The Effect of Surface Treatment on The Degradation of Composite Adhesives

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The Effect of Surface Treatment on The Degradation of Composite Adhesives

- Motivation and Key Issues

  - Commercial composite aircraft use surface preparations such as peel ply and abrasive techniques for bonding primary structure.

  - Critical parameters which dictate the durability of the adhesive bond are
    - Adherend surface quality
    - Pre-bond and post bond moisture effects
    - Service loads

- Objective
  - Quantify how surface preparation techniques affect the integrity of adhesive bonds.
  - Investigate test methods that may accelerate environmental degradation.

The Effect of Surface Treatment on The Degradation of Composite Adhesives

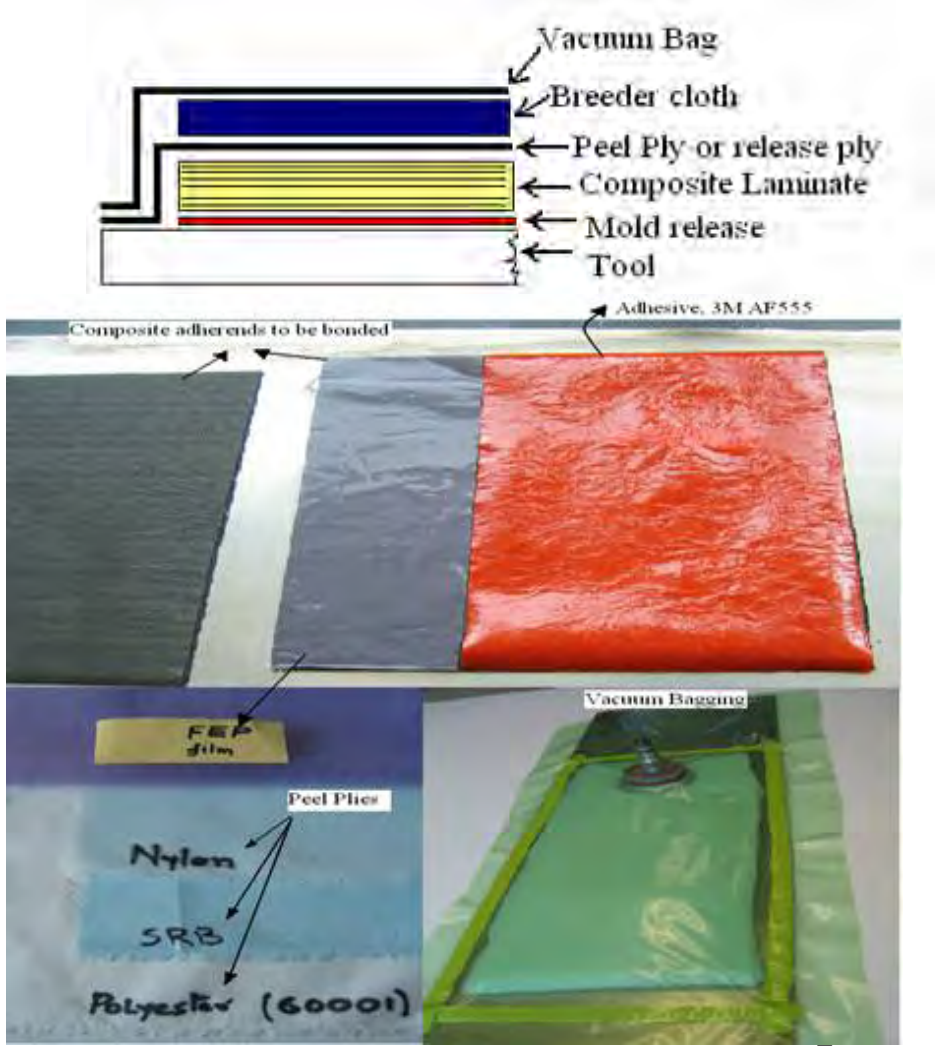
- Approach
  - Compare relative degradation in 140°F water
    - Crack growth
    - Residual strength
    - Failure mode
  - Material
    - Boeing 8-276 form 3 laminates
  - Surface preparations
    - Peel ply: Polyester (precision fabrics 60001)- fine
      Nylon (precision fabrics 52006)- medium
      Siloxane coated polyester (super release blue, SRB) - coarse
    - Sanding: Grit-220
    - Grit blasting: Grit-220 and Grit-80
  - Adhesive Type
    - 3M AF555

FAA Sponsored Project Information

- Principal Investigators & Researchers
  - Lloyd Smith
  - Prashanti Pothakamuri
- FAA Technical Monitor
  - Peter Shyprykevich
- Other FAA Personnel Involved
  - Curt Davies
- Industry Participation
  - Boeing: Peter VanVoast

Specimen Preparation

- Material Specifications
  - BMS 8-276 Form 3 (Toray) uni-tape
  - Peel ply (surface prep)
  - 3M AF555 adhesive
- Laminates autoclave cured, 350°F and 85 psi, 45 min ramp, 2 hr soak
- Coupons bonded with AF555 (3M) at 350°F
- Coupons machined to form:
  - Double cantilever beam (DCB)
  - Wide area lap shear (WLS)
  - Wedge crack (WC)

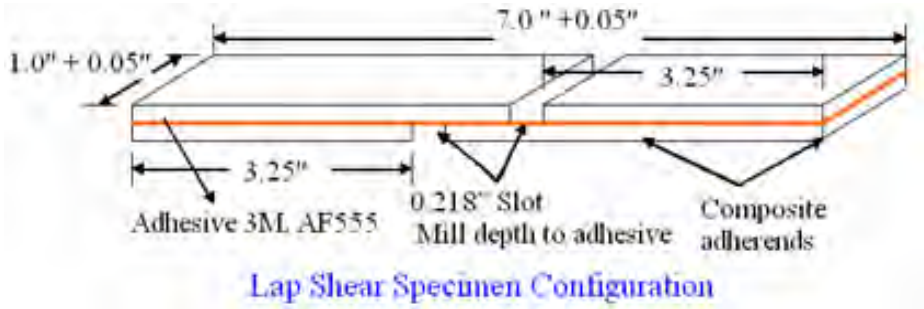


The Effect of Surface Treatment on The Degradation of Composite Adhesives

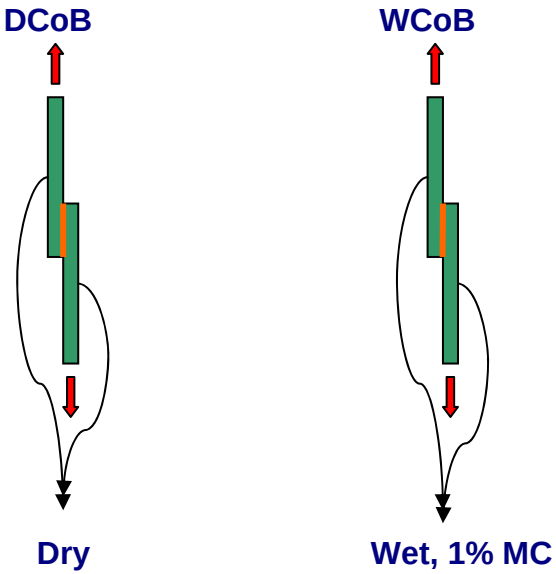
- Part I – Adherend moisture sensitivity
- Part II - Peel ply
- Part III – Abrasive techniques

Part – I Moisture Sensitivity

- Material Specifications
  - 20 unidirectional plies
  - Polyester peel ply (precision fabrics 60001)
  - Adhesive, 3M AF555
- Specimen type
  - Dry co-bonded (DCoB) adherends
  - Wet co- bonded (WCoB) adherends
    - Pre-cured adherends soaked to 1% moisture content prior to bonding uncured skin

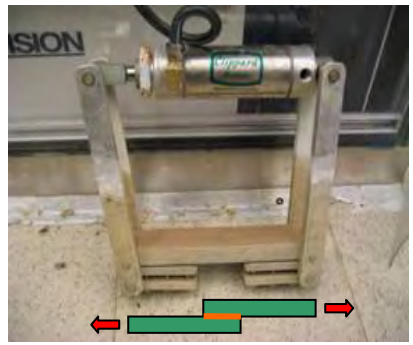


Lap Shear Specimen Configuration

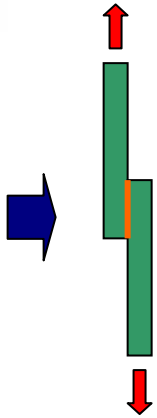


Part – I Moisture Sensitivity

- Lap Shear Tests
  - Ultimate lap shear strength (L_{ST})
  - Failure modes of the bonds
- Conditioning and loads
  - Water immersion, 140 ° F, 1k hrs
  - Load of 0, 2, 3 and 4 ksi



Creep test

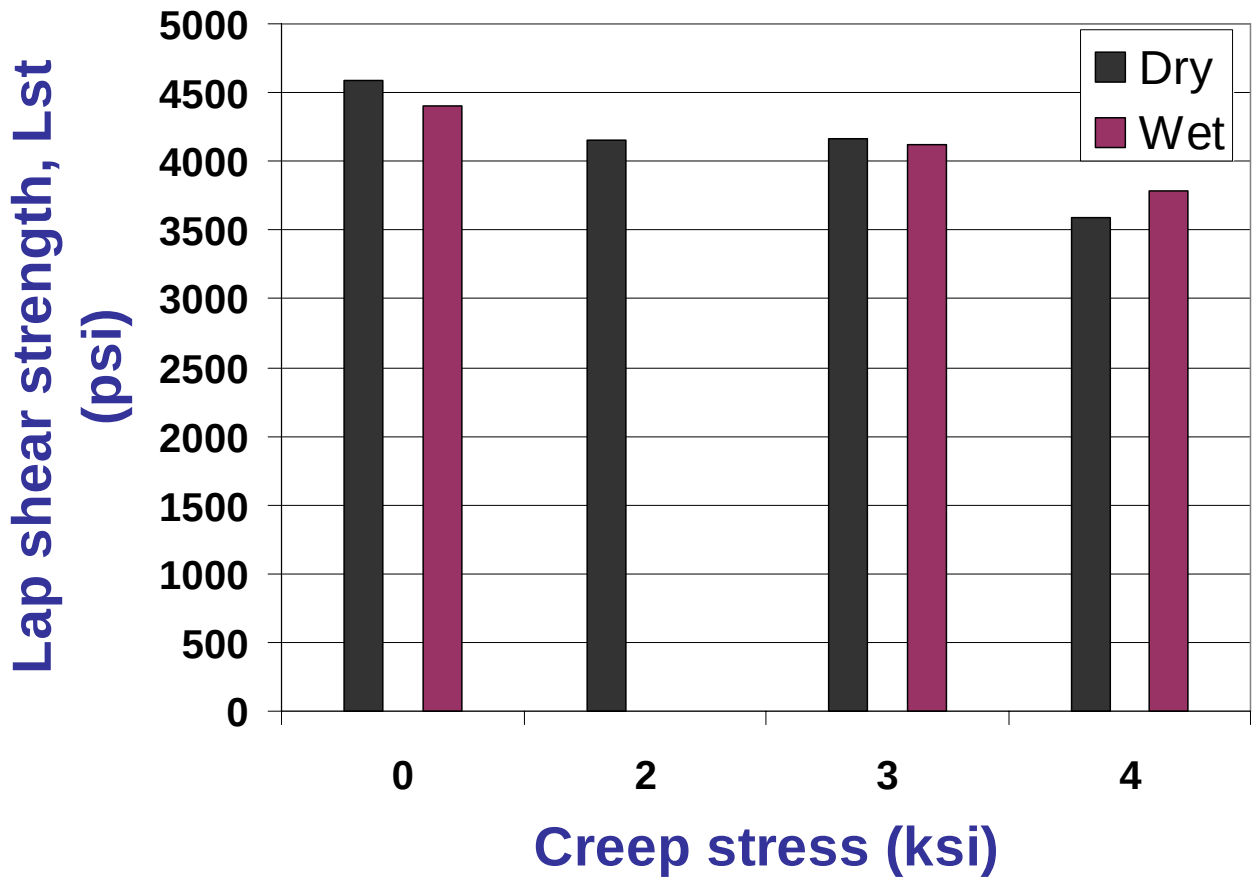


Lap Shear test

- Test matrix

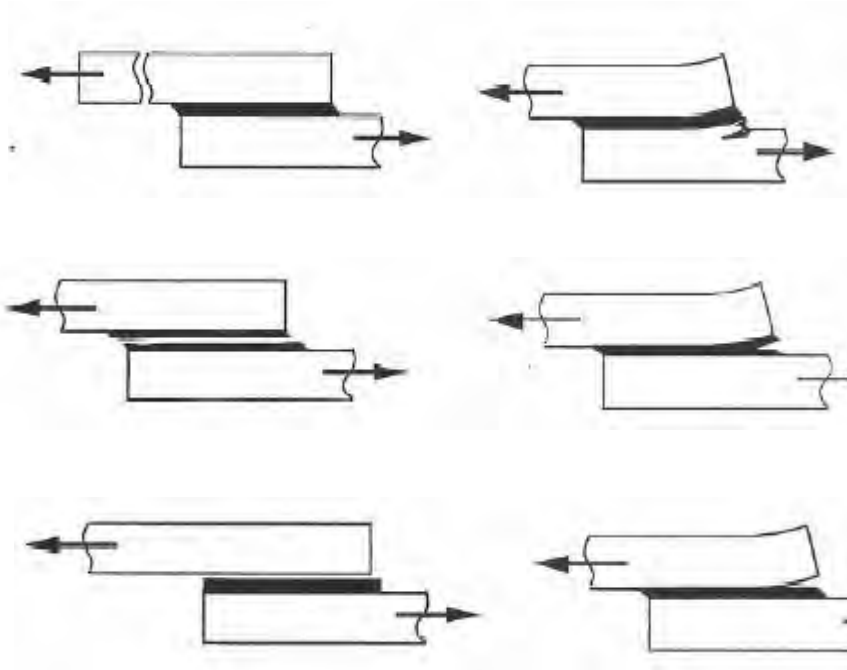
		Creep Stress		
Process	0 ksi	2 ksi	3 ksi	4 ksi
Dry (DCoB)	3 (avg. 4.6 ksi)	3	3	3
Wet (WCoB)	3 (avg. 4.4 ksi)	-	3	3

Part I-Moisture Sensitivity Results



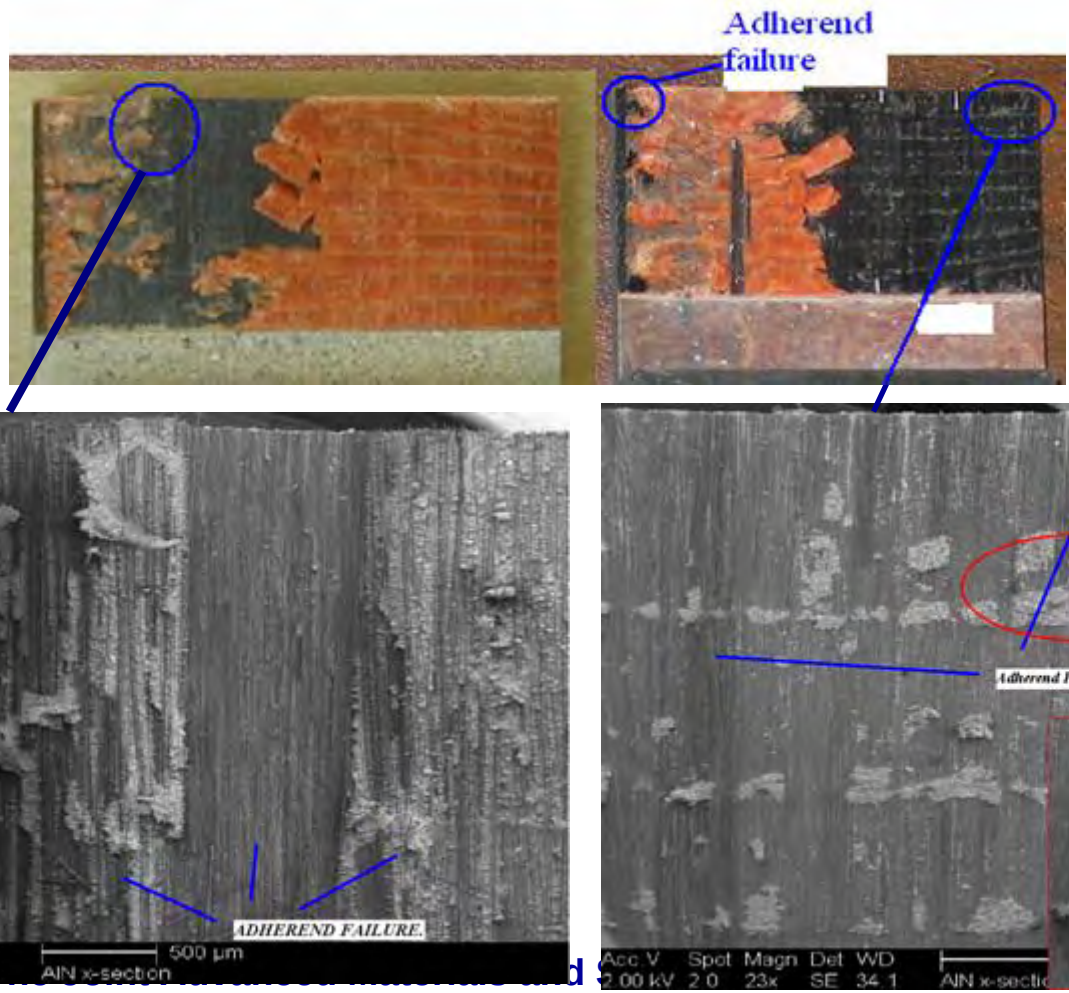
Failure modes

- Failure mode: Shear Peel
  - Adherend
  - Cohesive
  - Adhesion



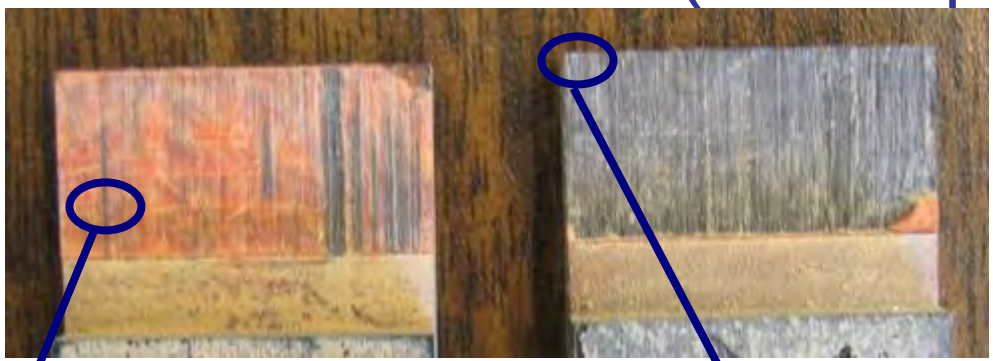
Part I- Moisture Sensitivity Results – failure modes

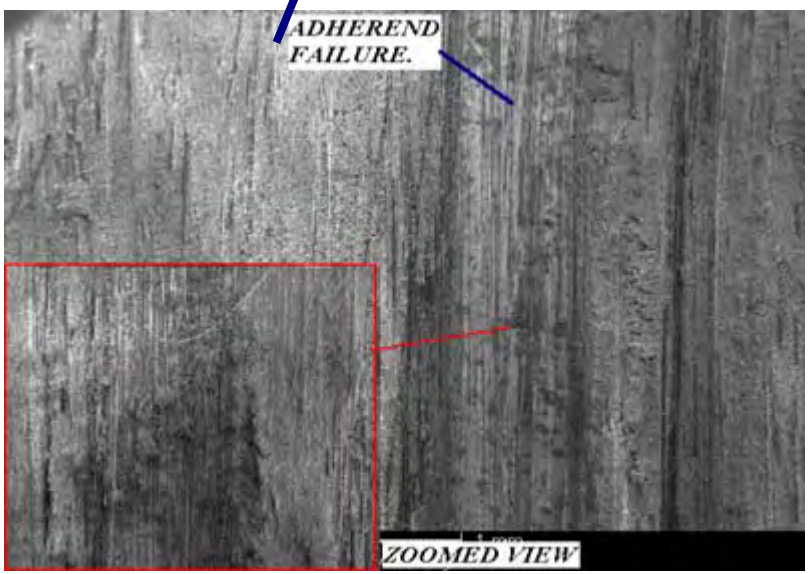
- Adherend Moisture Effects (0 ksi, dry)

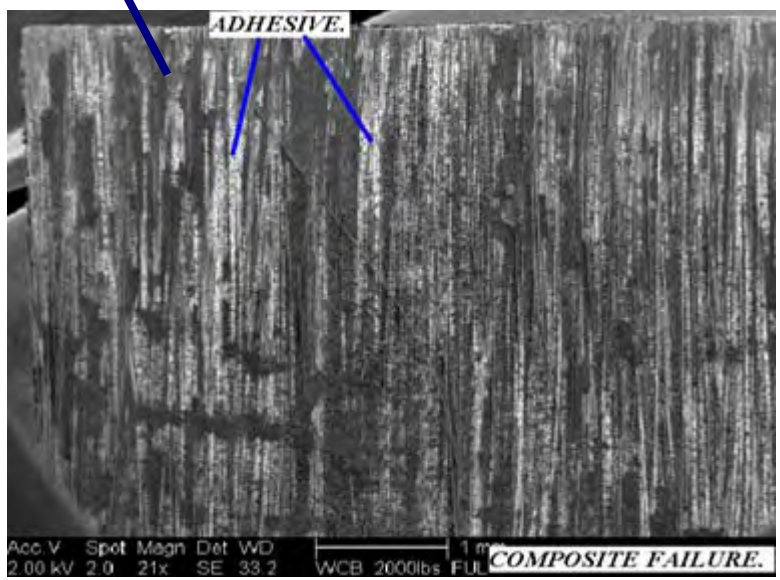


Part I – Moisture Sensitivity Results - failure modes

- Adherend Moisture Effects (4 ksi rupture, wet)

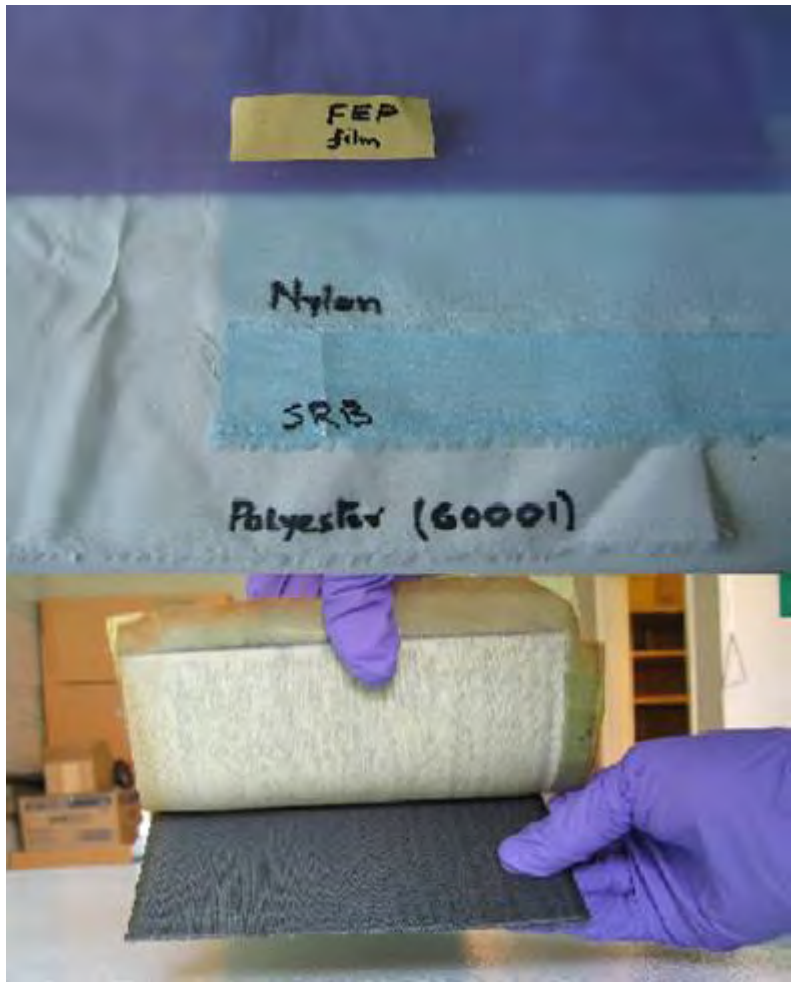






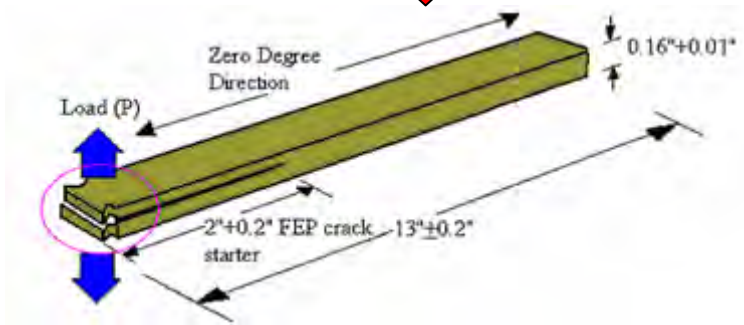
Part II – Peel Ply

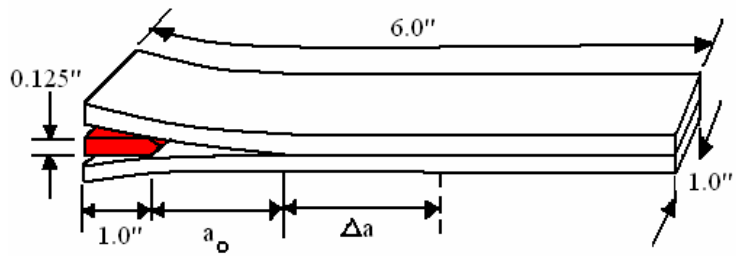
- Peel ply
  - Polyester (precision fabrics 60001)- fine
  - Nylon (precision fabrics 52006)- medium
  - Siloxane coated polyester (super release blue, SRB)- coarse



Part II – Peel ply

- Tests
  - Lap shear test (20 plies)
    - Saturate in 140°F water (6k hrs)
    - 80% UTS creep
    - Compare creep rupture duration
  - Double cantilever beam (DCB) test (10 plies)
    - Saturate in 140°F water (6k hrs)
    - Compare strain energy release rates
  - Wedge crack (WC) test (10 plies)
    - Insert wedge
    - Immerse in 140°F water
    - Compare crack growth





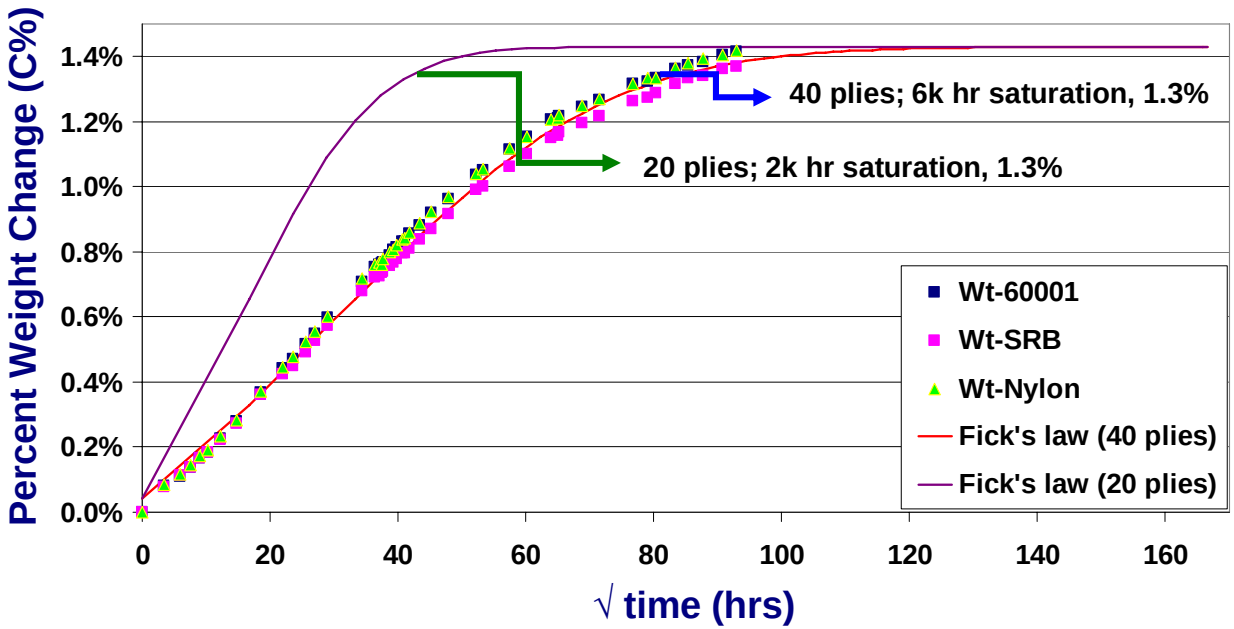
Part II – Peel ply

Test Matrix:

Coupon/peel ply	6k hr	6k hr	10k hr
WLS/60001	5	10 (80% UTS)	-
WLS/Nylon	5	10 (80% UTS)	-
WLS/SRB	5	10 (80% UTS)	-
DCB/60001	5	-	5
DCB/Nylon	5	-	5
DCB/SRB	5	-	5

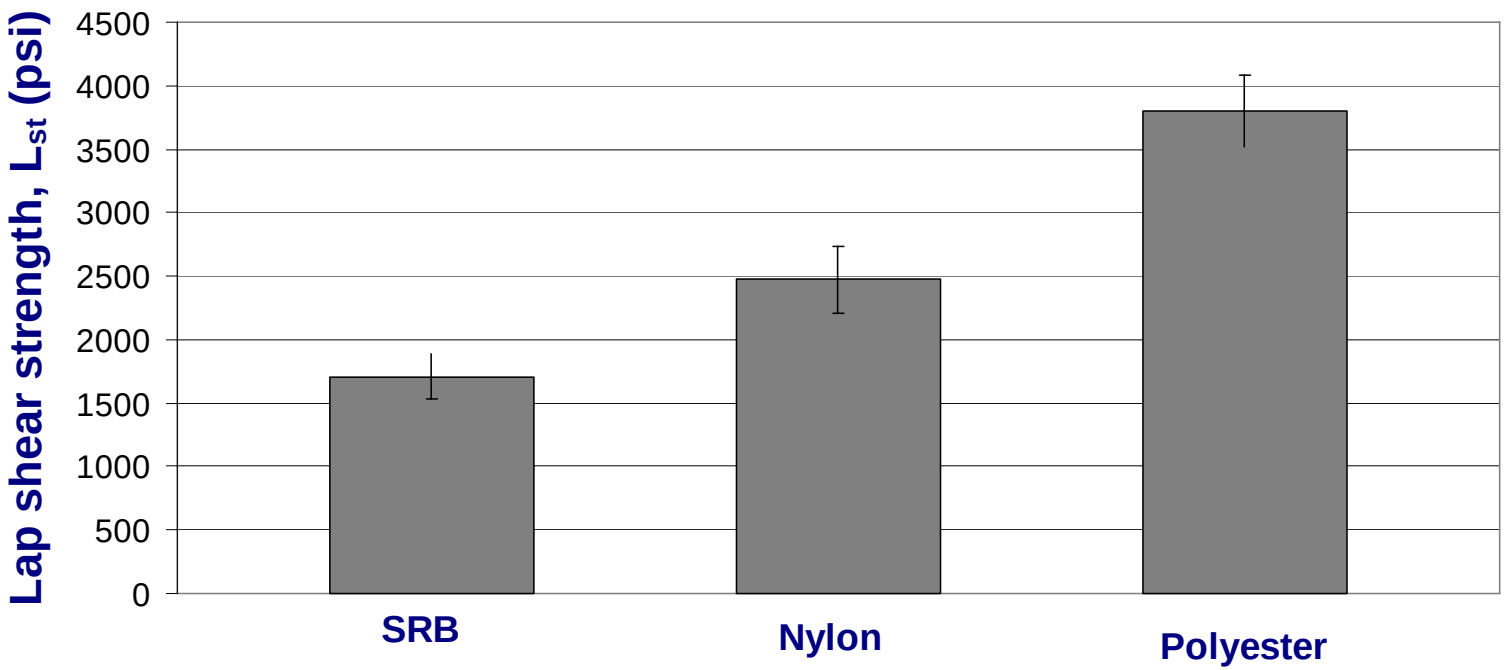
Coupon/peel ply	0 hr
WC/ SRB	5
WC/Nylon	5
WC/60001	5

Part II – Peel Ply



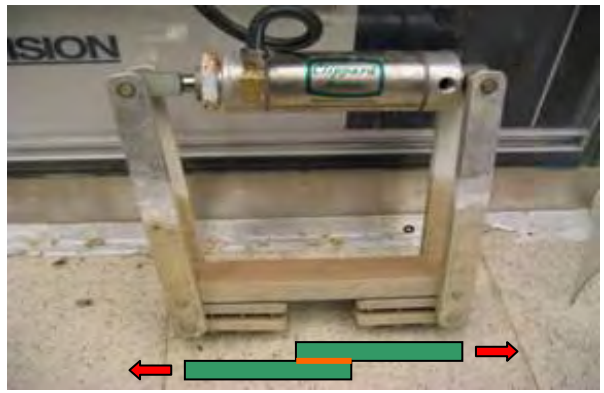
- D = 6 x 10^{-7} mm^2/s , at 140°F
- Saturation after 100 hr immersion is often assumed

Part II – Peel ply
a) Lap shear test – Baseline Results

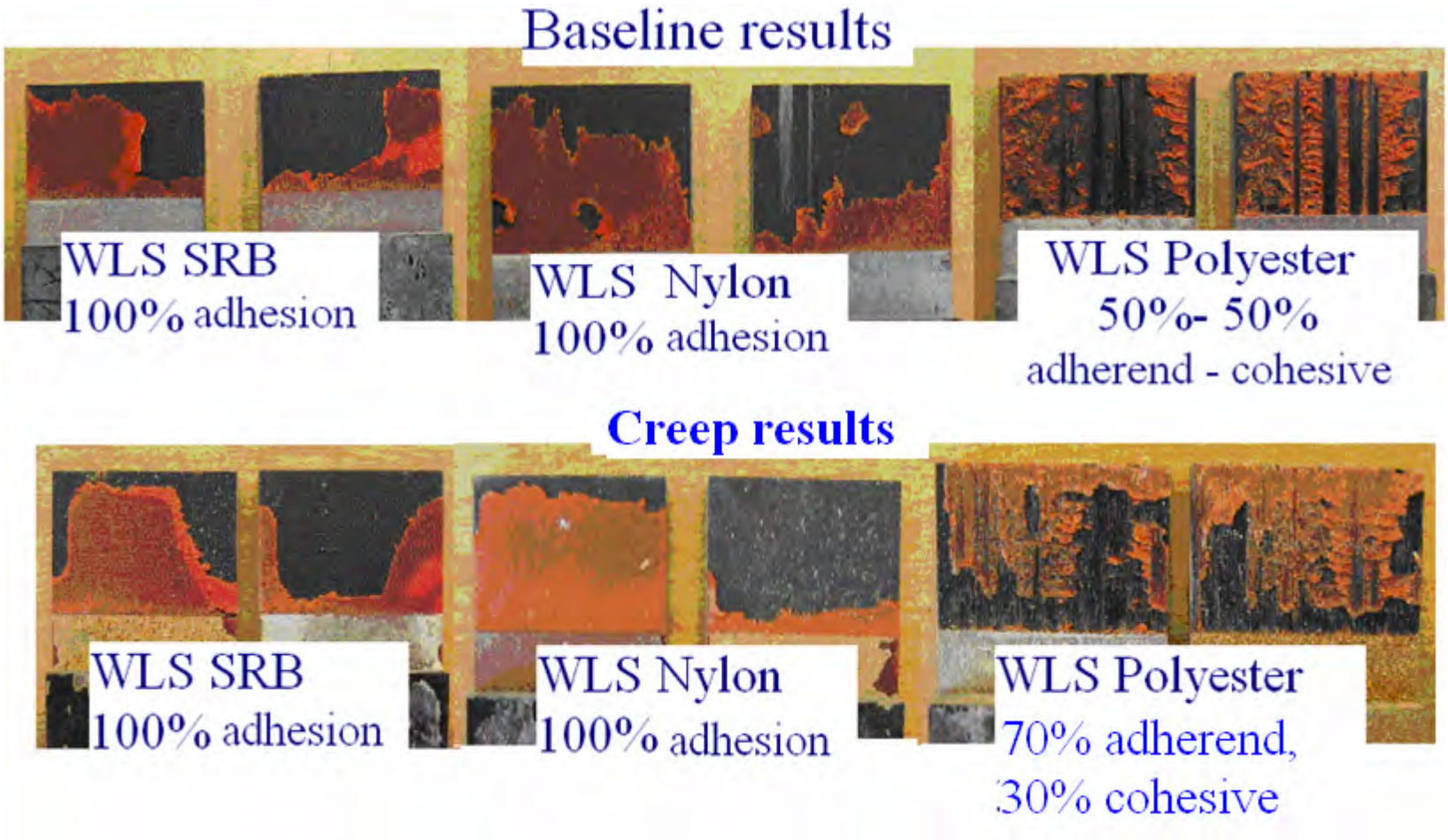


Part II – Peel ply
a) Lap shear test –Creep test

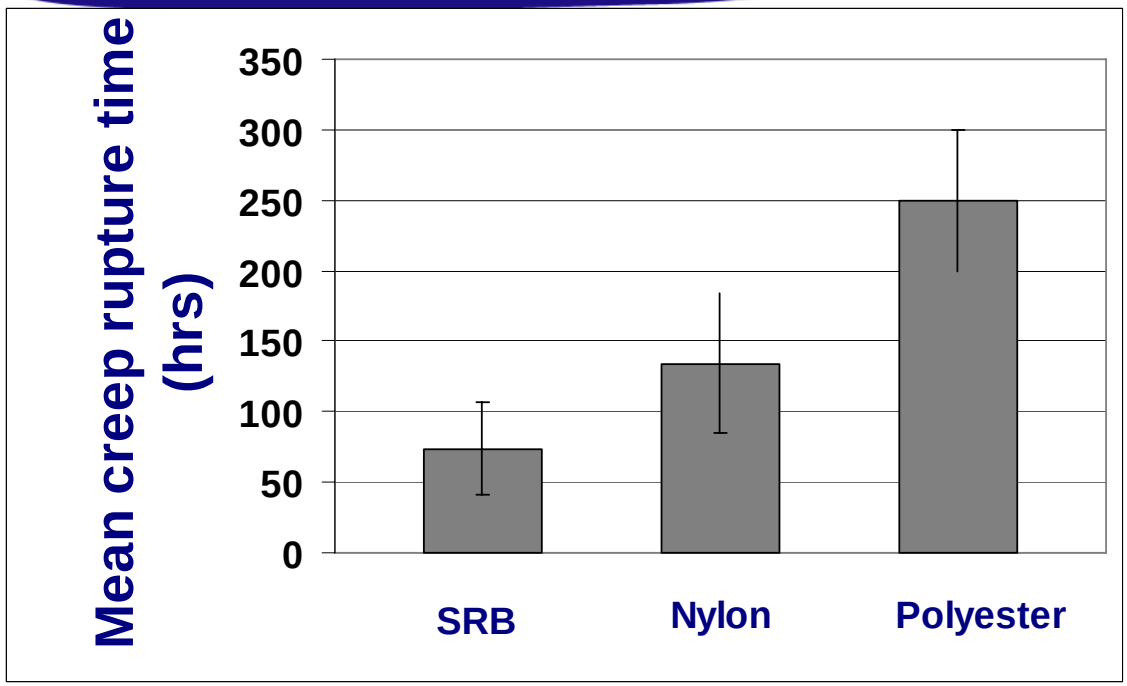
- Creep load
  - 80% of P_{max} SRB = 700 lbs
    Nylon = 1000 lbs
    Polyester = 1700 lbs



Part II – Peel ply
a) Lap shear test – Failure modes



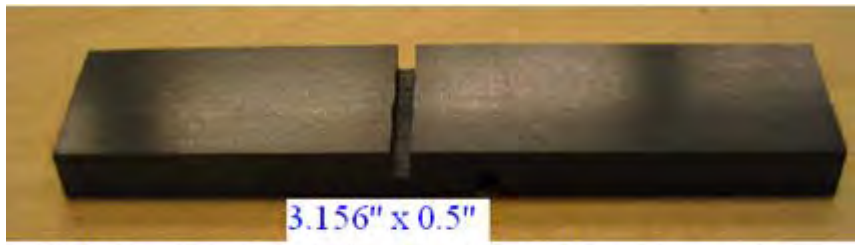
Part II – Peel ply
a) Lap shear test – Creep Results



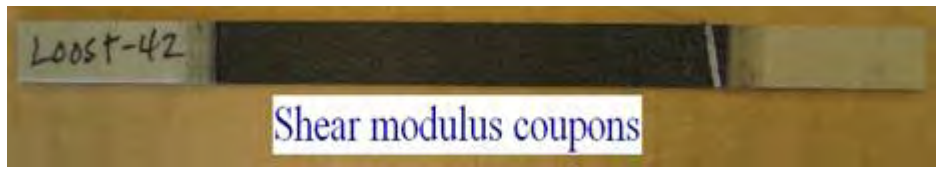
- Creep rupture duration correlated with bond quality
- Large variation typical of creep rupture
- Moisture enhanced substrate failure

Part II
Work in progress

- Study the effect of moisture on the composite substrate integrity
- Immersion in water at 160°F from 2 to ~13 weeks (1.2%)
- Compression interlaminar shear (CILS) test
- Shear modulus test

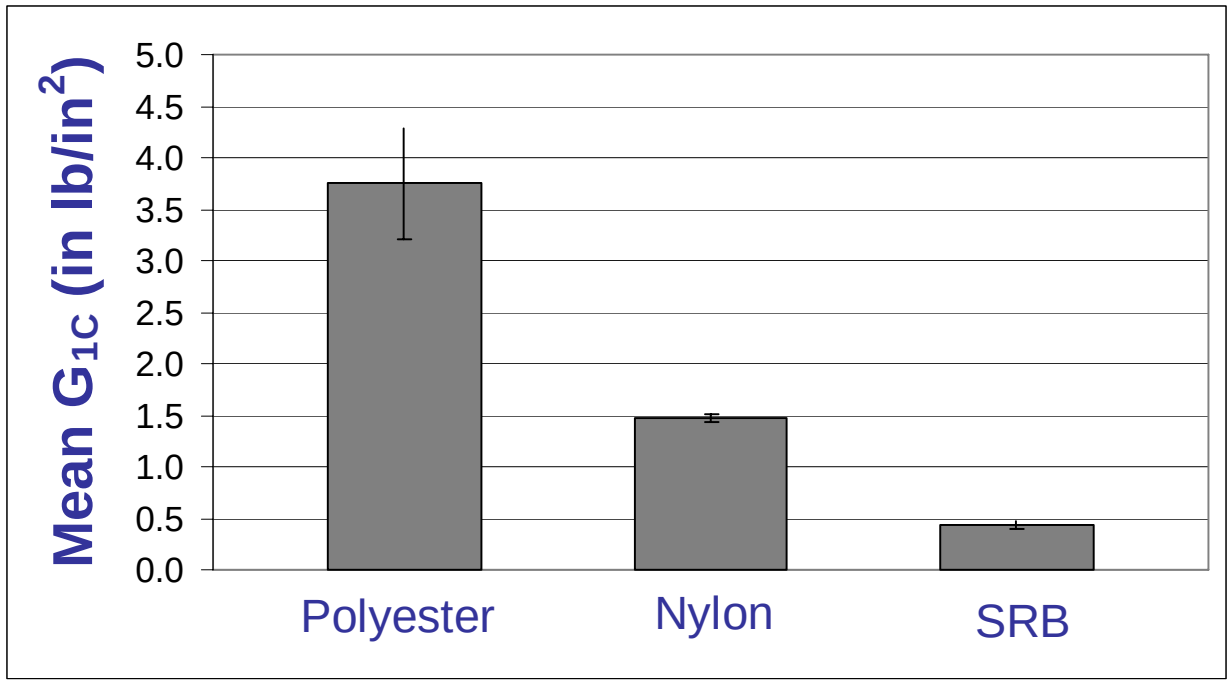


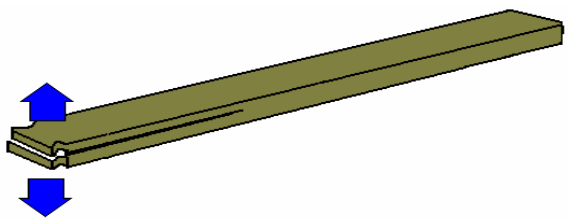
Compression interlaminar shear coupon



Shear modulus coupons

Part II – Peel ply
b) DCB baseline test results

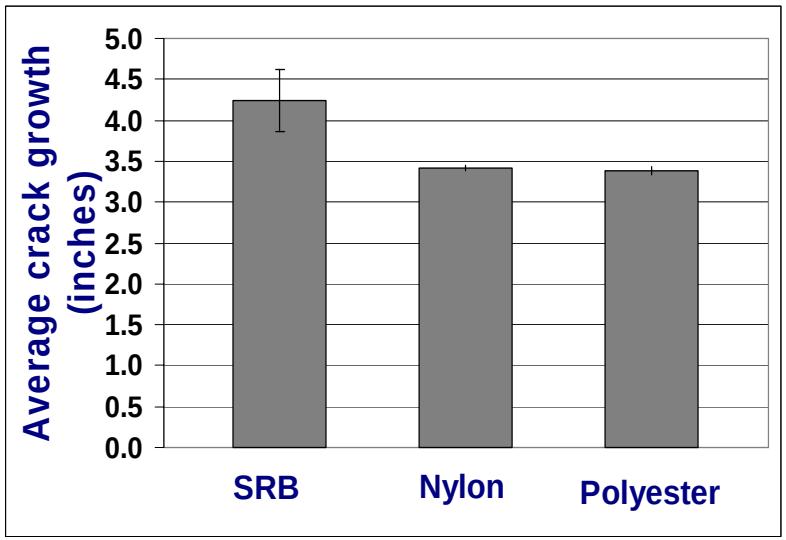




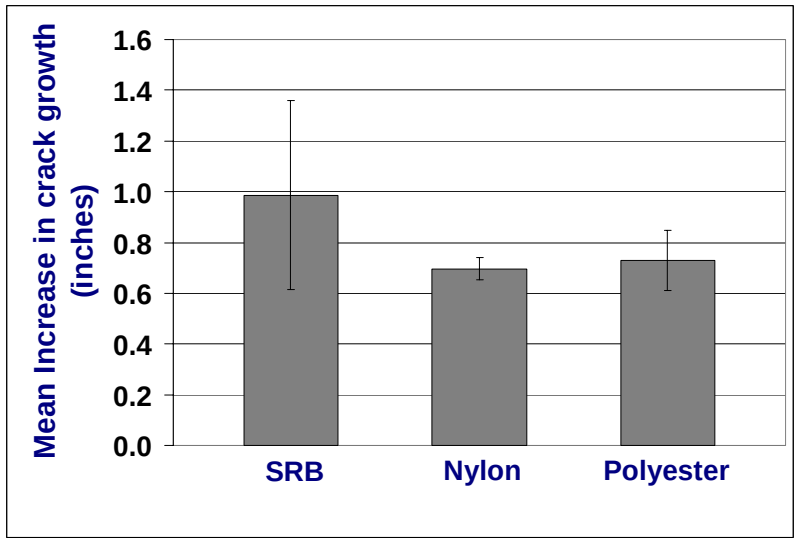
Part II – Peel ply
b) DCB baseline results- failure modes

DCB SRB	DCB Nylon	DCB Polyester
100% adhesion	90% adhesion, 10% adherend	100% adherend

Part II – Peel ply
c) Wedge Crack Test- Results



After inserting the wedge

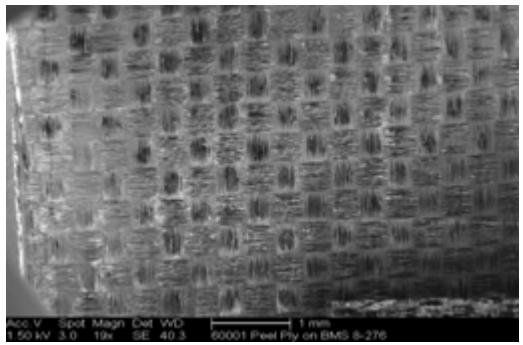


After 24 hrs water immersion

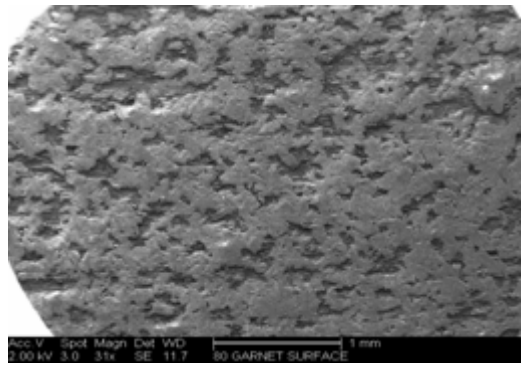
- 6 inch SRB coupons failed at 750 hrs
- 12 inch coupons showed small increase in crack growth

Part III – Abrasive Techniques

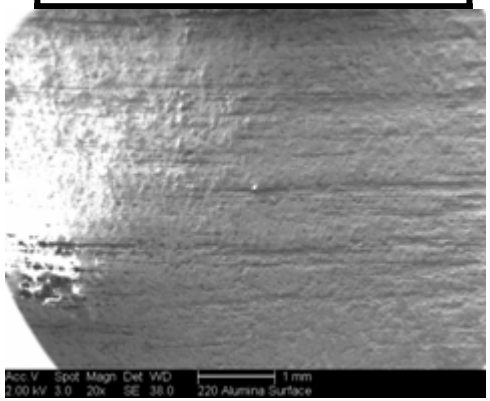
- Adherend surface preparations



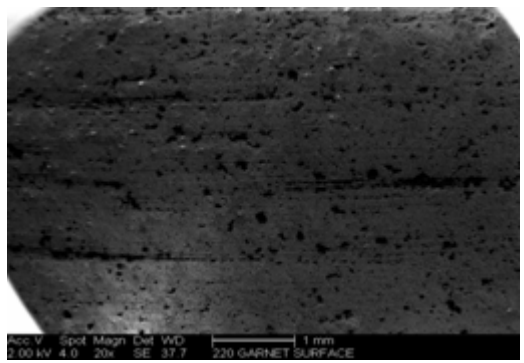
Polyester peel ply



Grit blast 80

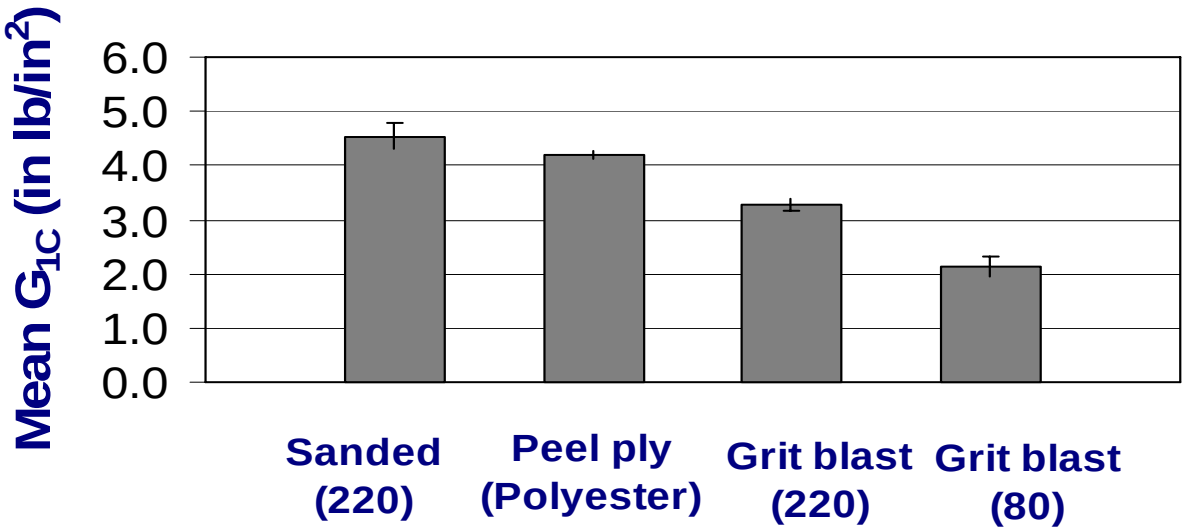


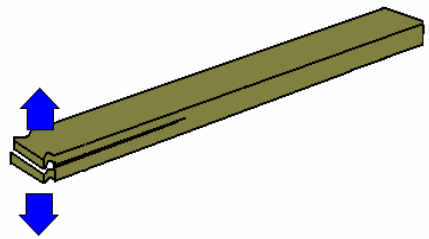
Sanding 220



Grit blast 220

Part III – Abrasive Techniques Baseline results

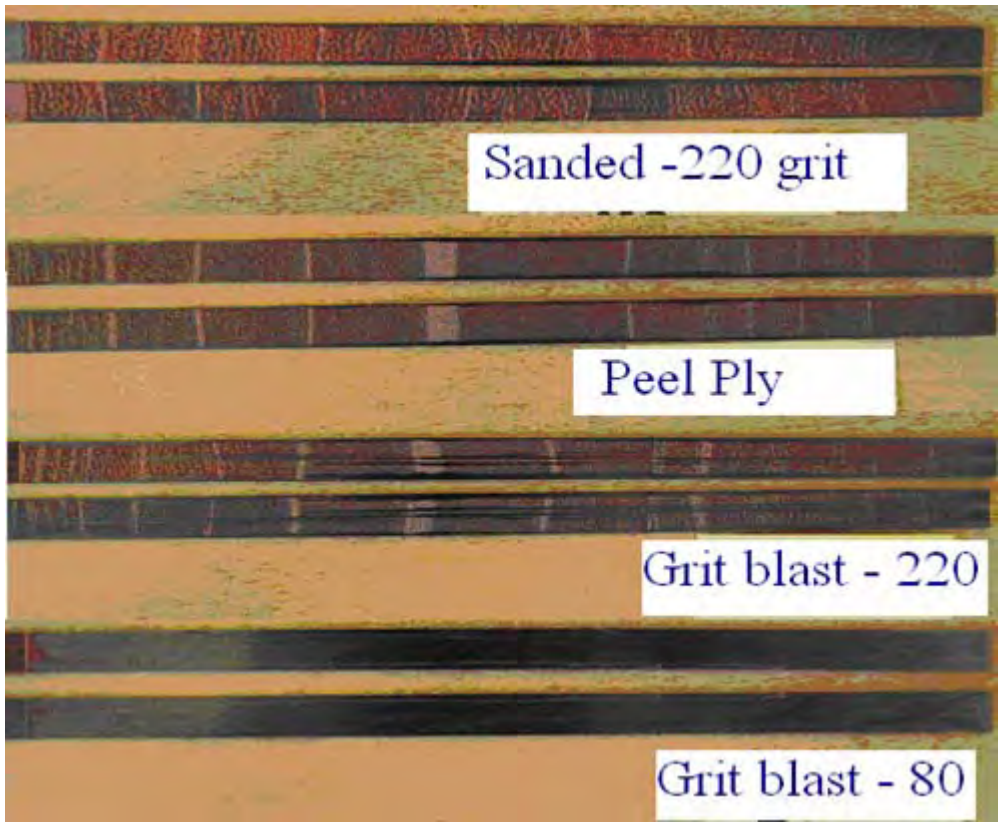




- Double cantilever beam test
- Lower G_{1c} of grit blasted surfaces, may be due to erosion (fiber damage)
- SEM results reveal harsher effects on grit blast surfaces

Part III – Abrasive Techniques Baseline results

Failure modes



Sanded → 99% cohesive, 1 % adherend

Peel ply → 90% cohesive, 10% adherend

Grit blast 220 → 70% cohesive, 30% adherend

Grit blast 80 →100% adherend

Part III – Abrasive Techniques

- Work in progress
  - Effect of creep and cyclic load on DCB coupons with sanded and grit blasted surfaces has begun

DCB creep and repeated load setup

Part III – Abrasive Techniques Test Matrix

Specimen Type	140 F water immersion			-65 F in air			
	Constant load	No load	Fluctuating load	Constant load	No load	No exposure	Total coupons
Peel ply (9.8lbs)	10	5	10	10	5	5	45
Sanded 220 (10.3lbs)	10	5	10	10	5	5	45
Grit blast 220 (8.4 lbs)	10	5	10	10	5	5	45
Grit blast 80 (6.2 lbs)	10	5	10	10	5	5	45

1. Coupons dried in oven at 160F
2. Applied load = 90% G_{1C}
3. Crack growth measured daily for 100 hours, weekly for up to 4000 hours
4. G_{1C} may be measured at the conclusion of the test.

Part III – Abrasive Techniques

- Repeated load movie

Summary

- Part I : Moisture sensitivity
  - Residual shear strength decreased with increasing creep load.
  - 3M AF555 showed little sensitivity to adherend moisture content
  - Predominantly adherend failure
- Part II : Peel ply
  - a) lap shear test
    - Polyester
      - Highest strength
      - Adherend and cohesive failure
    - SRB and nylon
      - Lower strength
      - Adhesion failure (also observed by Flinn et al.)
    - Moisture increased substrate failure
      - Motivated further study involving CILS and shear modulus coupons

Summary

- b) DCB test
  - Polyester : Higher G_{1C}
    : Adherend failure
  - SRB and nylon : Lower G_{1C}
    : Adhesion failure

- c) Wedge crack
  - SRB : High initial crack growth
    : Comparable crack growth under exposure
    : Does not clearly describe observed lower durability

- Part III : Abrasive techniques
  - Grit blast : Lower G_{1C}
    : Adherend failure
  - Sanded, peel ply : Higher G_{1C}
    : Cohesive failure

A Look Forward

- Benefit to Aviation
  - Better understanding of moisture, peel ply, abrasive technique effects on the bond integrity.
  - Greater confidence in adhesive bonds
  - Guide development of QA methods for surface prep.
- Future needs
  - Moisture effects on the composite substrate integrity
  - Application to other composite systems and adhesives
  - Durability of differing joint designs