Update on the Progress of Hygrothermal Aging of Triaxial Braided Carbon/Epoxy Composites

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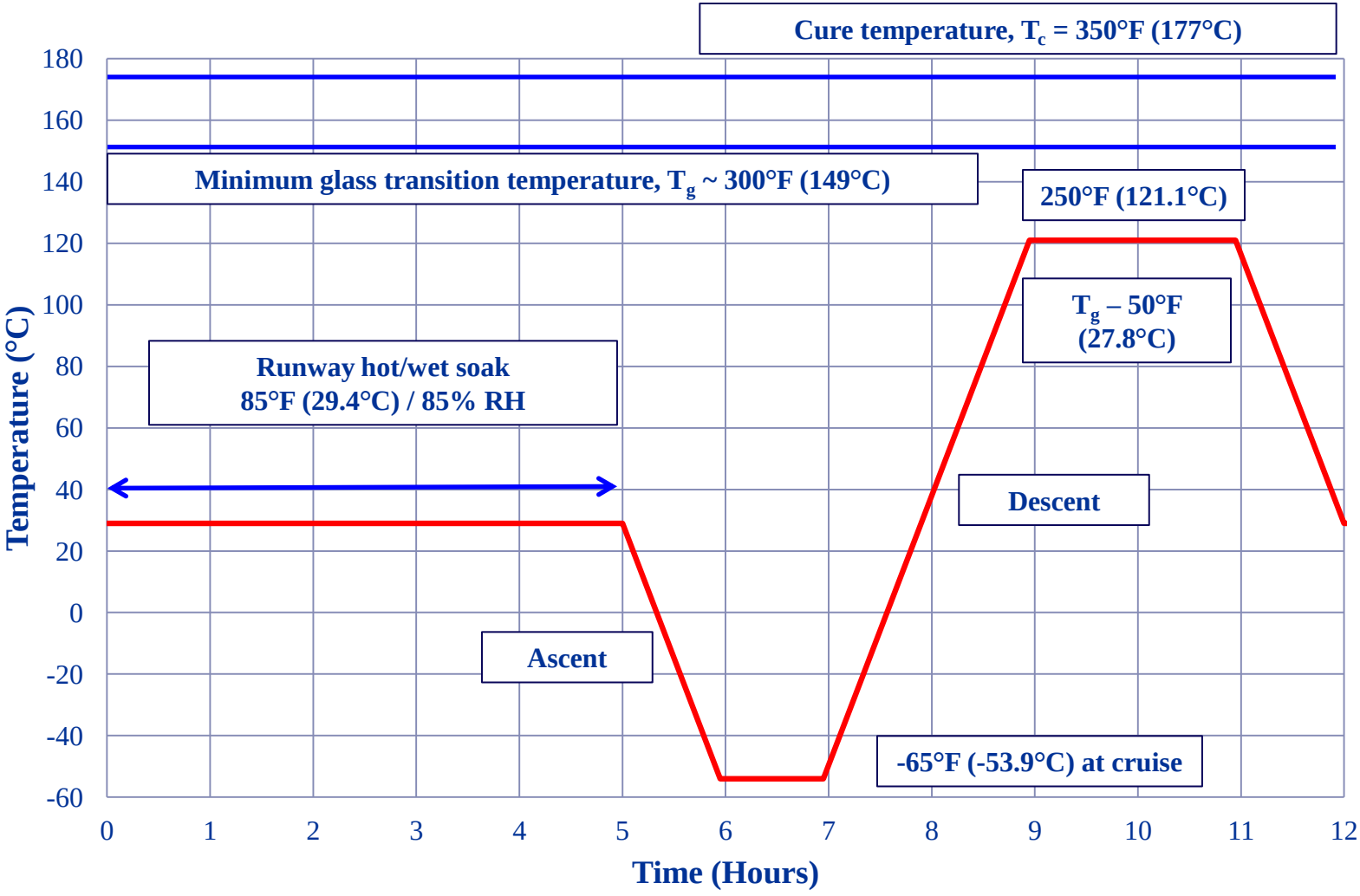
Material Fabrication

- Materials
  - Fiber: Torayca® T700S standard modulus carbon fiber
  - Matrix Materials: 4 ranging from brittle to toughened
    - Hexcel 3502
    - Cytec 5208
    - EPIKOTE Resin 862/EPIKURE Curing Agent W
    - Cytec PR520
- Processing
  - Resin transfer molding (RTM) for both resin and composite
    - Final cure at 350°F (177°C) for 2 hr
    - Resin glass transition temperature, $T_g \geq 300°F$ (149°C)
  - 6 plies, [+60°/0°/-60°] 2D triaxial braid preform
    - 24k axial tows, 12k bias tows
    - Equal fiber volume in all directions
- Cured composite properties
  - 0.125 in thick, 2'x2' panel
  - ~56% fiber volume fraction

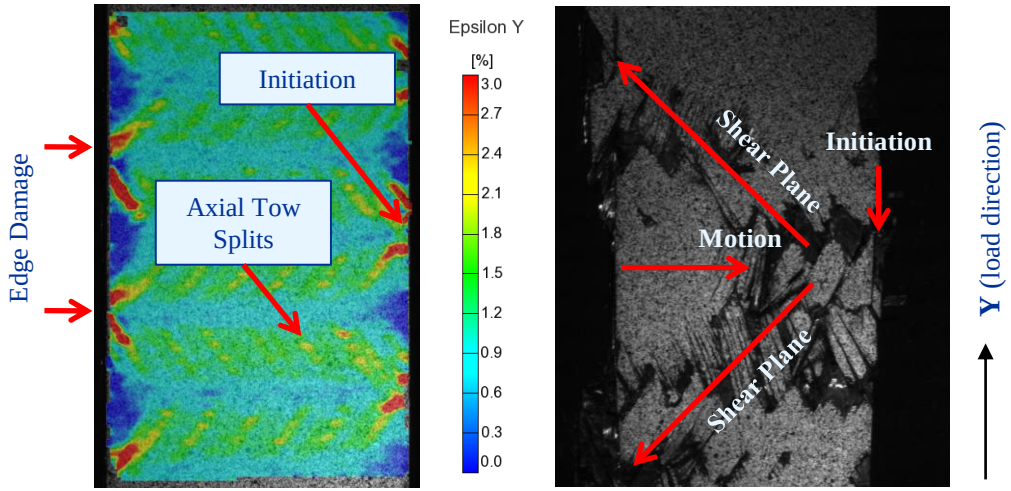
Hygrothermal Aging Cycle



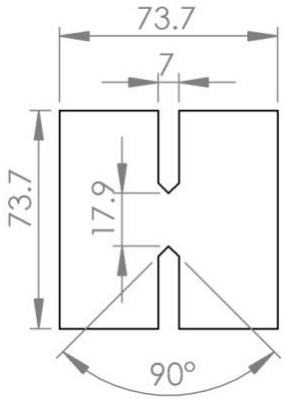
Composite Mechanical Property Test Methods

- ASTM D 3039 Tension
- ASTM D 3410 Compression
- ASTM D 7078 Modified V-Notch Rail Shear

Transverse Tension Test



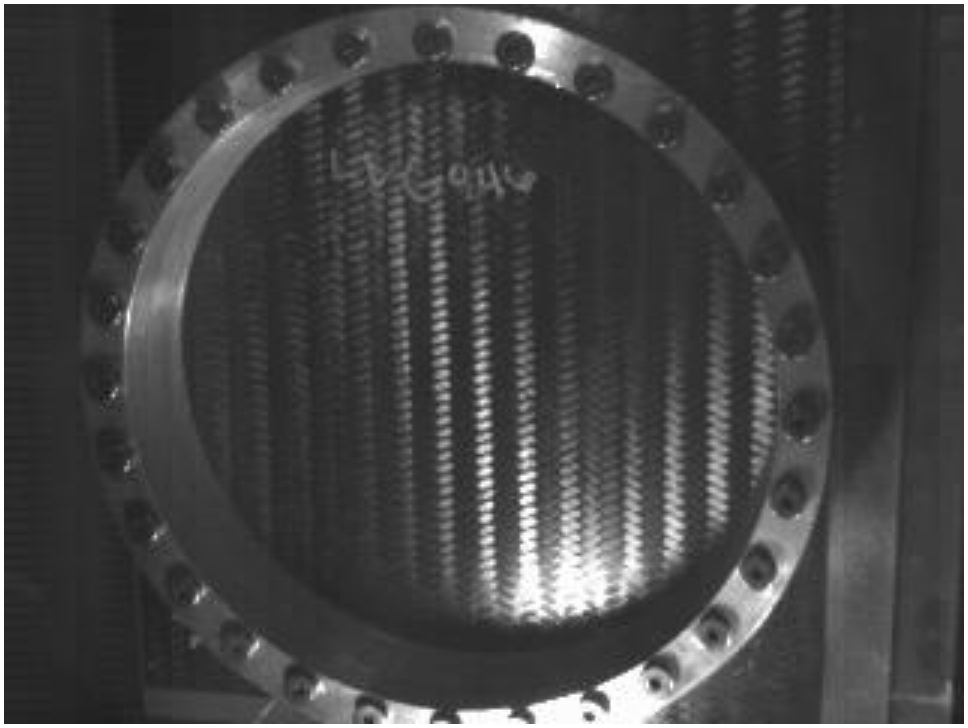
ASTM D 7078
V-Notched
Rail Shear
"H" Specimen



Test plan limitations

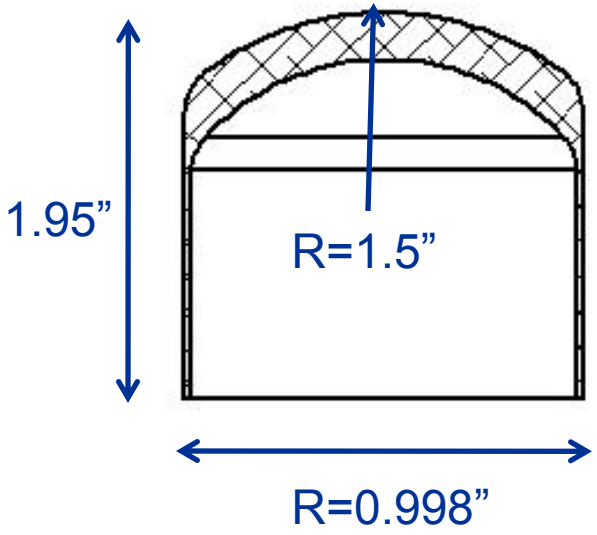
- The number of tests per aging condition was limited by material availability
- The ASTM D 3039 test method does not provide an accurate measure of transverse tensile strength for braided composites
  - Used only to provide an indication of aging effects
  - Improved test methods are being developed

Ballistic Impact Test Method



Test method considerations

- Blunt impact allows large deformation before failure
- Simple method enables easier use in other labs
- 12 in X 12 in panel size provides efficient use of material

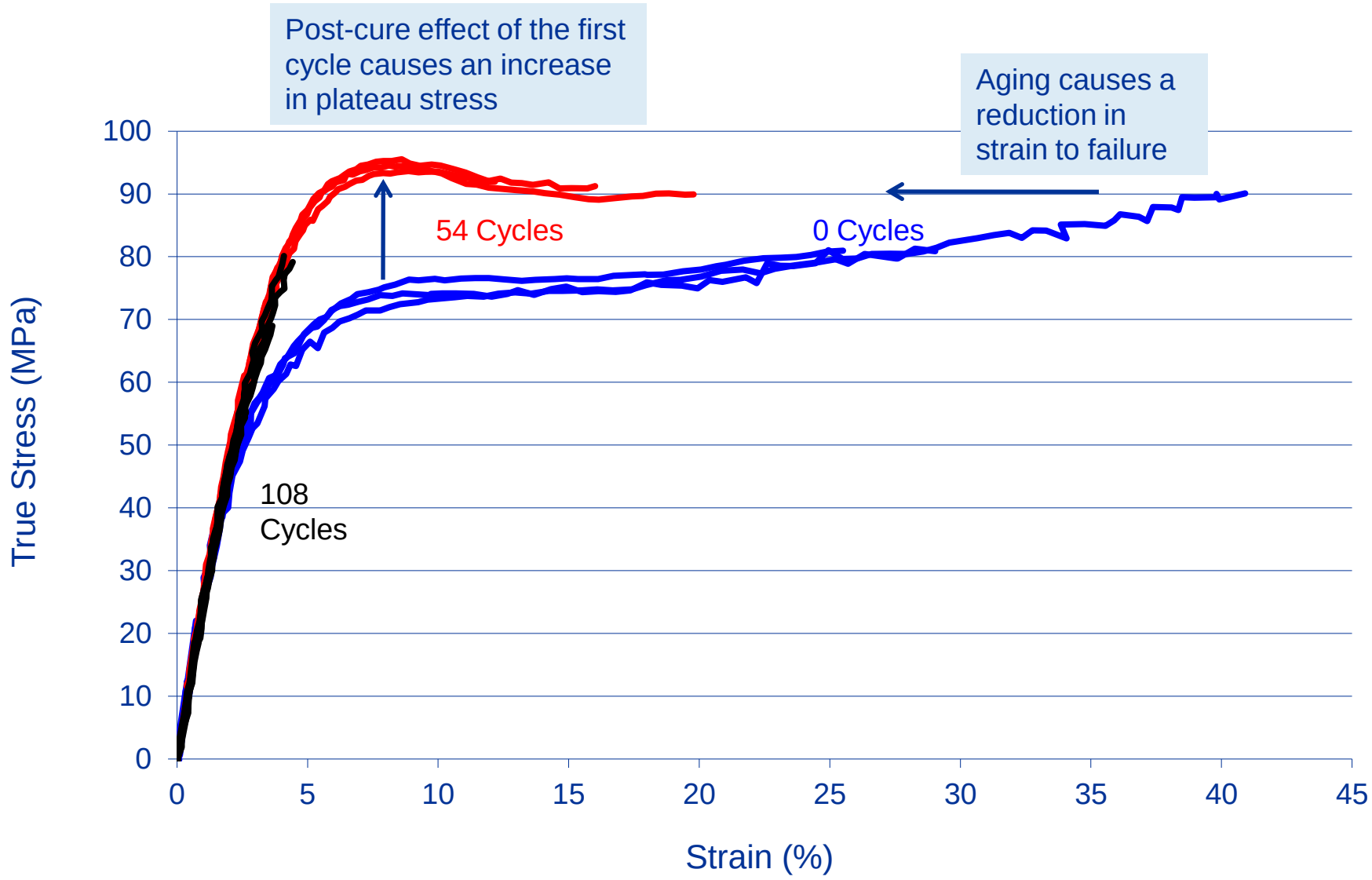


Previously Reported E862 Results

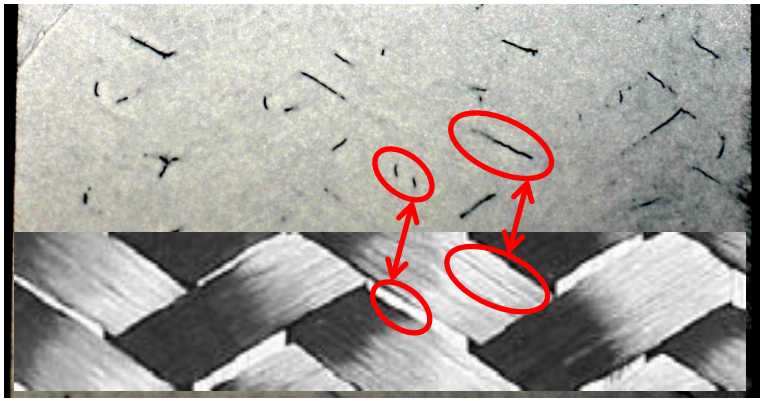
E862 Resin/Composite to 2 Years of Aging

- E862 Resin properties
  - Chemical structure
    - Surface oxidation identified
    - Limited continuation of cure identified
  - Physical properties
    - Glass transition temperature was not affected
    - Physical aging resulting in embrittlement and volume loss identified
  - Mechanical properties
    - Resin tensile strength reduced and ductile response eliminated
- Composite properties
  - Microcracking was observed
  - Mechanical properties
    - Tensile strength was not reduced
    - Compression strength was reduced
    - Shear had not yet been tested
  - Impact penetration threshold was not found to change

E862 Resin Tensile Properties



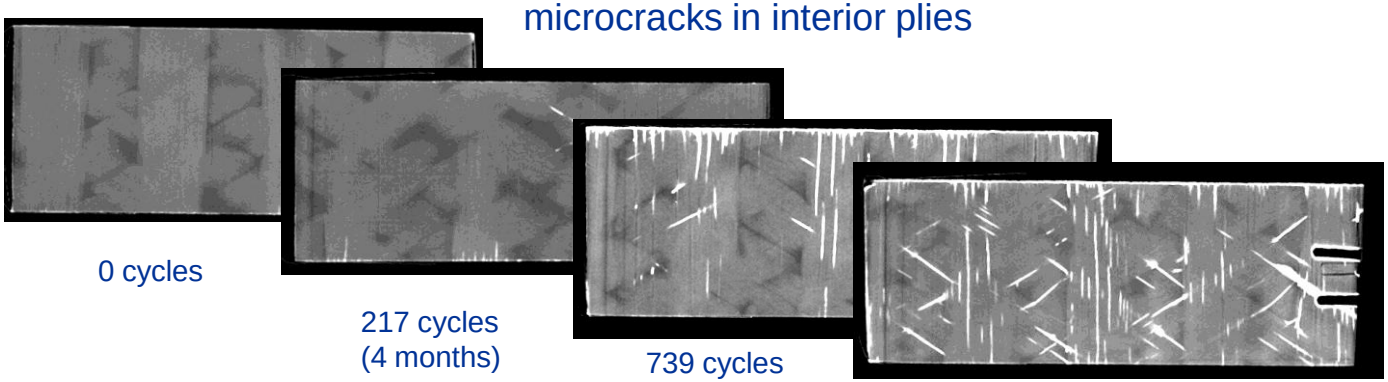
E862 Composite Microcracking



Microcracks visible on a painted surface

Overlaid image of braid architecture showing crack locations within fiber tows

Contrast enhanced X-ray CT images of microcracks in interior plies



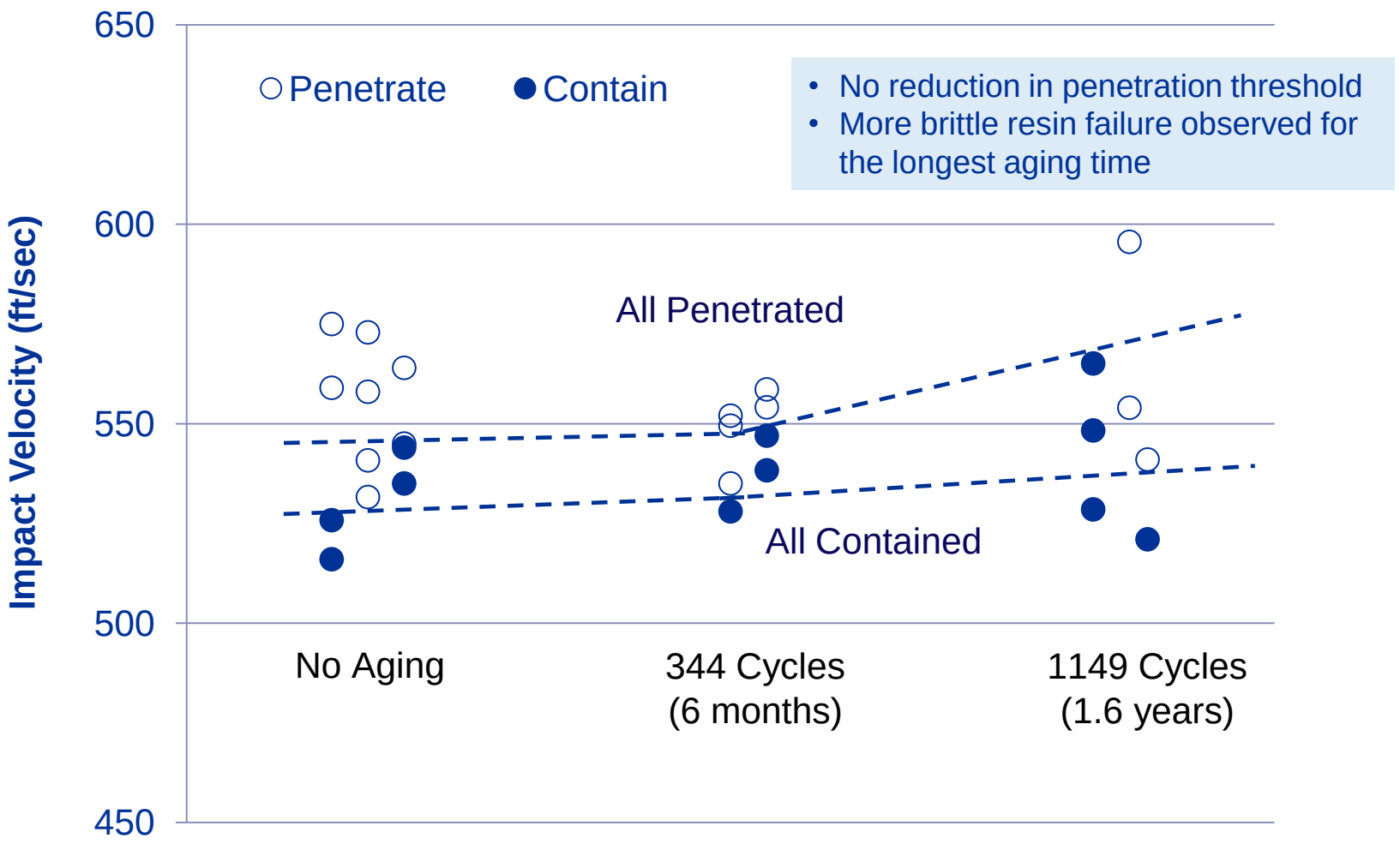
0 cycles

217 cycles
(4 months)

739 cycles
(12 months)

739 cycles – different ply
(12 months)

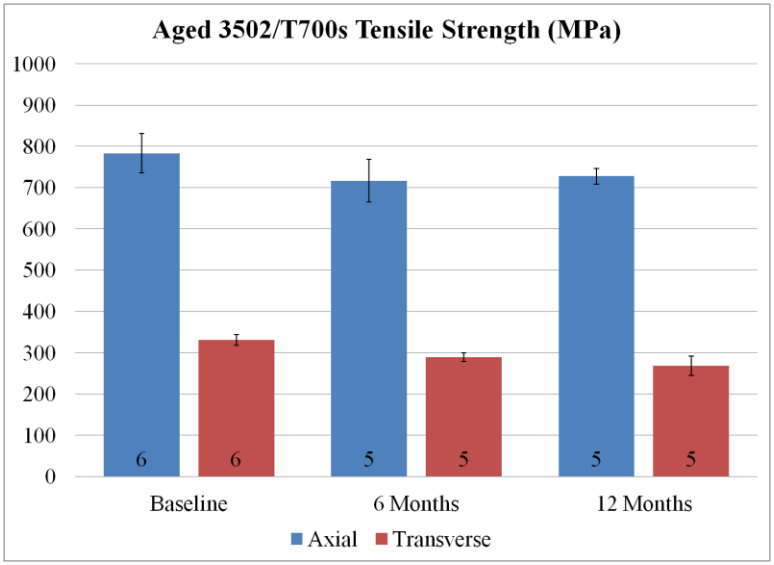
E862 Ballistic Impact Results

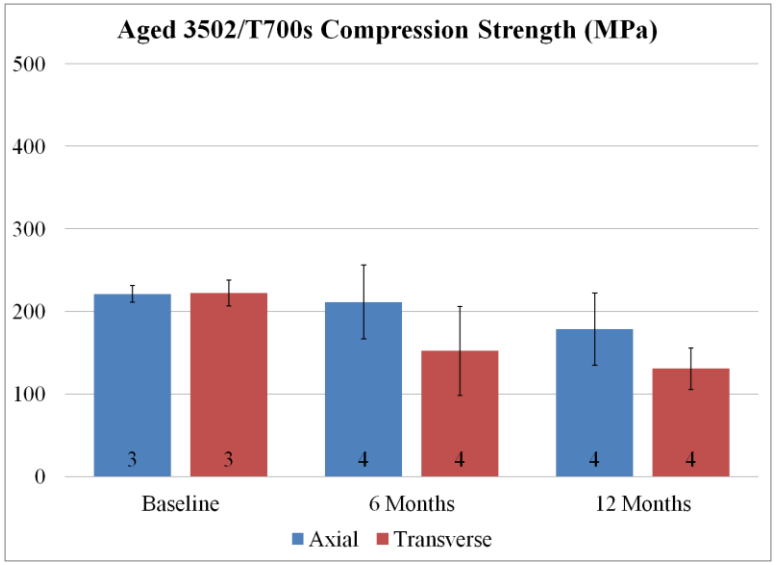


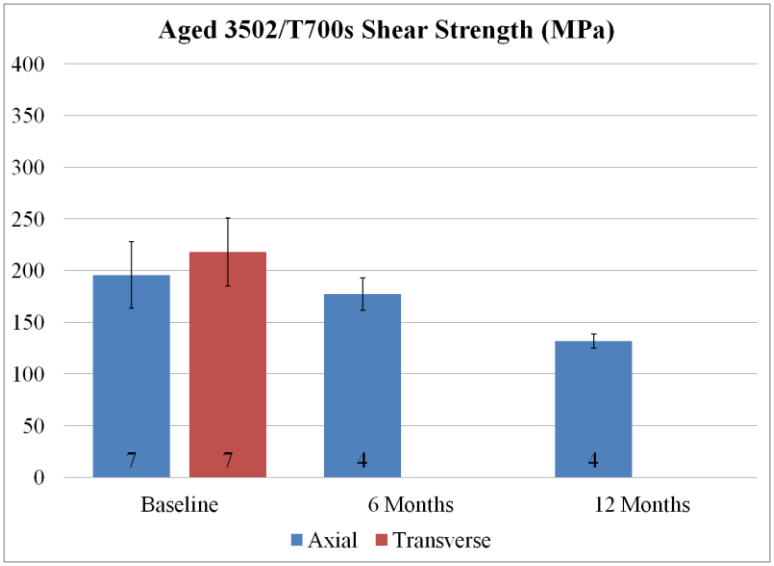
New Mechanical Results

3502, 5208, E862, PR520

3502 Composite Mechanical Results (12 Months)

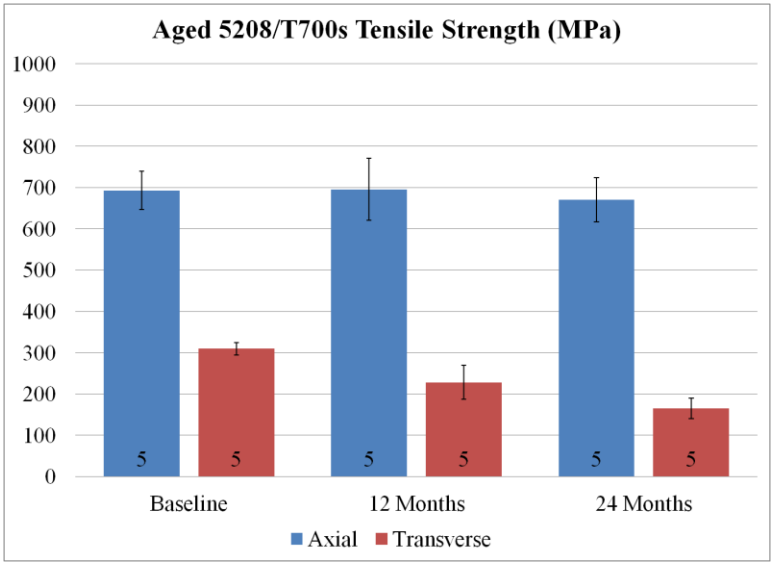


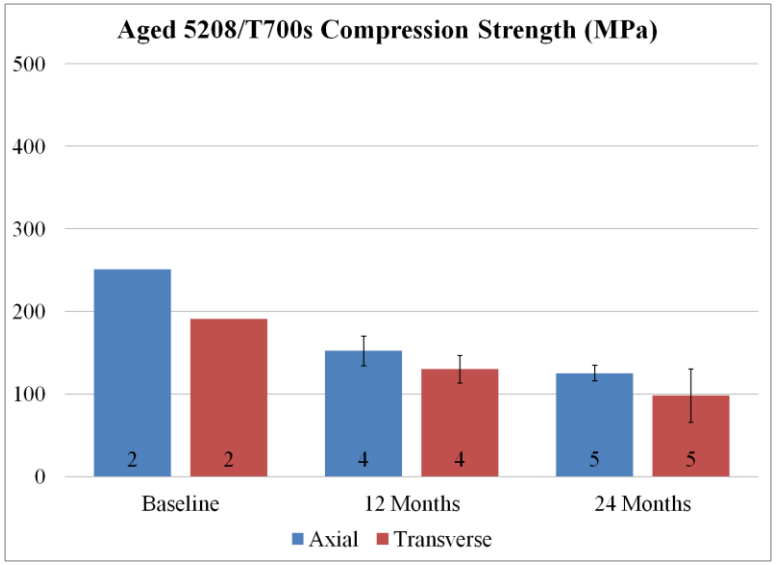


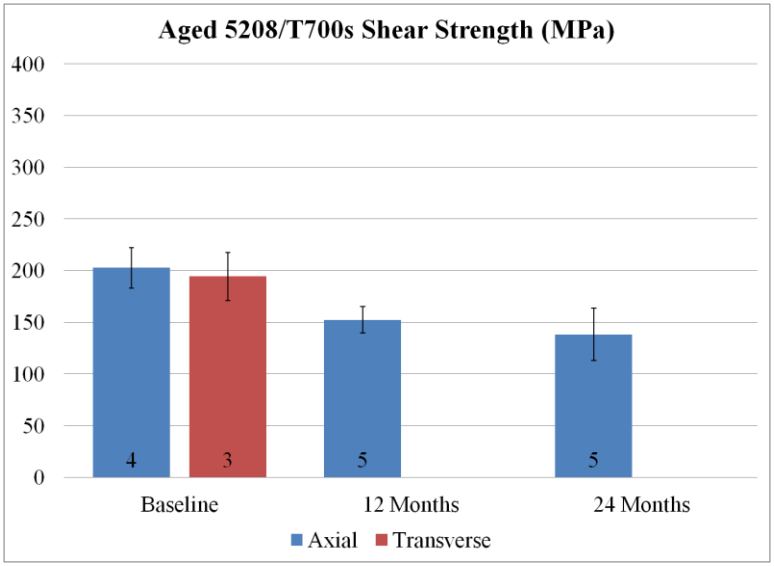


- Possible transverse tension strength reduction
- Shear strength reduction
- Compression strength reduction
- Likely due to observed microcracks initiating failure
- Aging to 24 months is ongoing

5208 Composite Mechanical Results (24 Months)

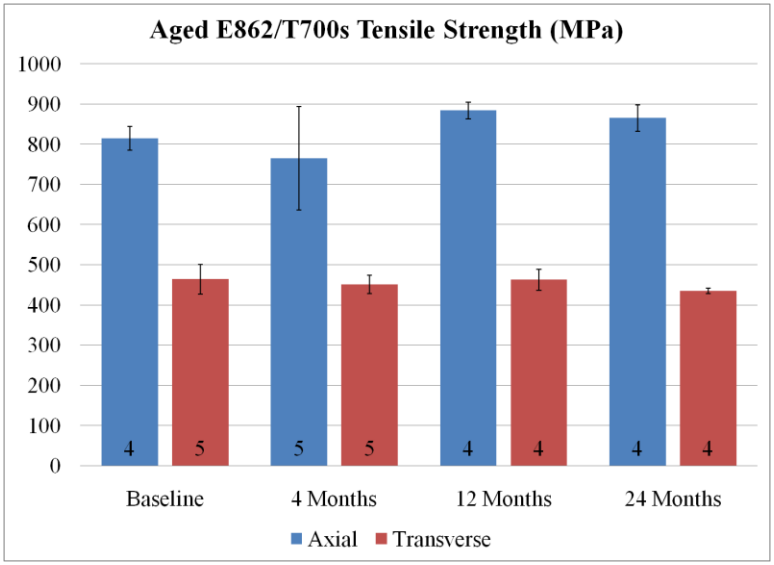


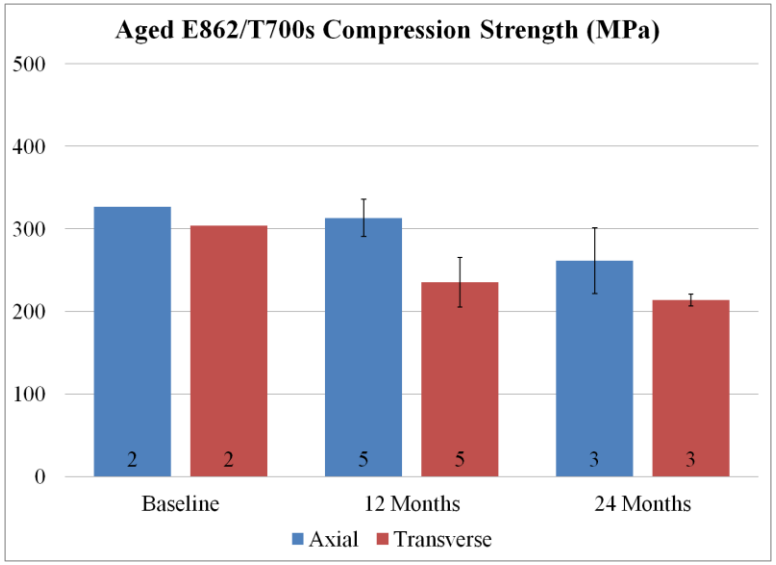


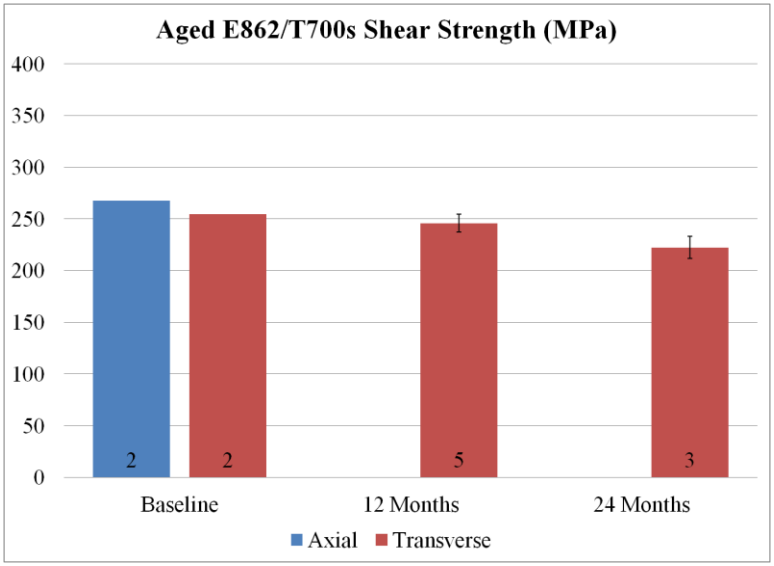


- Transverse tensile strength reduction (correlates with shear reduction because of failure mode)
- Shear strength reduction
- Compression strength reduction
- Likely due to observed microcracks initiating failure

E862 Composite Mechanical Results (24 Months)

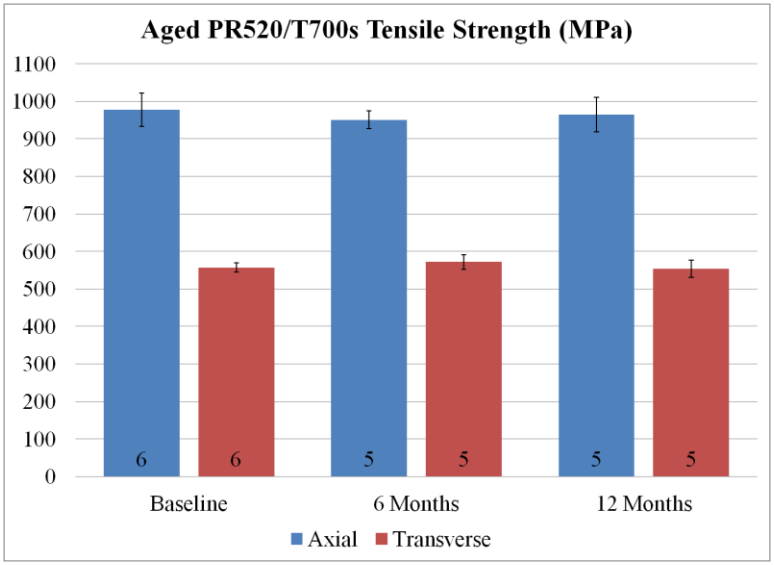


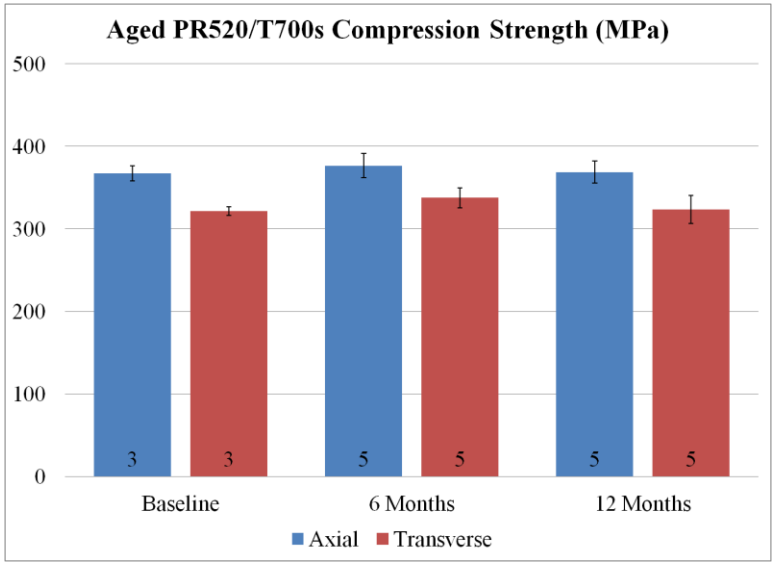


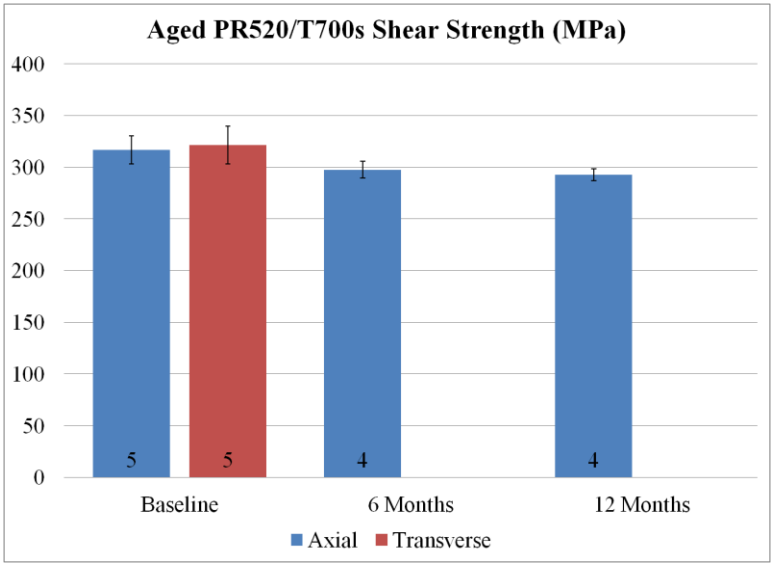


- No significant tensile strength changes
- Compression strength reduction likely
- Possible shear strength reduction
- Changes are likely due to observed microcracks initiating failure

PR520 Composite Mechanical Results (12 Months)







- No significant strength changes observed
- Very little evidence of microcracking was observed
- Aging to 24 months is ongoing

Summary of Mechanical Results

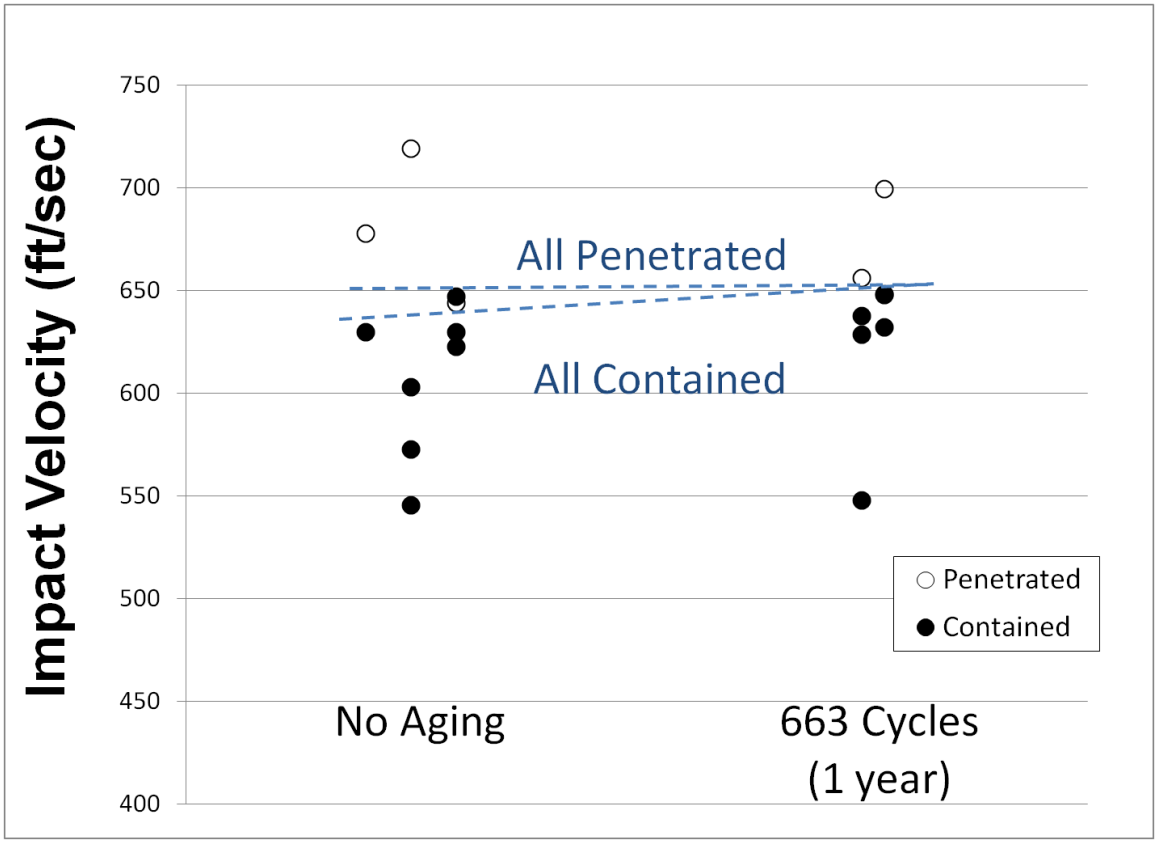
- Microcracking has been identified as the most likely cause of strength reduction in compression, shear, and transverse tensile strength
- Previous work with E862 indicated that resin embrittlement can occur
- Preliminary studies indicate that microcracking is occurring during the low temperature part of the cycle as a result of differences in thermal expansion coefficients of fiber and resin

New Ballistic Impact Test Results

3502, PR520

Ballistic Impact Results: 3502

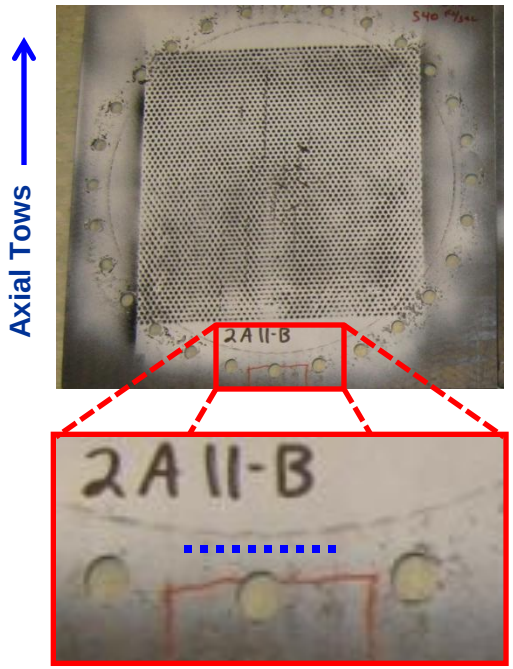
- No aging effect was observed.

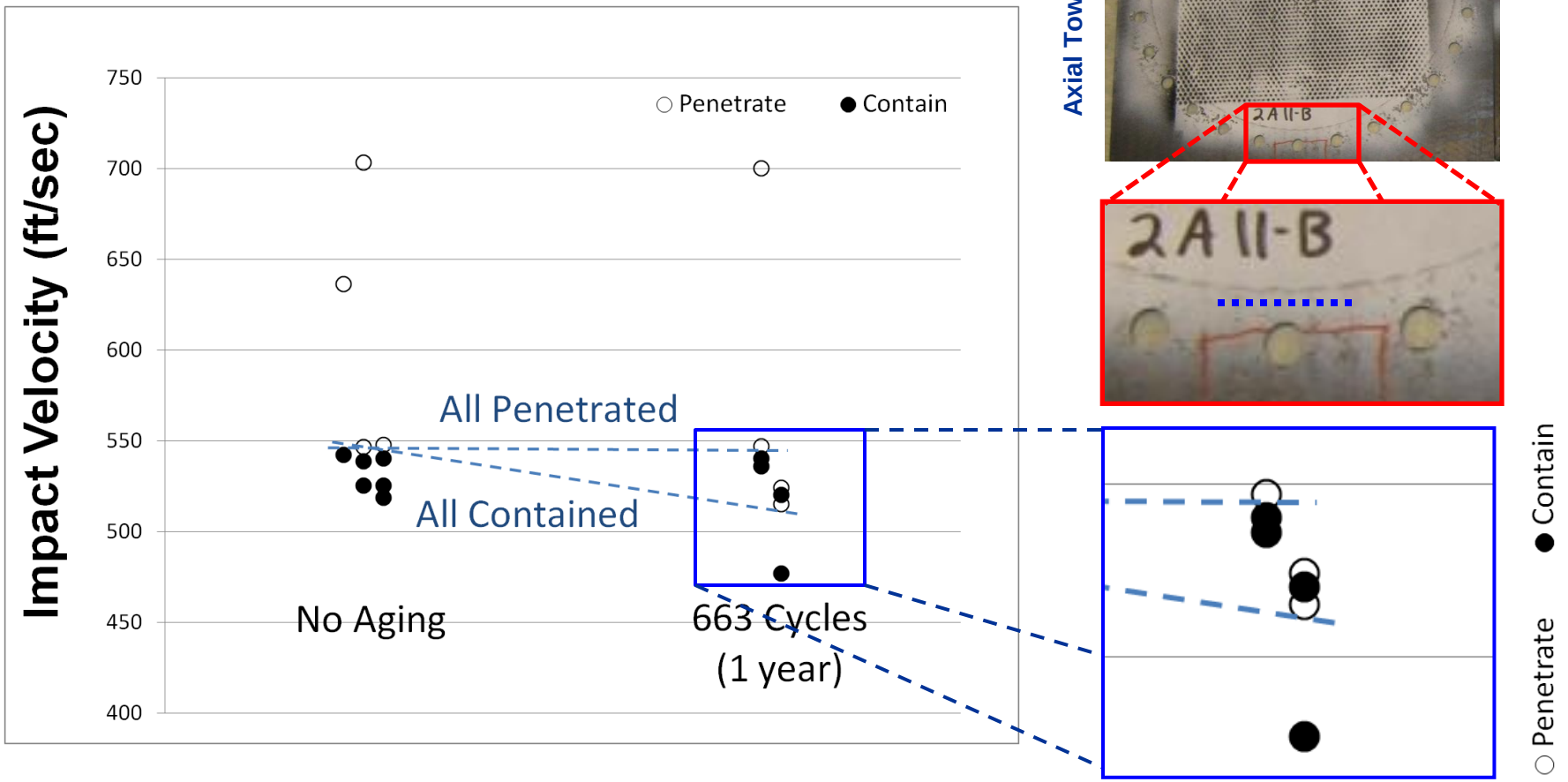


Ballistic Impact Results: PR520

- No aging effect observed.
- Panel variation effect was observed.

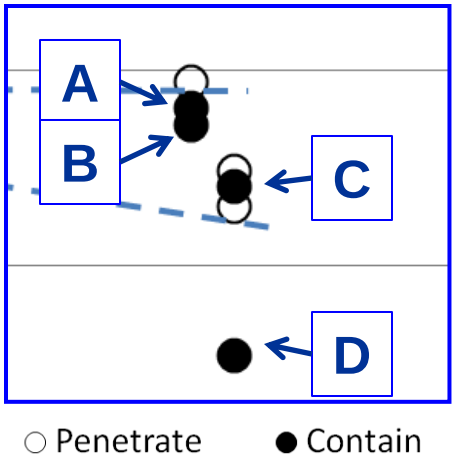
Cross Section Location

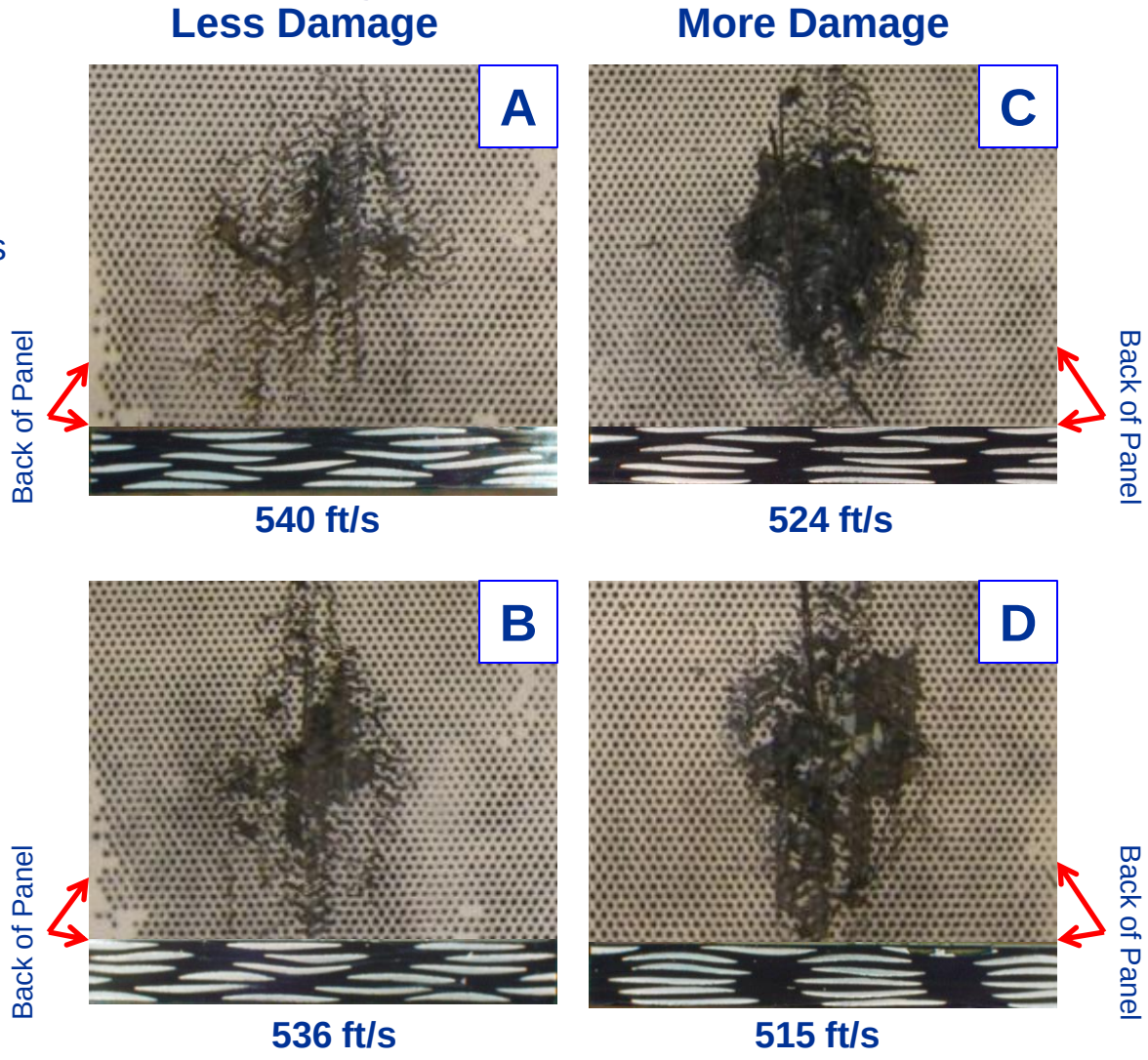




Impact Damage and Axial Tow Nesting: PR520 Aged

- Nesting is observed by sectioning the panel near the edge, in line with the axial tows passing through the panel center.
- More damage is observed on the side opposite the impact in panels with less axial tow nesting.





Summary of Ballistic Impact Results

- Previous aging of the E862 showed little change in impact threshold.
- Additional results on 3502 and PR520 also show little change after 12 months of aging.
- Fiber tow nesting has an influence on impact damage and possibly impact threshold.
- Impact threshold does not correlate with static coupon tests

Conclusions

- Hygrothermal aging has resulted in small reductions in transverse tensile, shear, and compression strengths in E862, 3502, and 5208 composite materials.
- The primary mechanism is the development of microcrack damage that initiates failure in matrix/delamination failure dominated static tests, but not in the fiber failure dominated axial tensile test.
- The impact penetration threshold does not appear to be sensitive to the presence of pre-existing microcrack damage.
- Axial fiber tow nesting can influence the extent of damage following impact and the impact penetration threshold.
- PR520 composite was not observed to be affected by aging up to 12 months; minimal microcrack development was observed.

Continuing Work

- 3502 and PR520 Composite
  - Aging to 2 years
    - Tension
    - Compression
    - Shear
    - Impact
- PR520 Resin
  - Aging to 2 years
    - Tension
    - Compression
    - Shear
    - FTIR, DSC, DMA

The End.