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Environmental Factor Influence on Composite Design and Certification

2016 Technical Review

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Environmental Factor Influence on Composite Design and Certification

- **Principal Investigators & Researchers**
  - John Tomblin, *PhD*, and Waruna Seneviratne, *PhD*
  - Upul Palliyaguru
- **FAA Technical Monitor**
  - Zhi-Ming Chen
- **Other FAA Personnel Involved**
  - Larry Ilcewicz, *PhD* and David Westlund
- **Industry Participation**
  - Cirrus Aircraft

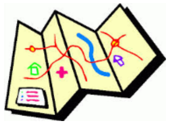
Environmental Factor Influence on Composite Design and Certification

- **Motivation and Key Issues**

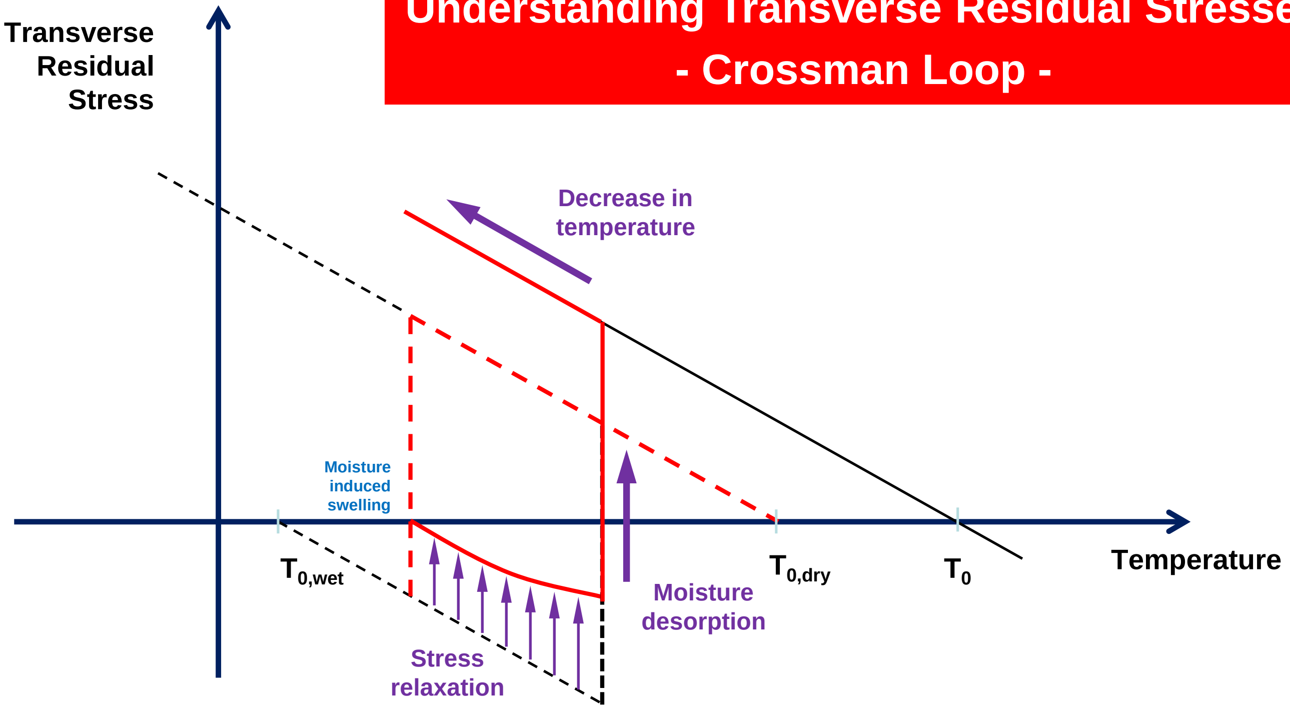
  Moisture absorption characteristics of composites can be coupled with realistic environmental data to design structurally efficient and economic composite components.

- **Objective**
  - Investigate the hygrothermal effects and ratchetting phenomenon on thermal residual stresses
  - Investigate the effects of ratchetting phenomenon on the microcrack development and failure mode of splice joints

Viscoelastic Behavior of TRS due to Hygrothermal History



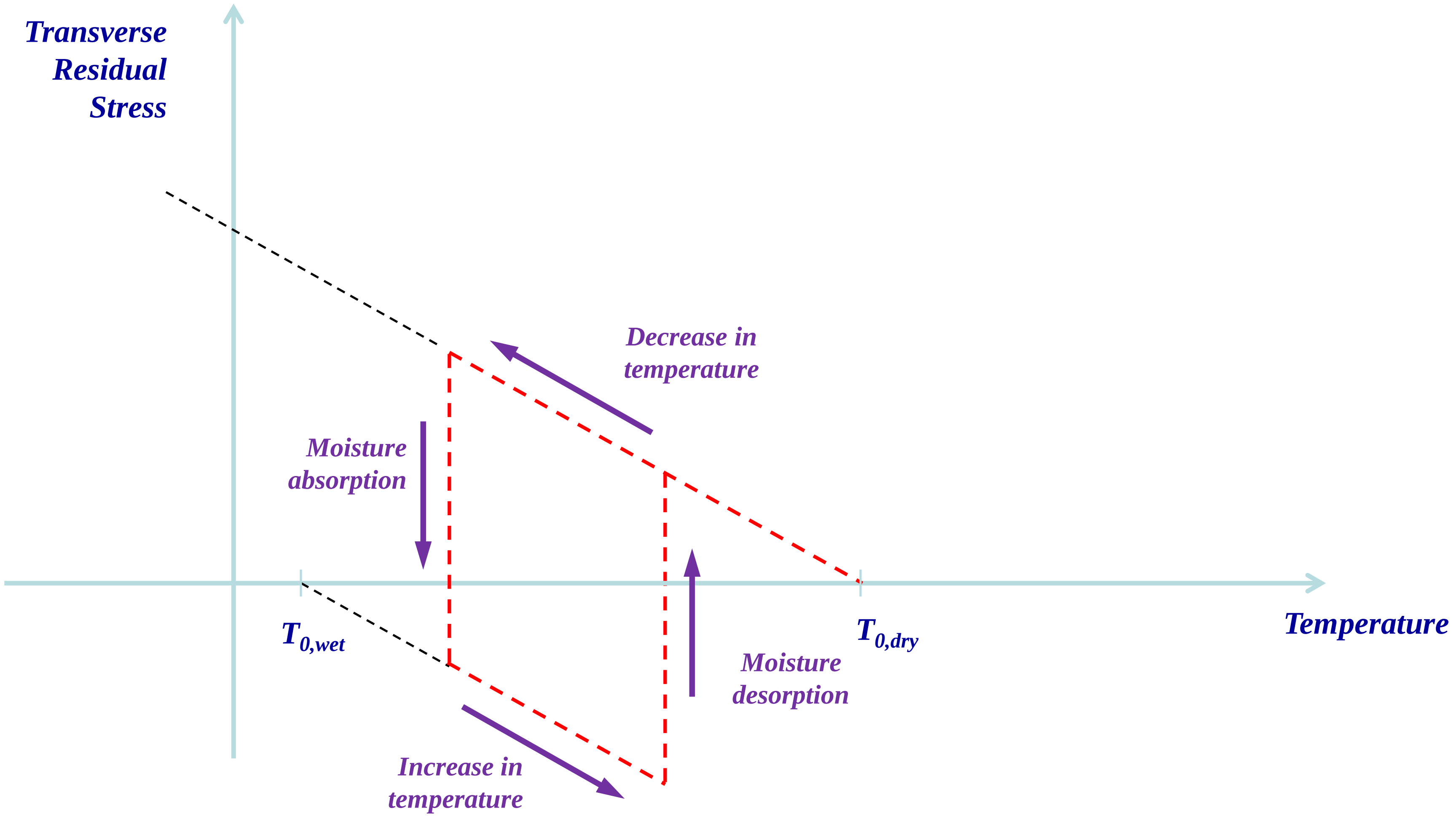
Understanding Transverse Residual Stresses
- Crossman Loop -



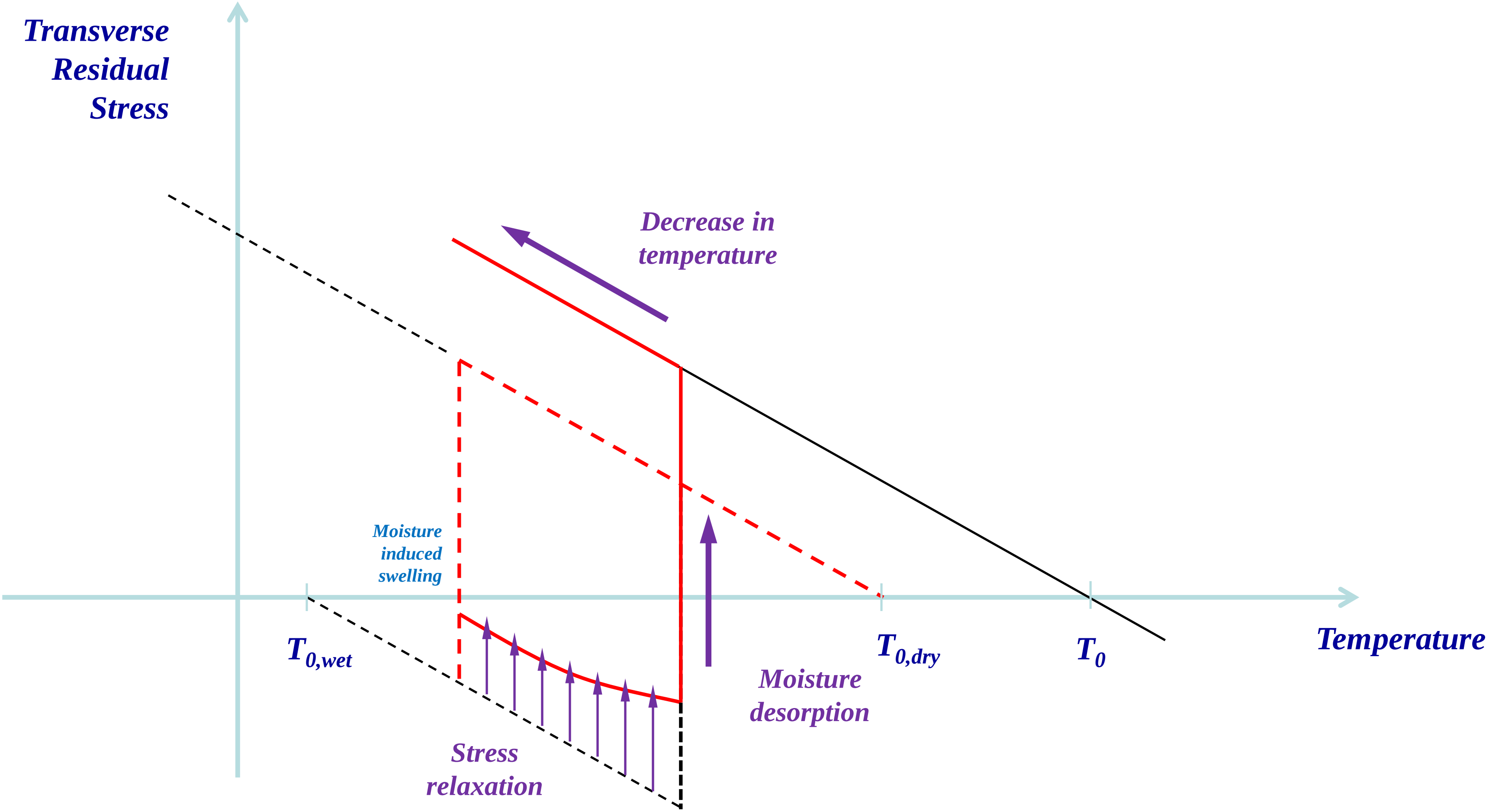
Research based on:

Rothschilds, R. J., Ilcewicz, L. B., Nordin, P., and Applegate, S. H., "The Effect of Hygrothermal Histories on Matrix Cracking in Fiber Reinforced Laminates," *Journal of Engineering Materials and Technology*, Vol. 110, pp. 158-168, 1988.

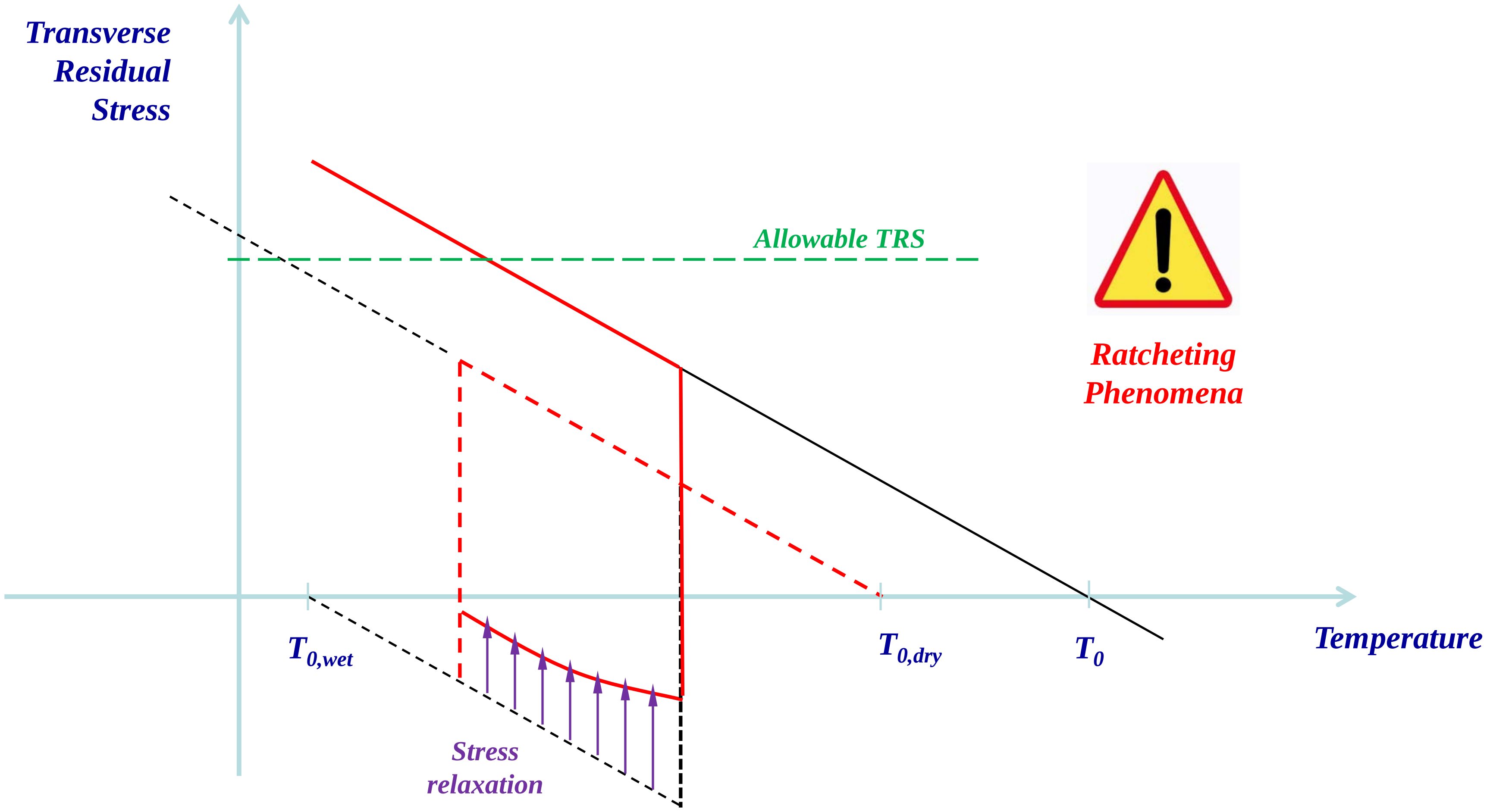
Elastic Behavior of TRS



Viscoelastic Behavior of TRS due to Hygrothermal History

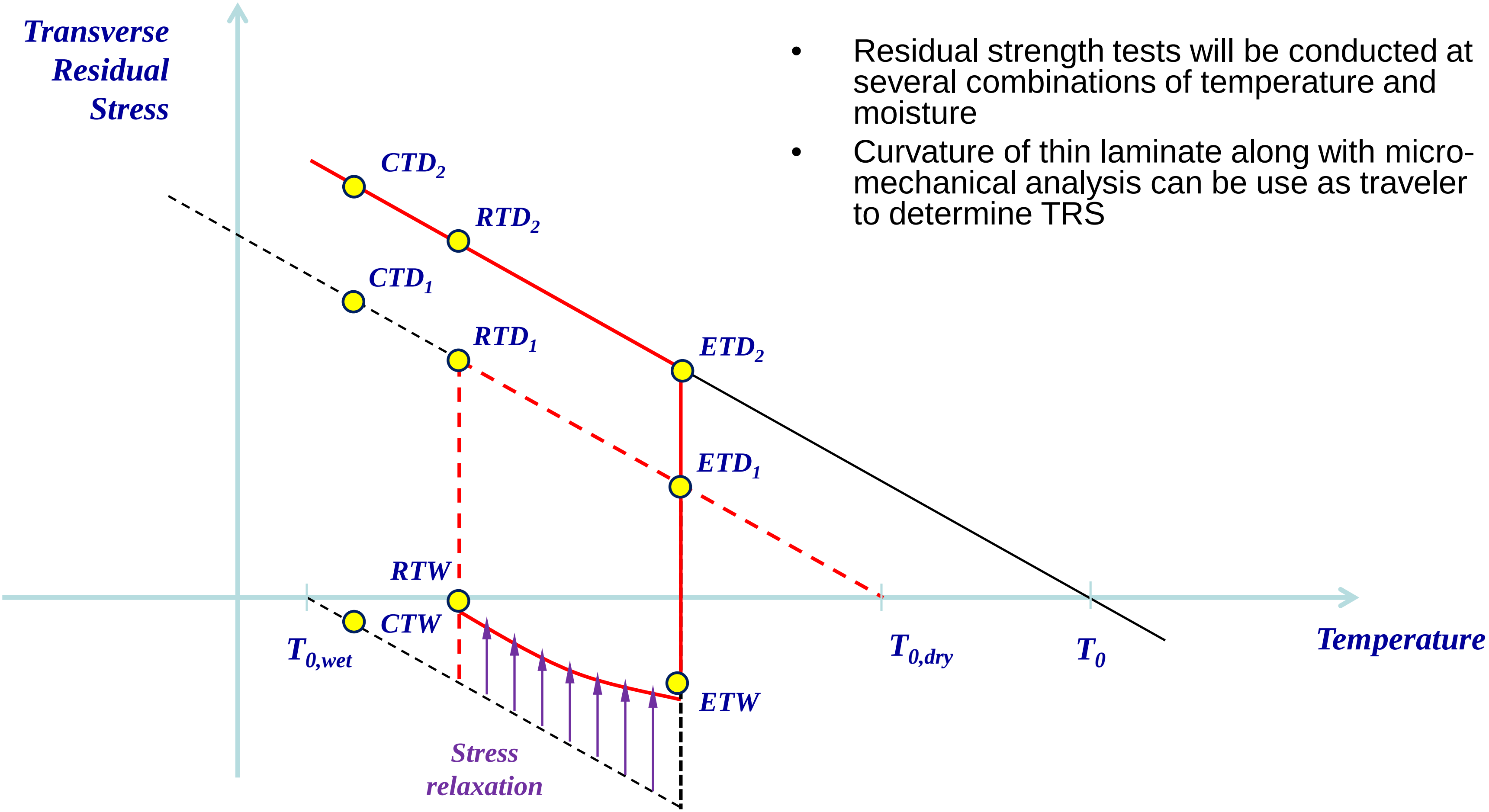


Safety Concern!



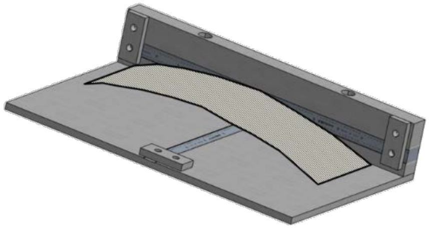
Ratcheting Phenomena

Residual Strength Evaluation



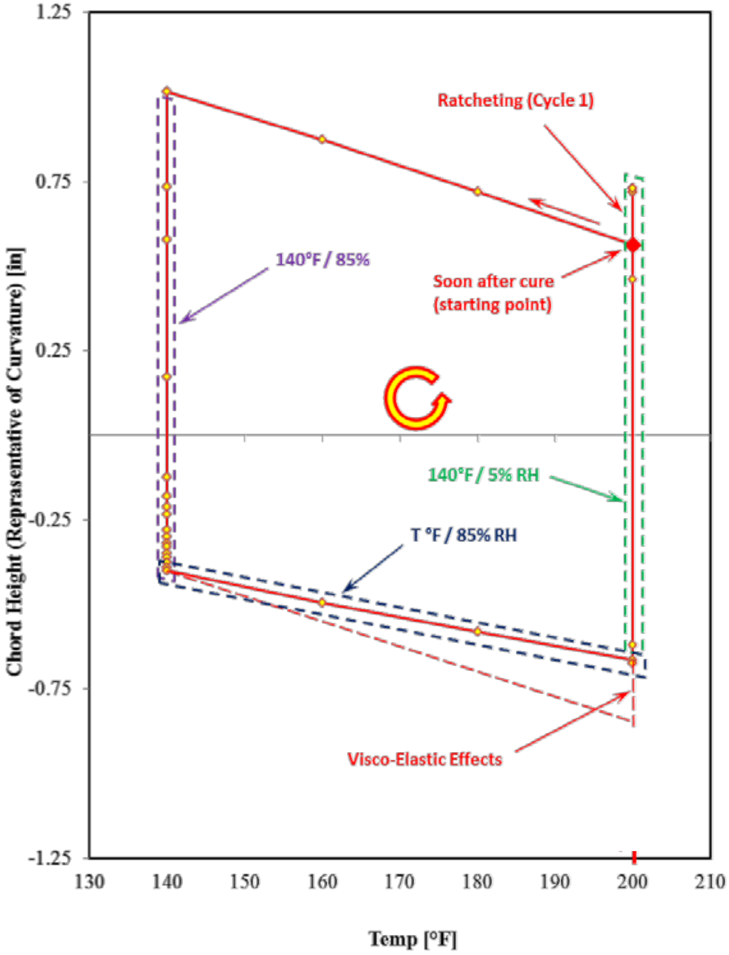
- Residual strength tests will be conducted at several combinations of temperature and moisture
- Curvature of thin laminate along with micro-mechanical analysis can be use as traveler to determine TRS

Hygrothermal Effects on Composite Splice Joints

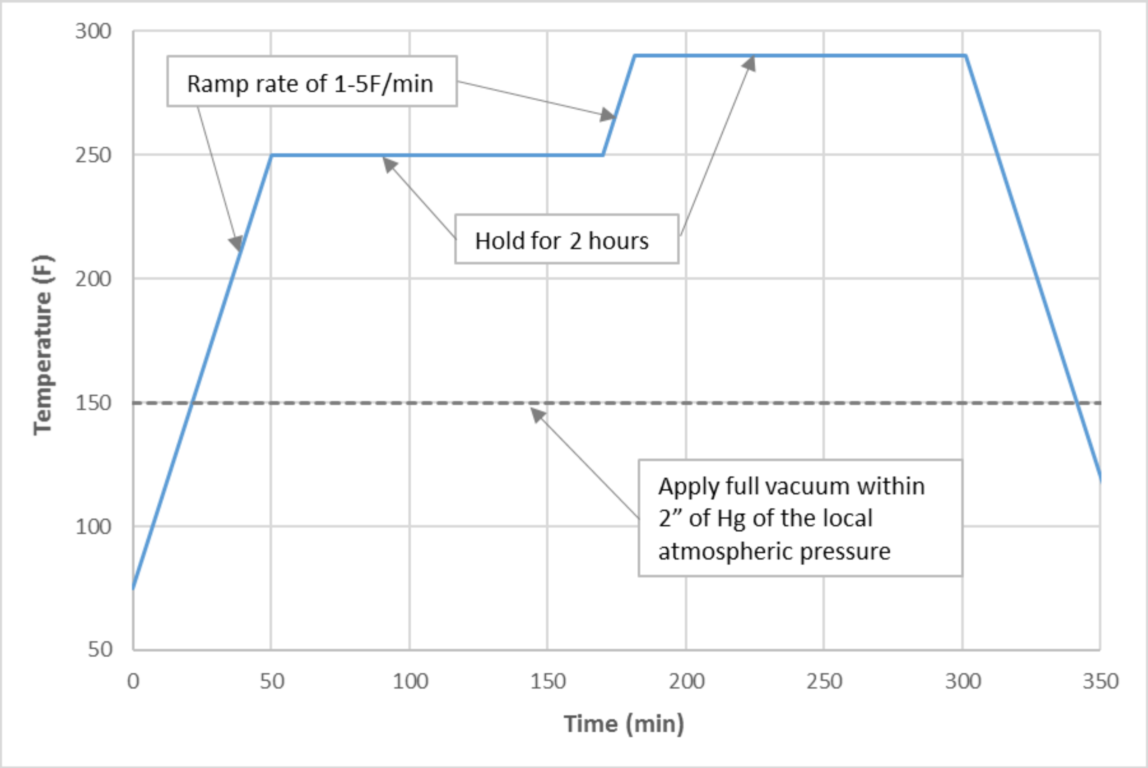


- Thin Specimen Hygrothermal Cycling (HTC)
  - Use curvature of thin unsymmetric laminate as a measure of residual stresses
  - Cycle thin laminate specimens through a Crossman Loop
  - Observe viscoelastic response and residual stress relaxation
  - Investigate ratchetting phenomenon

- Specimen Configuration
  - $[0_2/90_2]$ and $[0_4/90_4]$ Unsymmetric Layup
  - Cytec T650/5320-1 UNI
  - 290 °F Cure
  - 1.5” x 10” specimens



Cure Cycle



Ramp rate of 1-5F/min

Hold for 2 hours

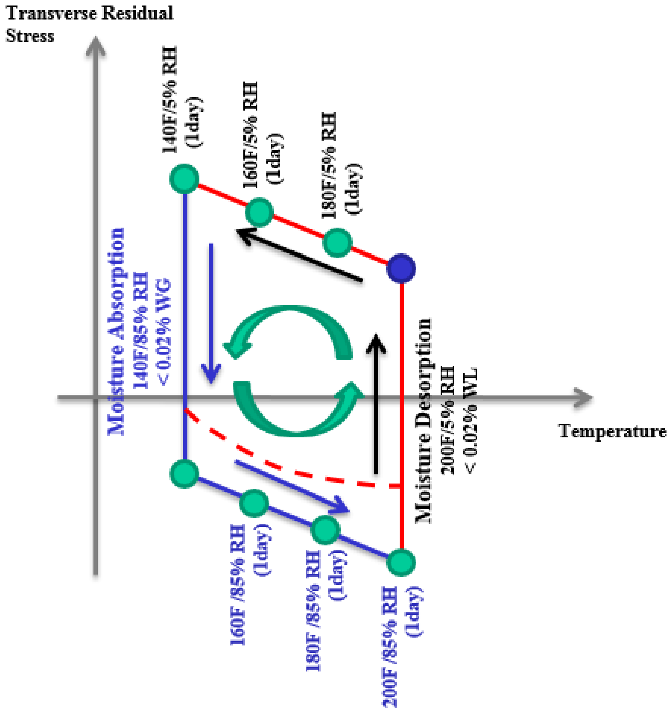
Apply full vacuum within 2” of Hg of the local atmospheric pressure

Hygrothermal Cycling (HTC)

- Cincinnati Sub-Zero Z-Plus 32 Programmable Environmental Chamber
  - Step 1: Temperature decrease at the dry condition. (200°F / 5% RH → 140°F / 5% RH)
  - Step 2: Moisture absorption at 140°F / 85% RH. (140°F / 5% RH → 140°F / 85% RH)
  - Step 3: Temperature increase at the wet condition. (140°F / 85% RH → 200°F / 85% RH)
  - Step 4: Moisture desorption at 200°F / 5% RH. (200°F / 85% RH → 200°F / 5% RH)

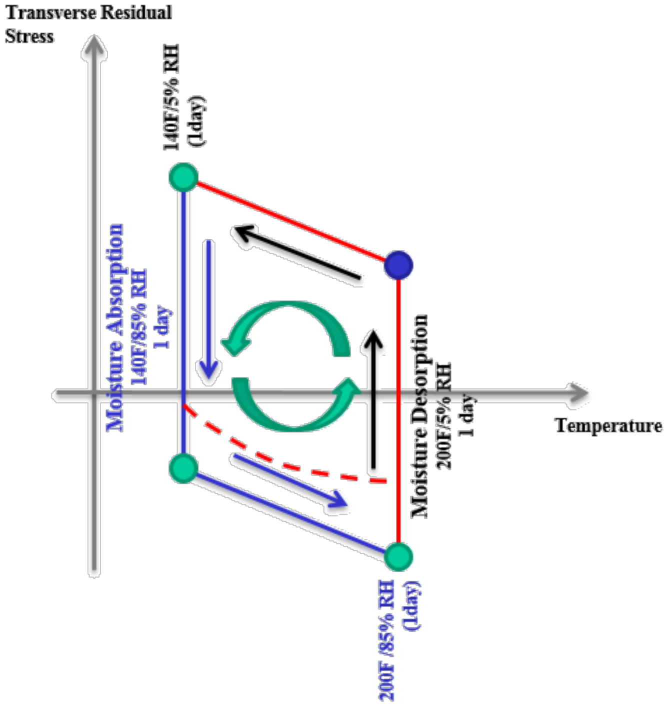
Full Cycle

- Specimens were kept in Step 2 (moisture absorption) and Step 4 (desorption) untill they reached the equilibrium condition of less than 0.02% daily moisture weight gain and weight loss, respectively.
- In Step 1 (temperature decrease) and Step 3 (temperature increase), the temperature changes were made in increments of 20°F and the specimens were kept at each temperature for one day.
- Over one month for a full cycle



Accelerated Cycle

- Specimens were kept in Step 2 (moisture absorption) and Step 4 (desorption) only for 1 day.
- In Step 1 (temperature decrease) and Step 3 (temperature increase), the temperature change was made in one increment of 60°F and the specimens were kept at each temperature for one day.
- 4 days for one full cycle

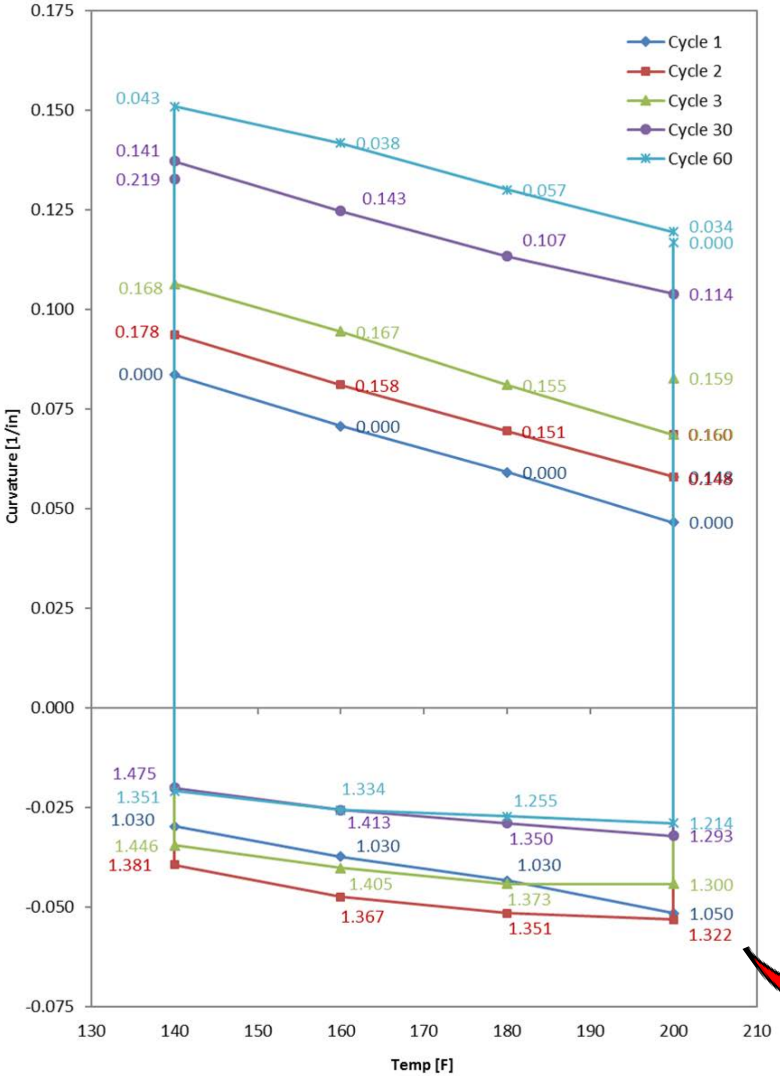


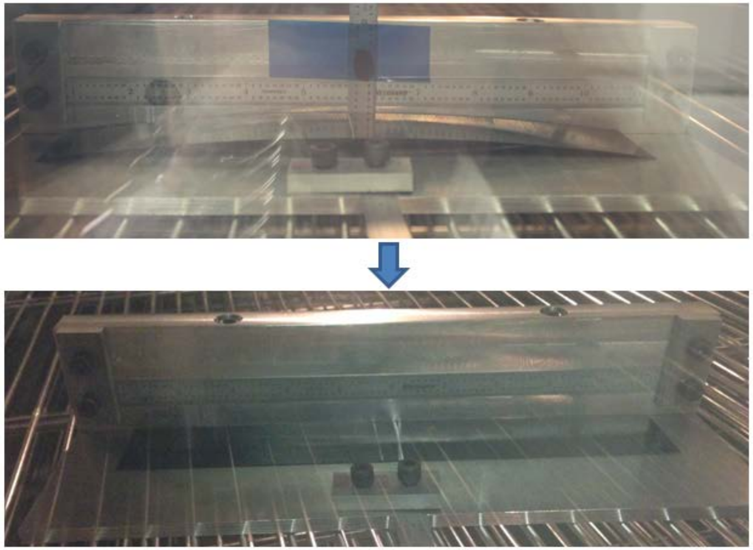
Hygrothermal Cycling Schedule

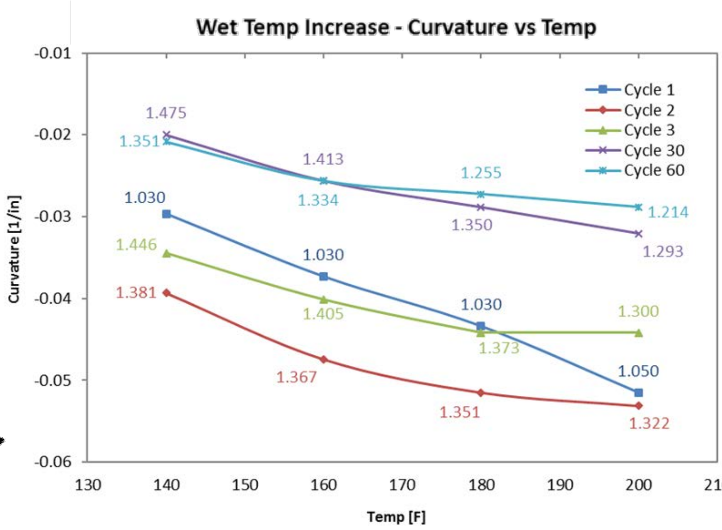
Cycling schedule for 4 ply specimens	
Cycle #1 - #3	Full Cycles
Cycle #4 - #29	Accelerated Cycles
Cycle #30	Full Cycle
Cycle #31 - #59	Accelerated Cycles
Cycle #60	Full Cycle

Cycling schedule for 8 ply specimens	
Cycle #1	Full Cycle
Cycle #2 - #29	Accelerated Cycles
Cycle #30	Full Cycle
Cycle #31 - #59	Accelerated Cycles
Cycle #60	Full Cycle

Ratcheting Effects – 4-Ply Specimens

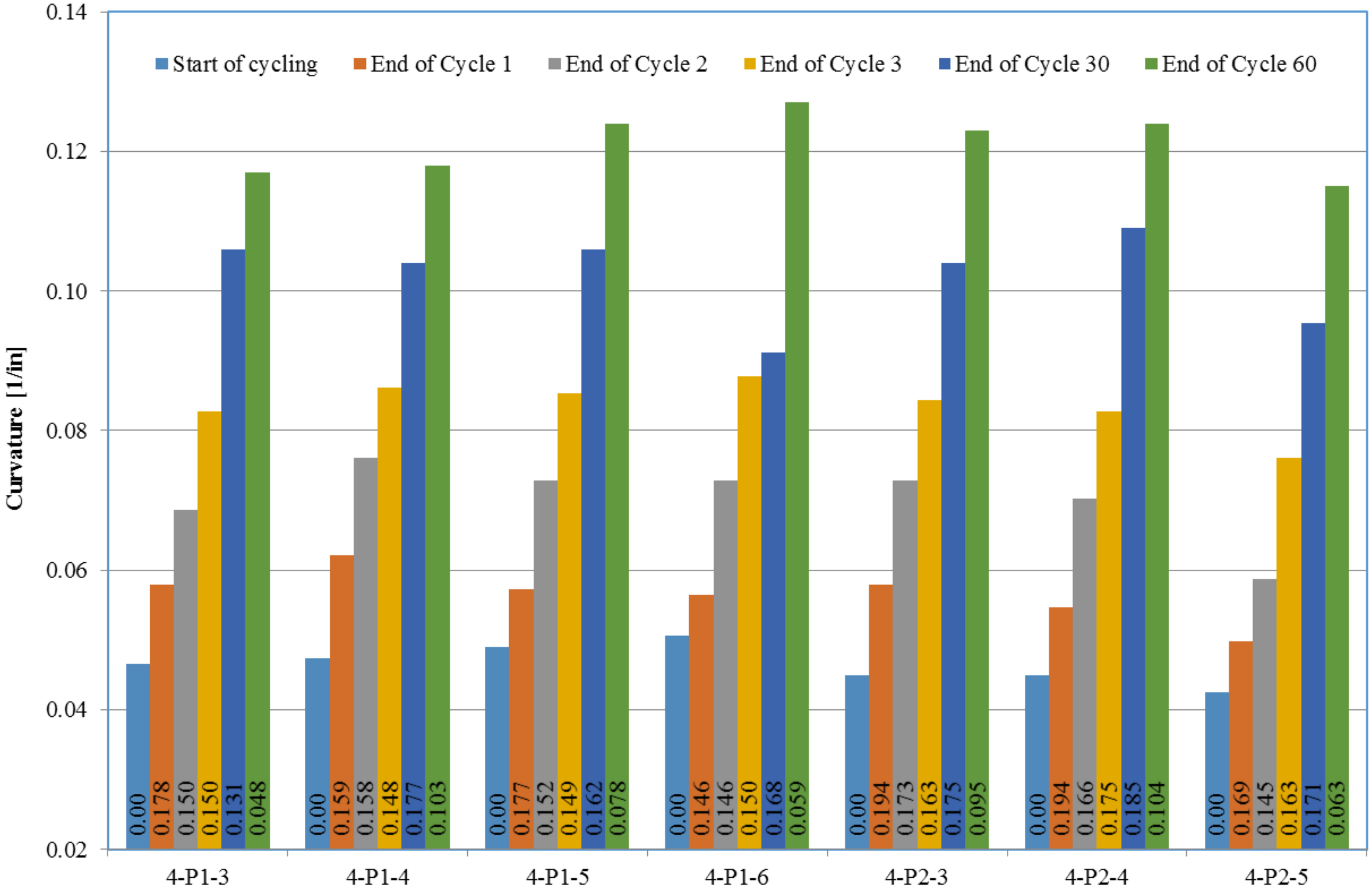






Wet Temp Increase - Curvature vs Temp

Curvature of 4-Ply Specimens



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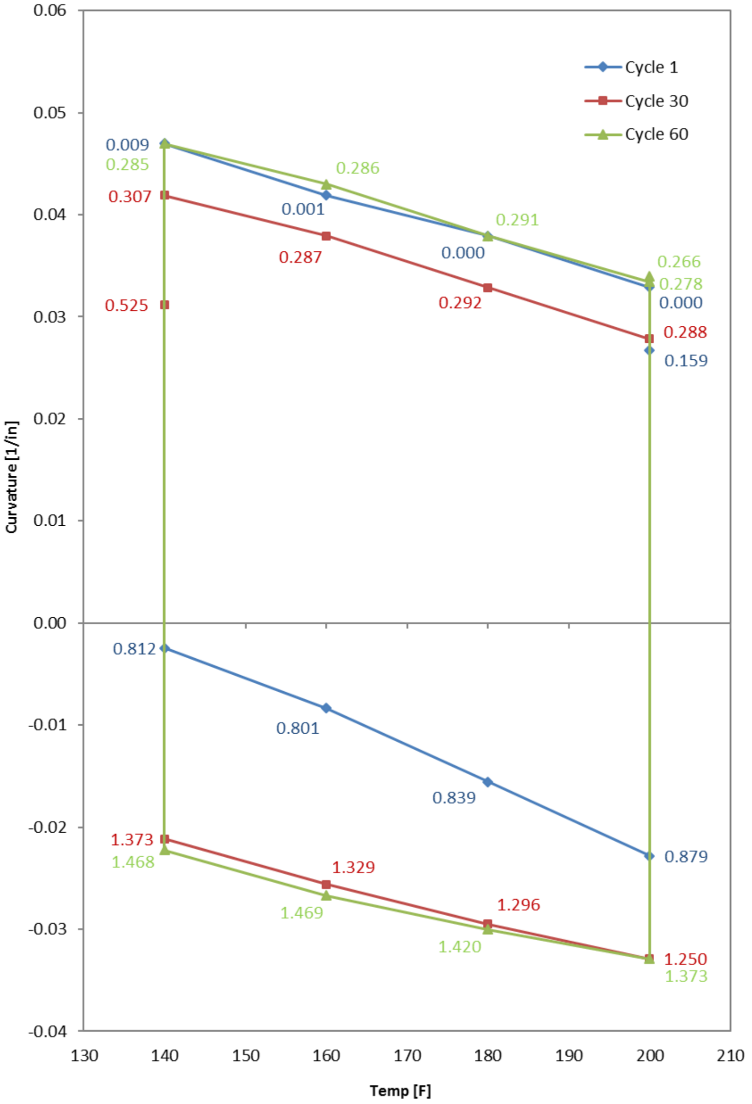
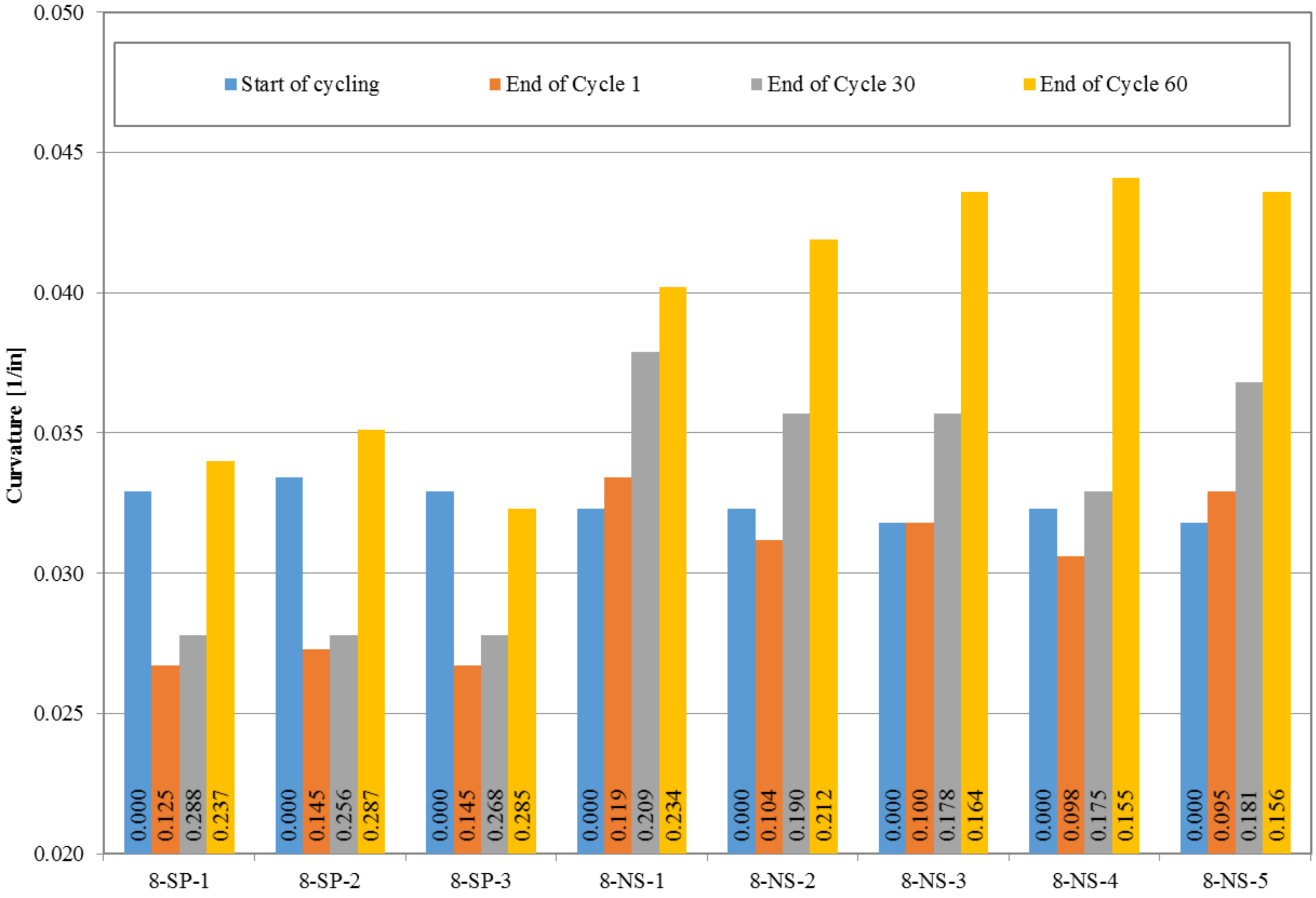
Ratcheting Effects – 8-Ply Specimens

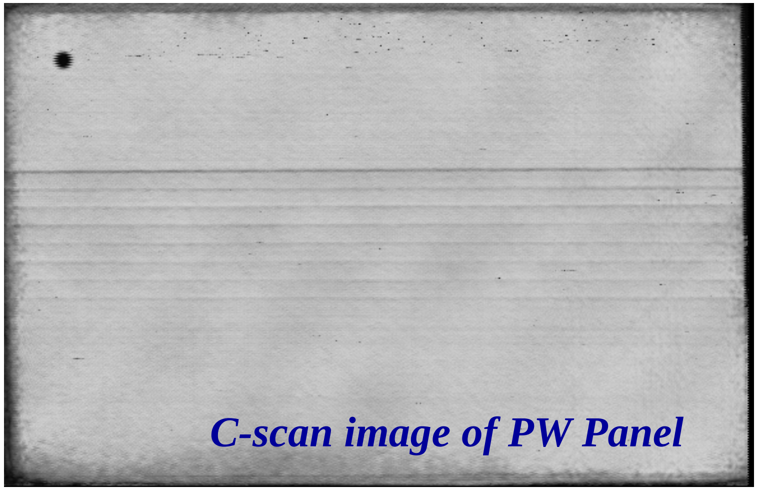


Curvature of 8-Ply Specimens

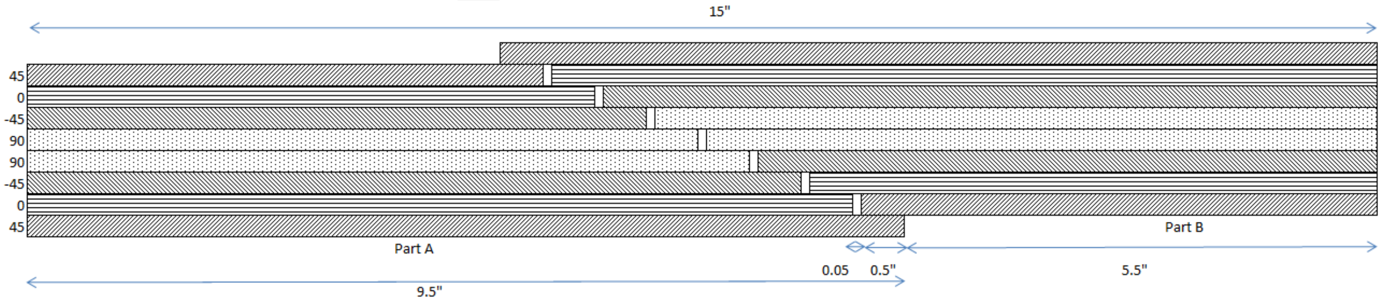


Spliced Tensile Specimens

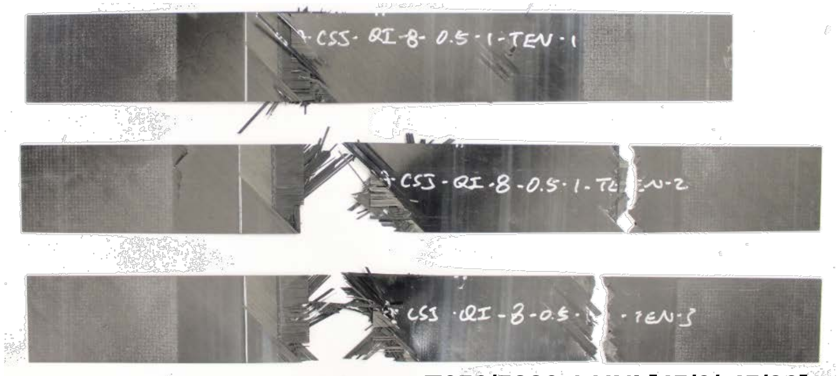
- Panels manufactured with the above splice configuration
  - T650/5320-1 Unidirectional material
  - T650/5320-1 Plain-Weave material
- Quasi-isotropic layup $[45/0/-45/90]_S$
- 0.5” Overlap, 0.05” Splice Gap
- 1.5”x12” tensile specimens



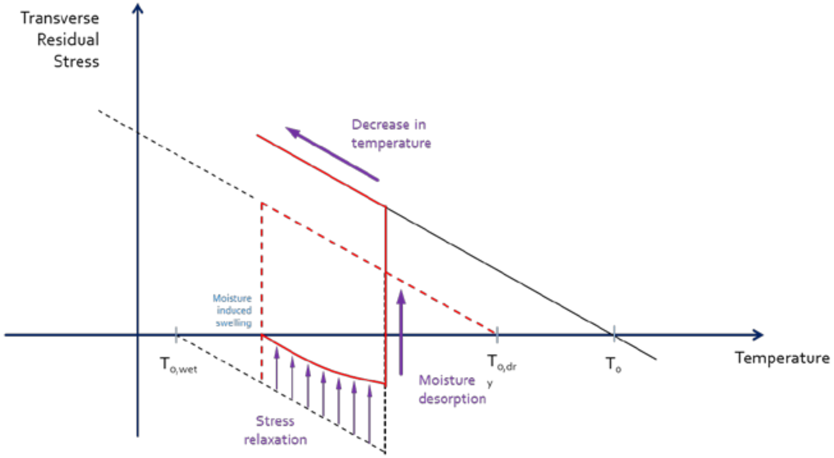
C-scan image of PW Panel

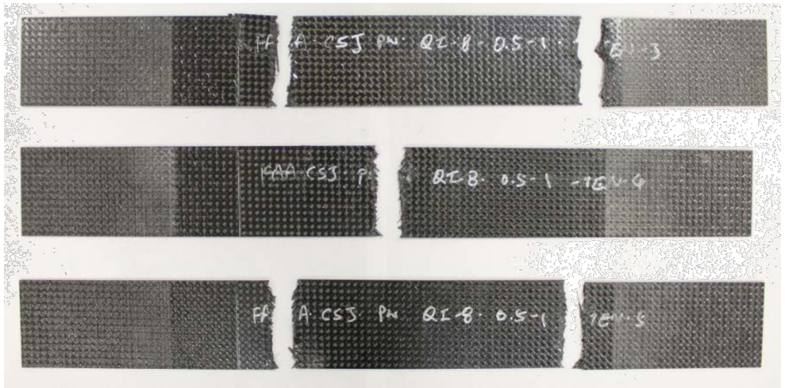


8-Ply Spliced Tensile Specimens

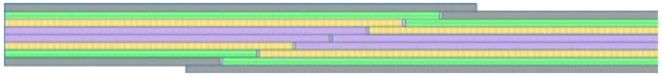


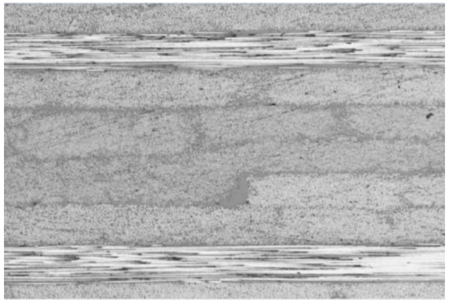
T650/5320-1 UNI [45/0/-45/90]$_S$





T650/5320-1 PW [45/0/-45/90]$_S$

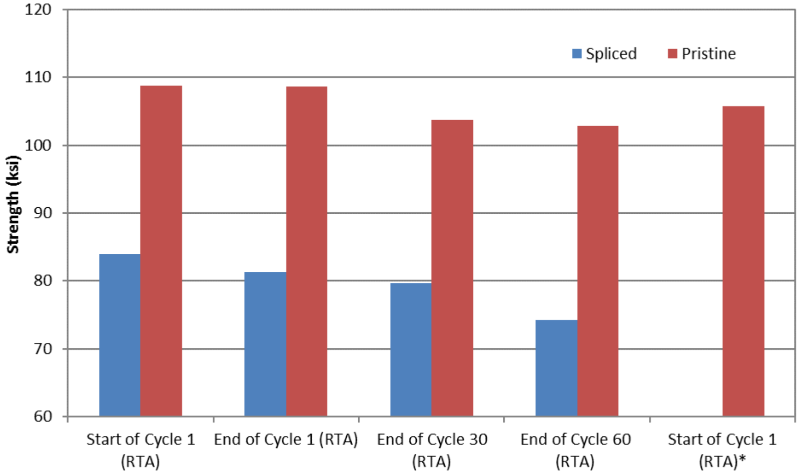


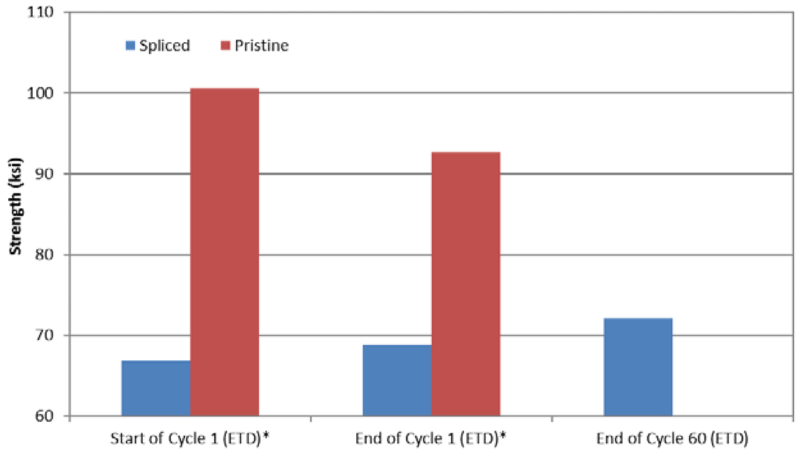


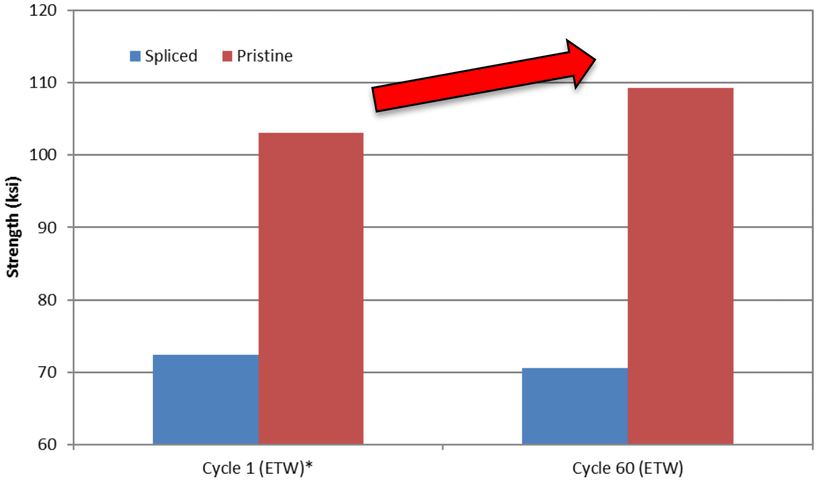
Summary of UNI

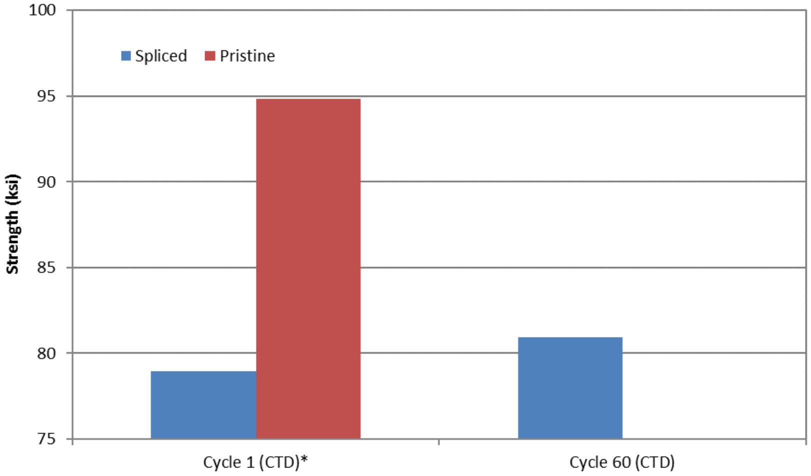
Test Point	Cycling Test Point	Testing Environmental Condition	Average Strength (ksi)		Average Modulus (Msi)	
			Spliced	Pristine	Spliced	Pristine
1	At end of initial drying	RTA	83.93	108.73	7.70	7.70
1a*		RTA	-	105.80	-	7.73
1b*		ETD (200°F)	66.80	100.60	6.64	7.29
2	Cycle 1: At end of Step 2	RTA	82.83	102.49	7.95	7.65
3	Cycle 1: At end of Step 2 and then held at -40°F for 1 day	RTA	80.11	-	7.81	-
3a*		CTD (-40°F)	78.96	94.87	7.09	7.44
4*	Cycle 1: At end of Step 3	ETW (200°F)	72.45	103.13	7.15	7.37
5	Cycle 1: End of cycle	RTA	81.33	108.66	7.96	7.87
5a*		ETD (200°F)	68.82	92.69	7.21	7.73
6	Cycle 30: End of cycle	RTA	79.62	103.75	7.64	7.32
7	Cycle 60: At end of Step 2 and then held at -40°F for 1 day	CTD (-40°F)	80.95	-	8.16	-
8	Cycle 60: At end of Step 3	ETW (200°F)	70.60	109.25	7.83	7.29
9	Cycle 60: End of cycle	RTA	74.27	102.82	8.28	7.85
9a		ETD (200°F)	72.12	-	8.08	-

UNI – Tensile Strength

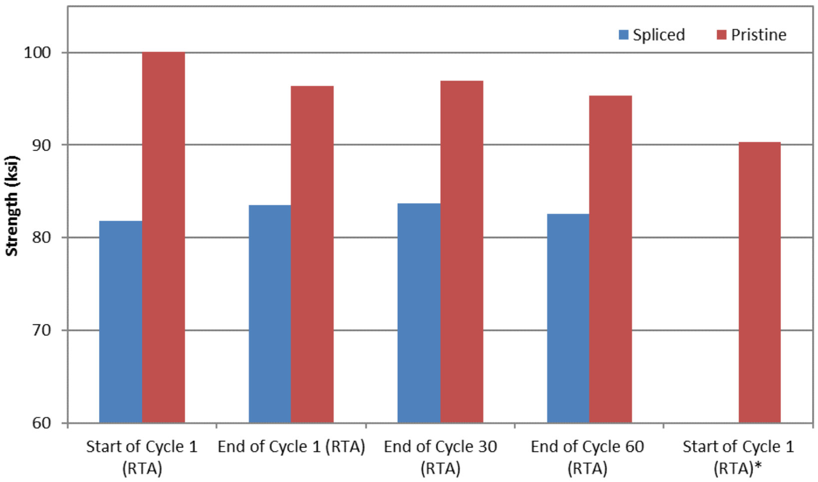


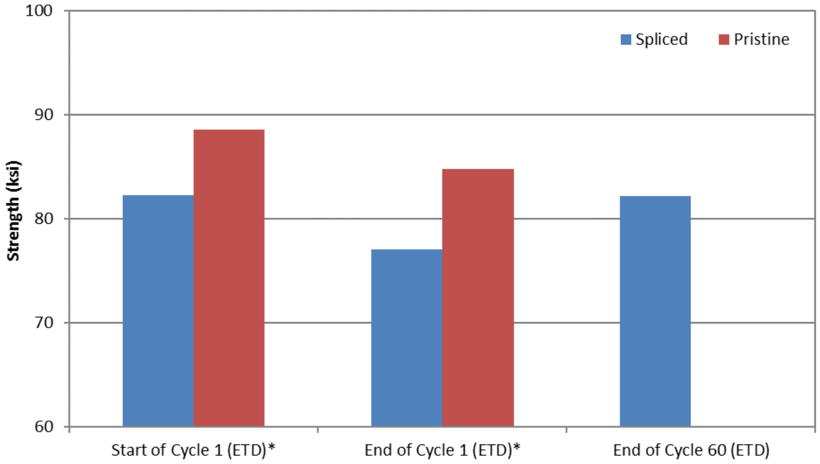


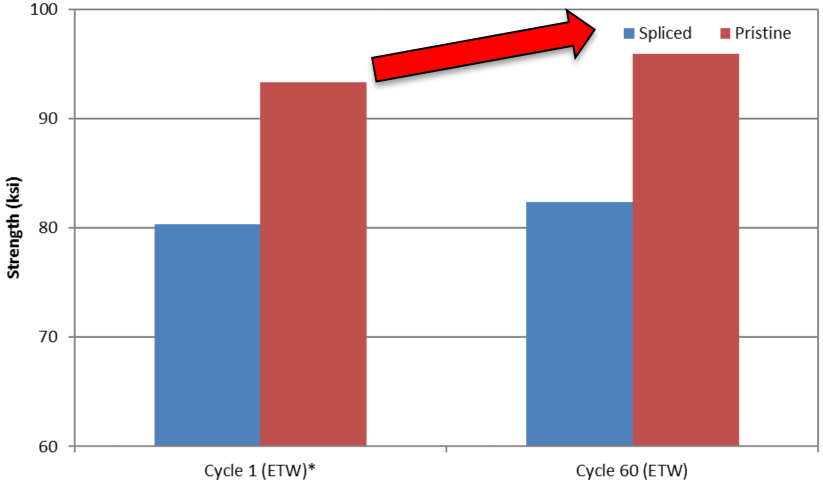


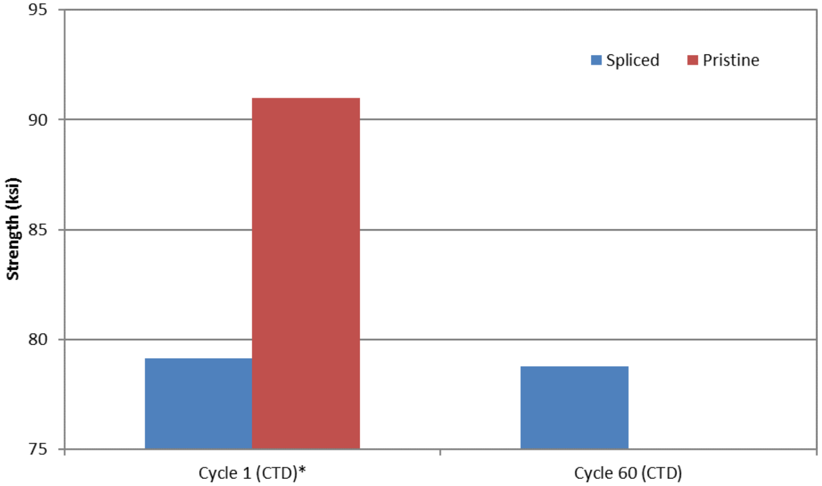


PW – Tensile Strength

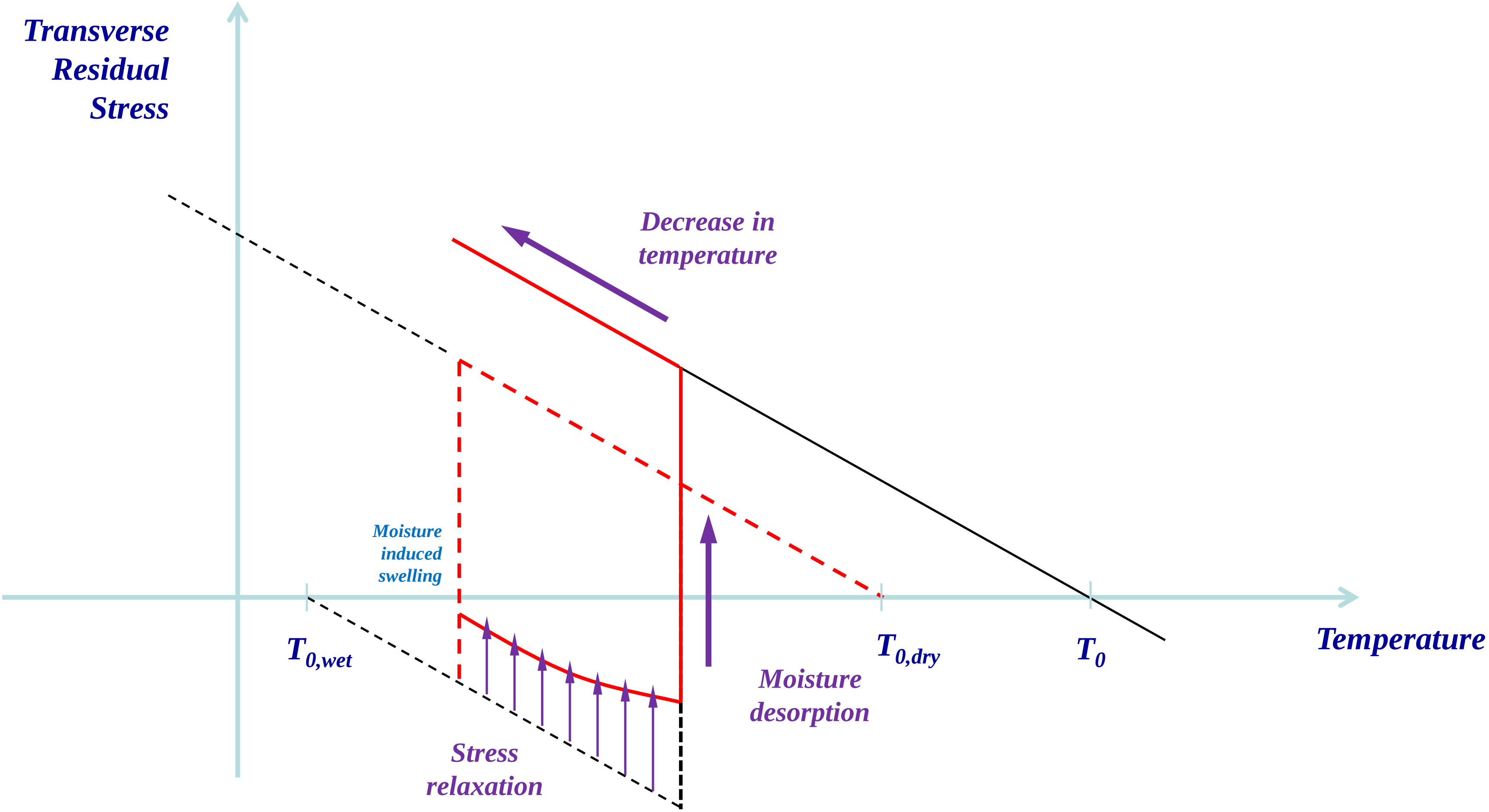








Crossman Loop



Summary

- Increase in transverse residual stresses (TRS) as specimens were cooled from cure temperature to room temperature
- Moisture absorption decreased TRS towards stress free state
  - Further absorption of moisture reversed the sign of TRS
- As the temperature was increased on wet specimens, TRS increased in the opposite sign of stress
  - Viscoelastic stress relaxation was observed towards the stress free state as the temperature was increased on wet specimens
  - VE response resulted in ratcheting phenomenon starting from cycle 1
- Effects of hygrothermal cycling on mechanical properties of splice joints indicated mixed results
  - UNI RTA specimens showed a decrease in strength with number of HTC
    - Significant strength knockdown on splice joints compared to pristine specimens
  - PW RTA specimens did not show a significant strength reduction with HTC
- Microcracks were not evident in splice area after 60 HTC
  - Failure initiated at the outermost splice joint

Looking Forward

- **Benefit to Aviation**
  - Understanding of hygrothermal effects on splice joints
  - Evaluation of ratcheting phenomenon and the effects of transverse thermal residual stress history on
- **Future needs**
  - Analytical model development accounting viscoelastic response for predicting transverse residual stress of splice joints undergoing hygrothermal cycling

End of Presentation.

Thank you.

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