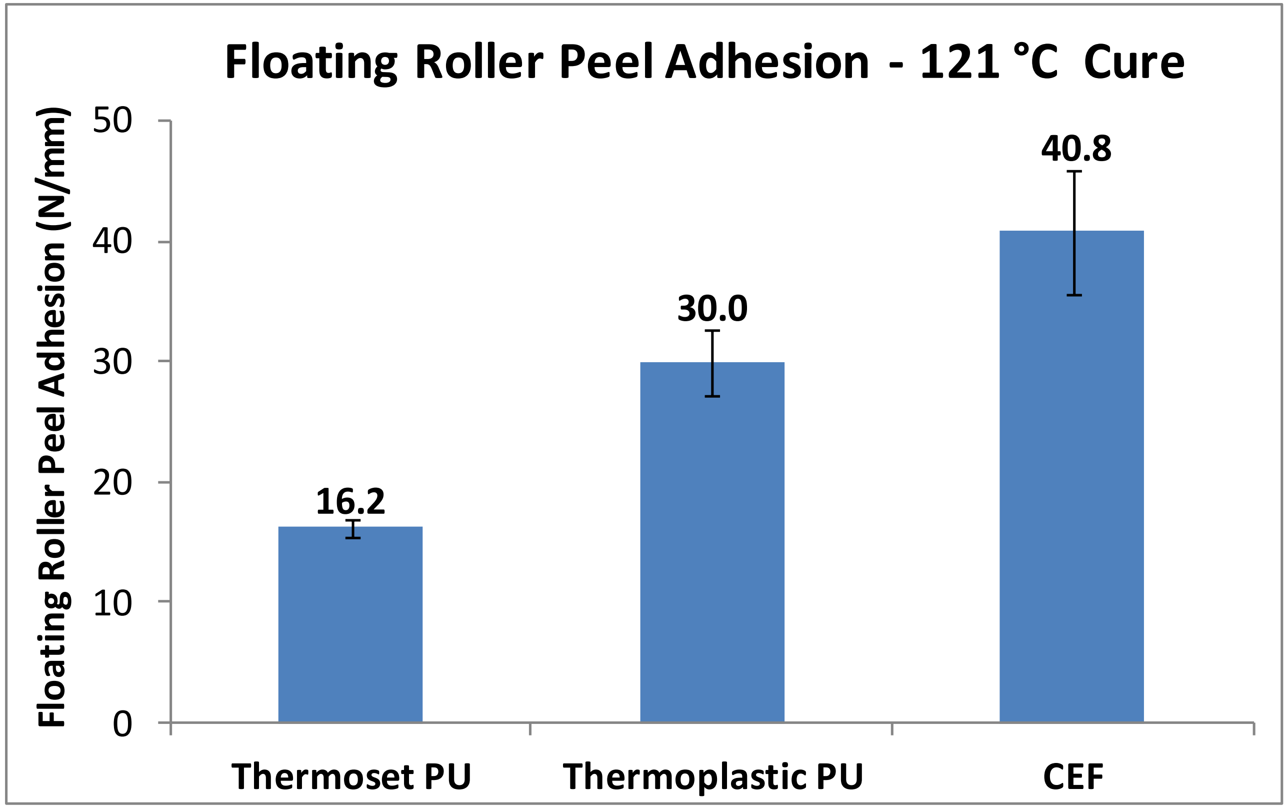
Surface Area Expansion



- The thermoplastic PU melts exhibiting a high surface area expansion
- Thermoset PU and CEF exhibit similar flow at both temperatures with the CEF flowing slightly more at 177 °C

Procedure:
Three samples of each polyurethane film were cut into 7.6 cm x 6.4 cm rectangles. The film samples were placed between two aluminum plates with a release liner on each side of the film and subjected to a cure. The heat and pressure from the cure cycle forced the films to expand during the cure. The surface area of the films after the cure was measured and compared to the initial surface area to determine the expansion.

Peel Adhesion



- Thermoset PU and thermoplastic PU failed adhesively at urethane/adhesive interface
- CEF failed cohesively in urethane layer
- Thermoplastic PU melted and flowed out of bond

Flexible Adherend - 2024 T3 Aluminum (0.508 mm thick)
Adhesive Primer (0.002 mm thick)
Epoxy Film Adhesive (0.146 kg/m²)
Polyurethane (0.305 mm thick)
Epoxy Film Adhesive (0.146 kg/m²)
Adhesive Primer (0.002 mm thick)
Rigid Adherend - 2024 T3 Aluminum (1.60 mm thick)

Floating roller peel layup

Procedure:
Tested per ASTM D3167-10

Conclusions

- Performance benefits of co-curable erosion films
  - Rain and grit erosion resistant
  - Lighter than metallic systems
  - More consistent weight than spray systems
  - Excellent adhesion to epoxy systems

- Process benefits of co-curable erosion films
  - Decreased cycle time by incorporating with composite part during cure
  - No VOCs or HAPs
  - Unique flow characteristics
    - More flow than thermoset polyurethanes yet less than thermoplastic polyurethanes
    - Able to mold to itself allowing thickness to be built up where needed to augment performance

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Thank you.

Please ensure products meet all applicable specifications, standards, maintenance manual requirements for the platform being worked on and validate aircraft approvals against current technical documentation.

Automotive & Aerospace Solutions Division
3M Center St. Paul, MN 55144-1000
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