Durability of Adhesively Bonded Aerospace Structures

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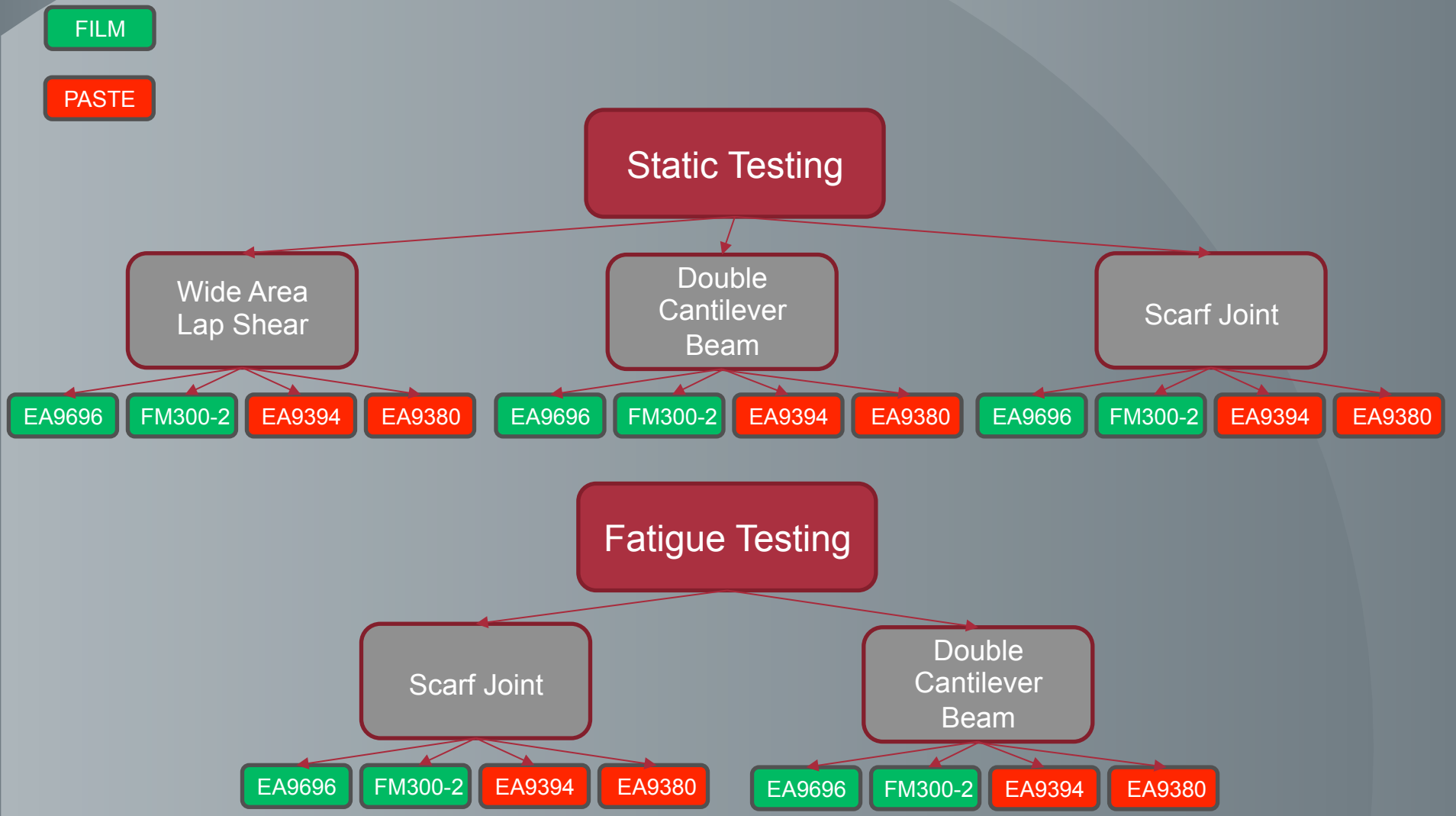
Washington State University
World Class. Face to Face.

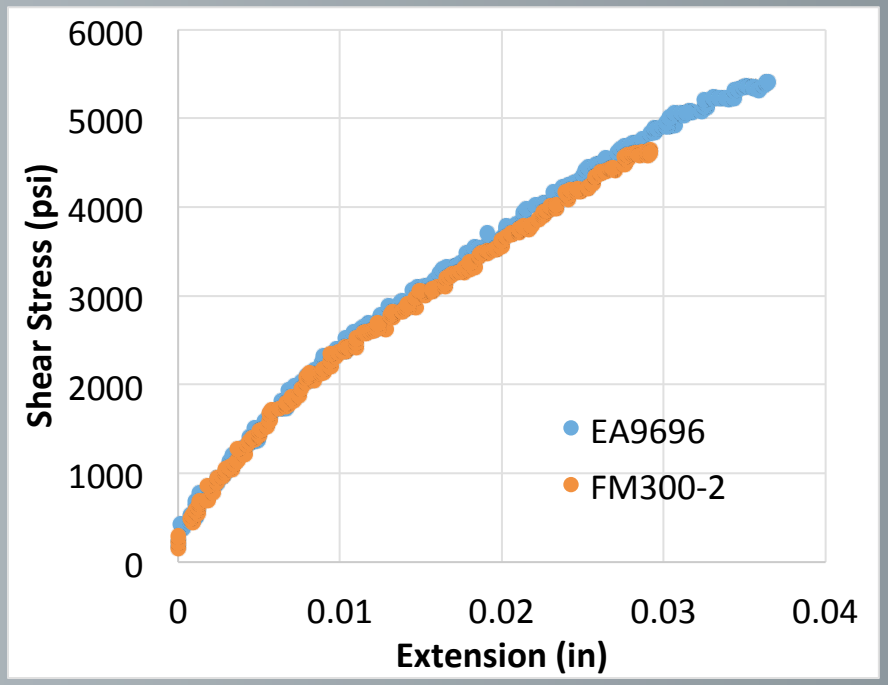
Outline

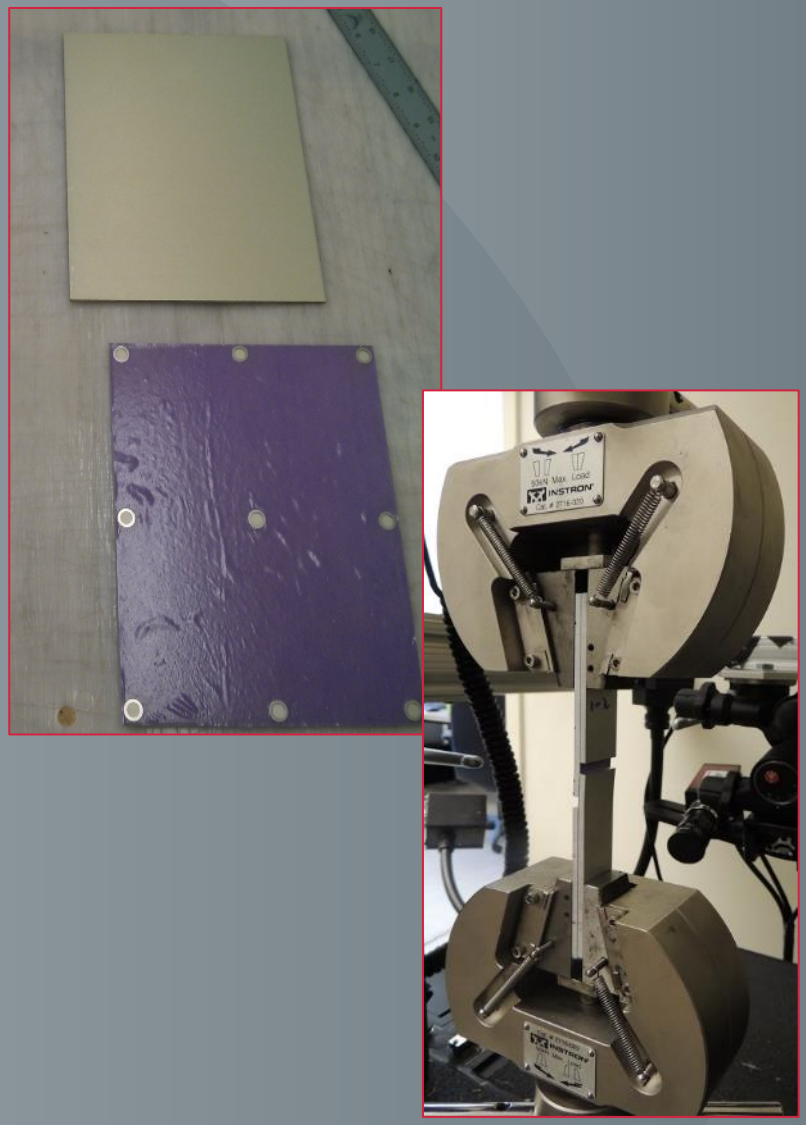
1. Fatigue
2. Ratcheting
3. Environment
4. Toughness (JCATI)

Fatigue Test Matrix



Wide Area Lap Shear



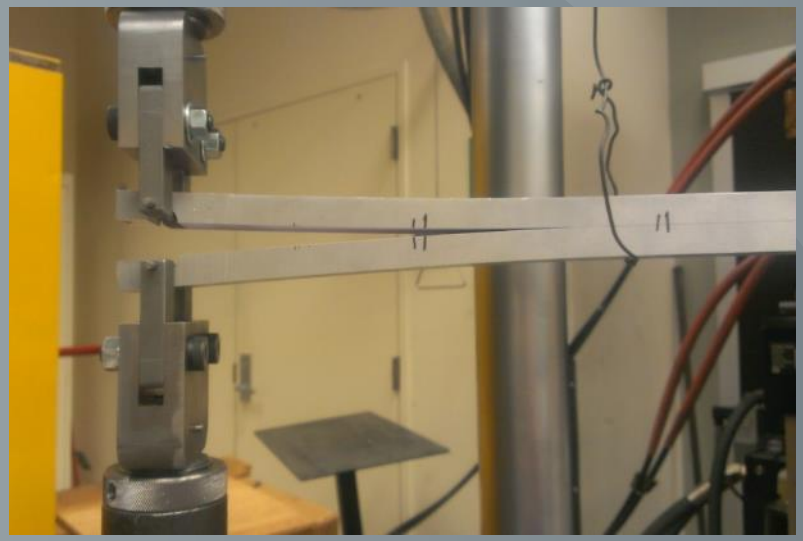


Double Cantilever Beam, EA9696

G_{1c}

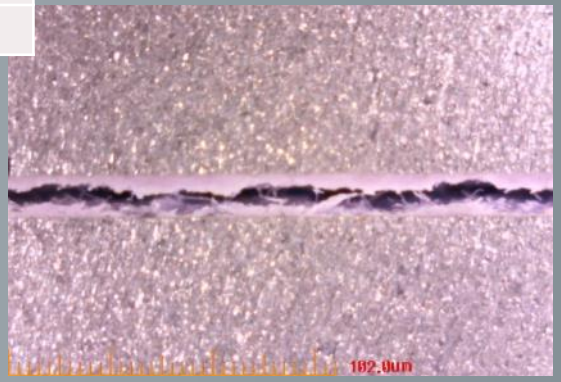
	BSS 7208	ASTM D3433
1st Crack	34.04 lb/in	21.59 lb/in
2nd Crack	30.72 lb/in	21.44 lb/in
3rd Crack	*	*
4th Crack	28.80 lb/in	22.02 lb/in
5th Crack	27.90 lb/in	21.94 lb/in

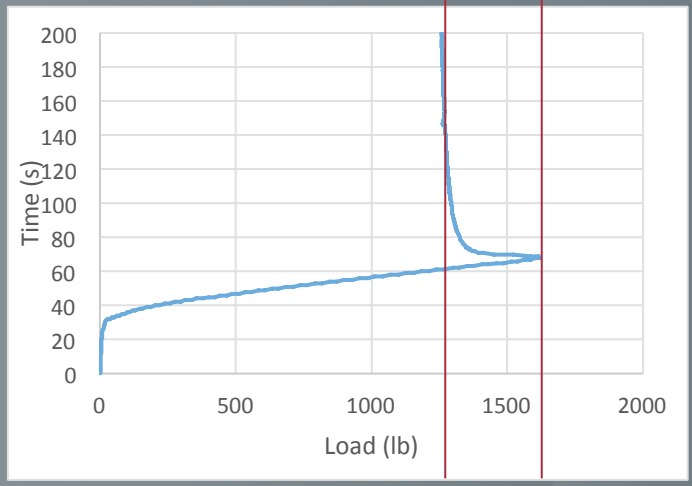
* Peak load wasn't captured



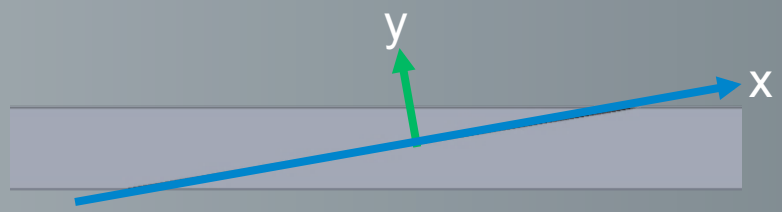
G_{1a}

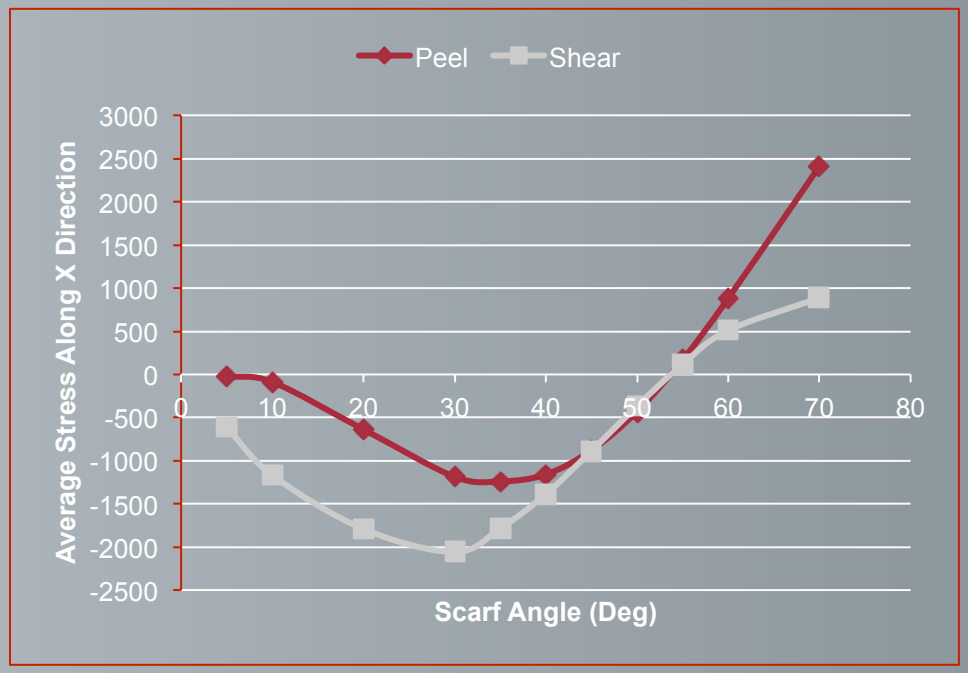
	BSS 7208	ASTM D3433
1st Crack	23.25 lb/in	16.23 lb/in
2nd Crack	21.33 lb/in	15.68 lb/in
3rd Crack	21.33 lb/in	16.31 lb/in
4th Crack	21.02 lb/in	16.52 lb/in
5th Crack	21.03 lb/in	16.95 lb/in

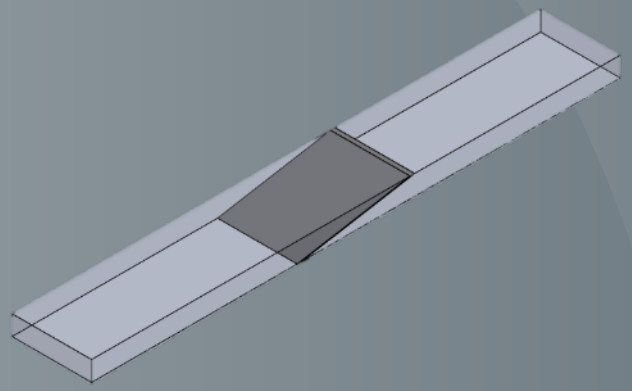




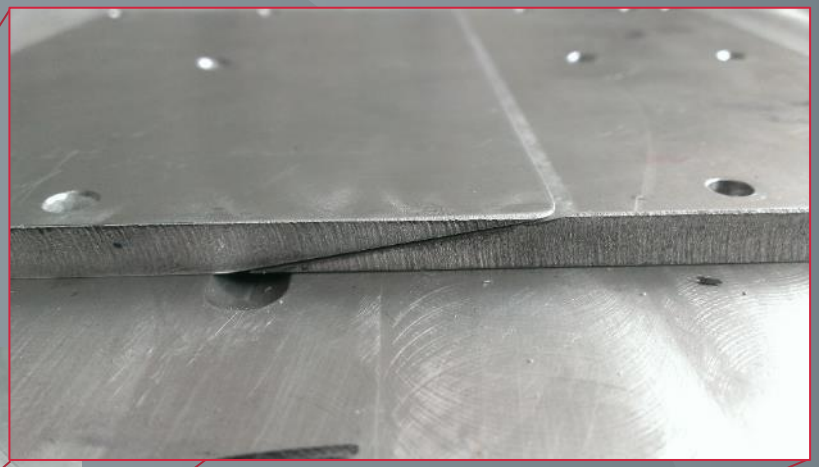
Scarf Stresses



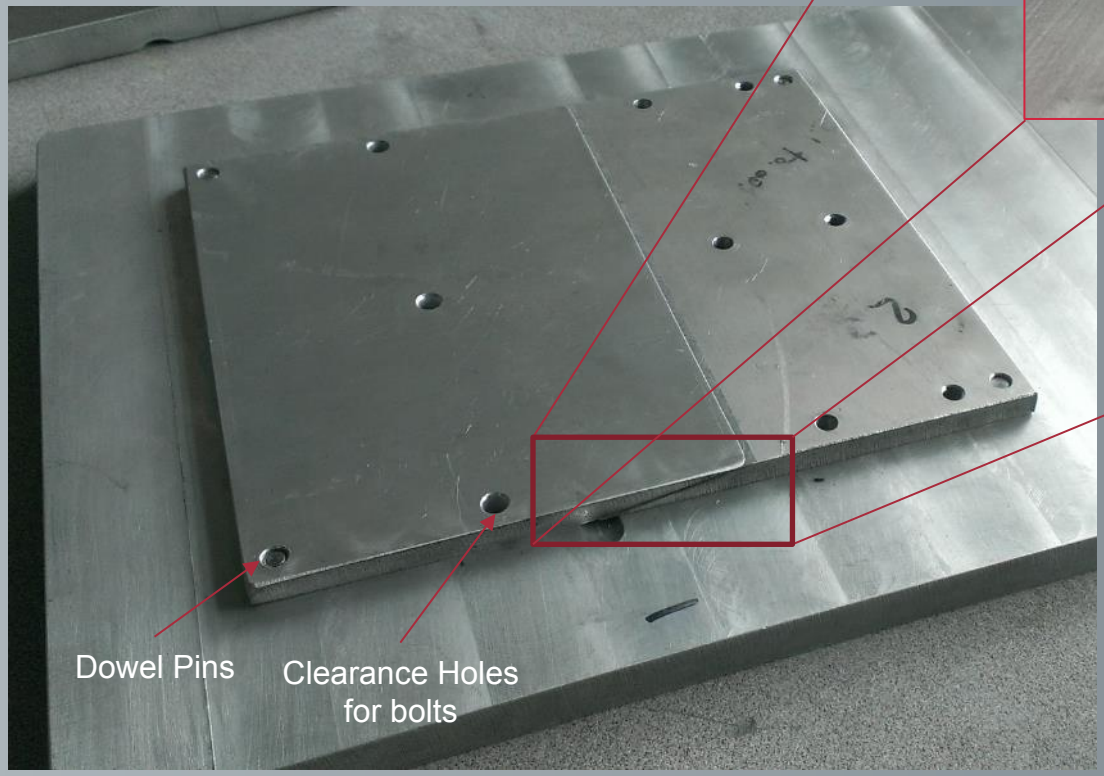




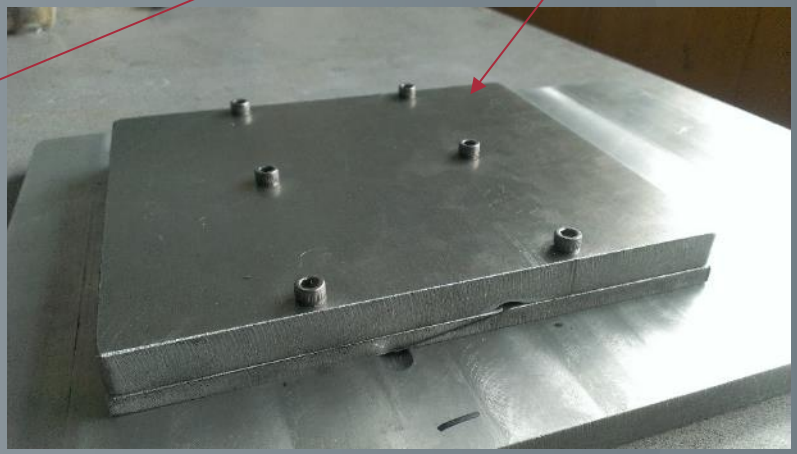
Scarf Fixture



Cure Plate



Top Plate

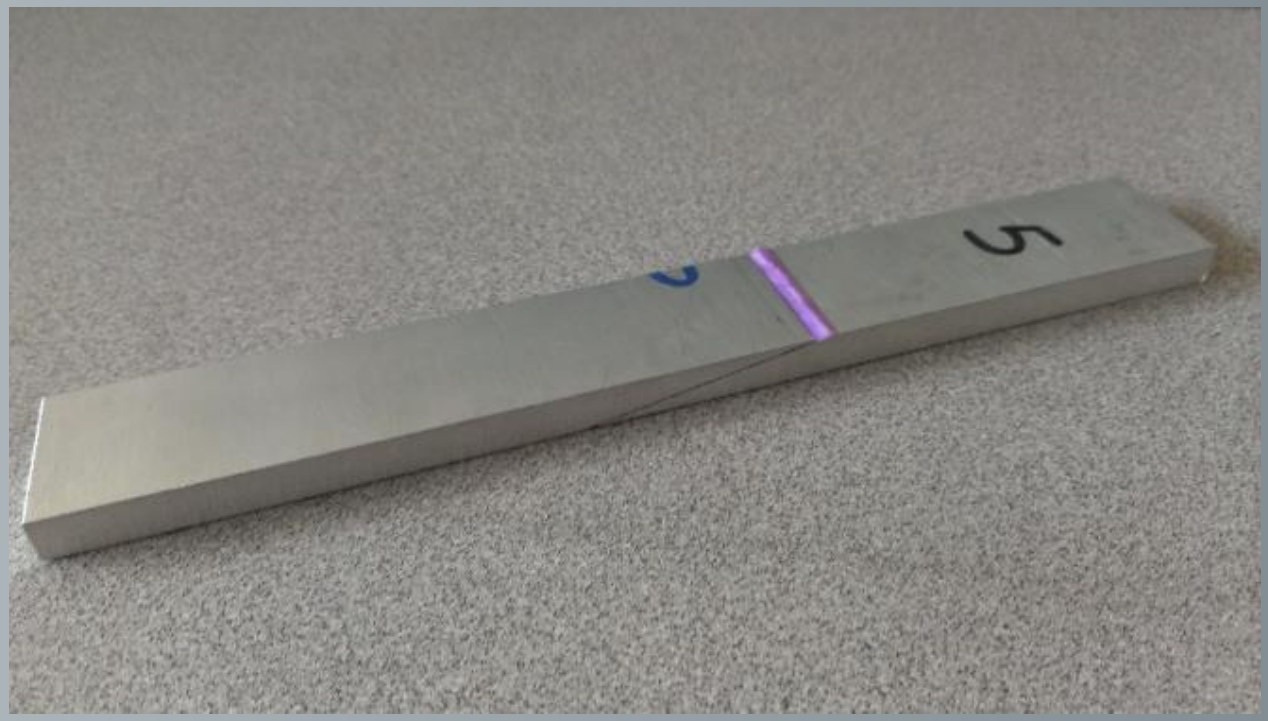


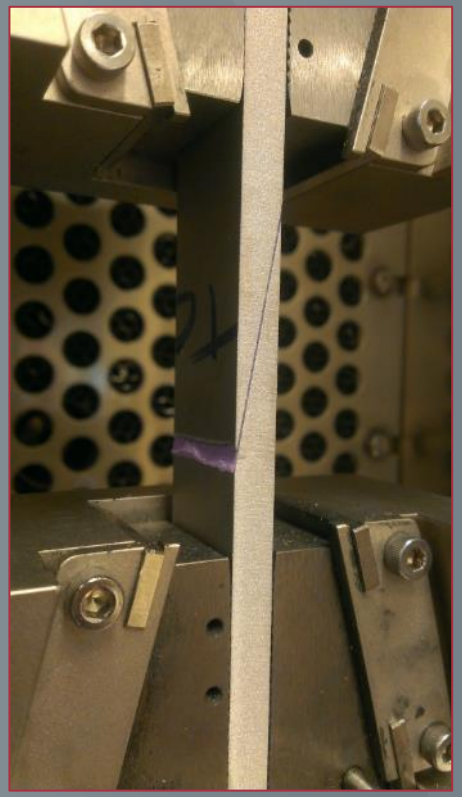
Scarf Joint

Status:

- Anodizing and priming complete and waiting for shipping
- Curing fixture has been developed
- Coupon dimensions have been finalized

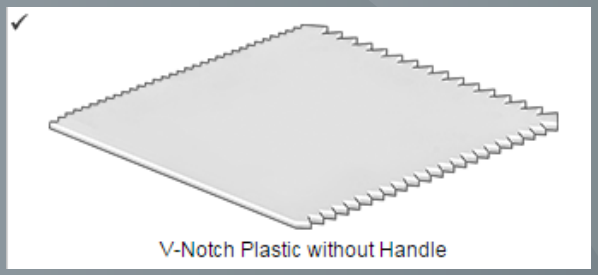
EA9696





Challenges

- Voids in paste adhesives



Next Steps

- Develop process for paste adhesive bonding
- Finish fabrication of WALS, scarf and DCB coupons
- Fabricate and test coupons

Viscoelastic Properties of Adhesives

Study the effects of creep, relaxation, and ratcheting in adhesives.

Ratcheting

Inputs:
- Mean Stress
- Stress Amplitude
- Strain Rate
- Peak Hold Time

Outputs:
- Cycles to Failure
- Strain at n Cycles

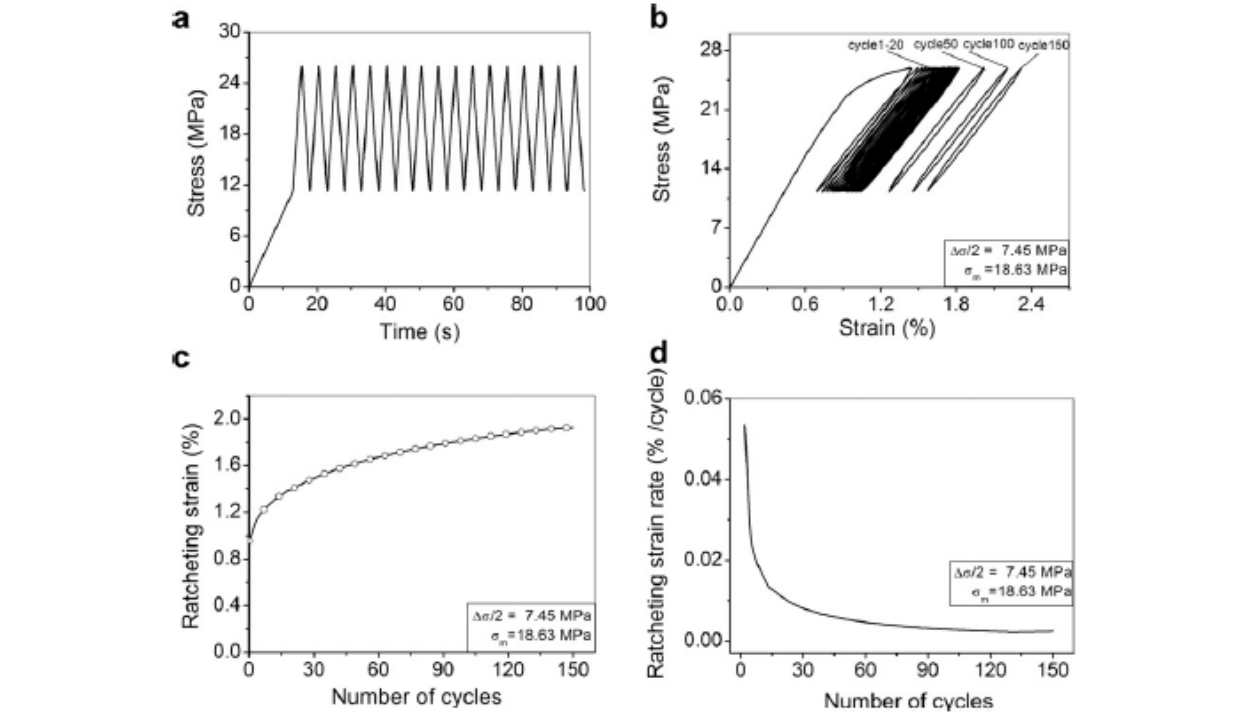


Fig. 3. Uniaxial ratchetting test of ACF: (a) stress control diagram; (b) stress–strain relationship; (c) ratchetting strain evolution; (d) ratchetting strain rate evolution.

Lin, Y.C., Xiao-Min Chen, and Jun Zhang. "Uniaxial ratchetting behavior of anisotropic conductive adhesive film under cyclic tension." *Elsevier* (2010). Print.

Adhesive: Hitachi AC-8955YW-23

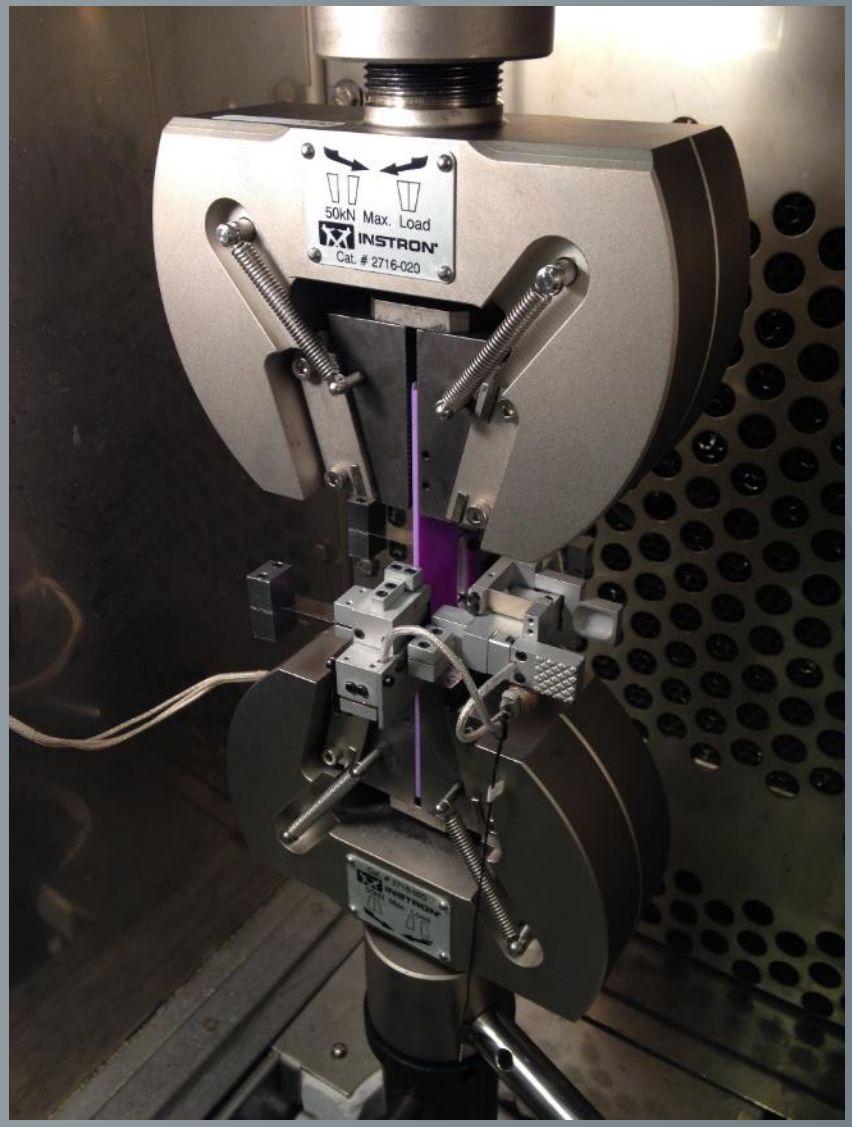
Viscoelasticity Test Matrix

	Creep	Relaxation	Ratcheting
Neat Resin	5 stress levels 4 durations 1 coupons per state **20 coupons total**	5 strain levels 4 durations 1 coupons per state **20 coupons total**	5 mean stresses 5 stress amplitudes 1 strain rates 3 coupons per state **75 coupons total**
Wide Area Lap Shear	5 stress levels 4 durations 1 coupons per state **20 coupons total**	5 strain levels 4 durations 1 coupons per state **20 coupons total**	5 mean stresses 5 stress amplitudes 1 strain rates 3 coupons per state **75 coupons total**
Scarf Joint	5 stress levels 4 durations 1 coupons per state **20 coupons total**	5 strain levels 4 durations 1 coupons per state **20 coupons total**	5 mean stresses 5 stress amplitudes 1 strain rates 3 coupons per state **75 coupons total**

Viscoelastic Properties of Adhesives

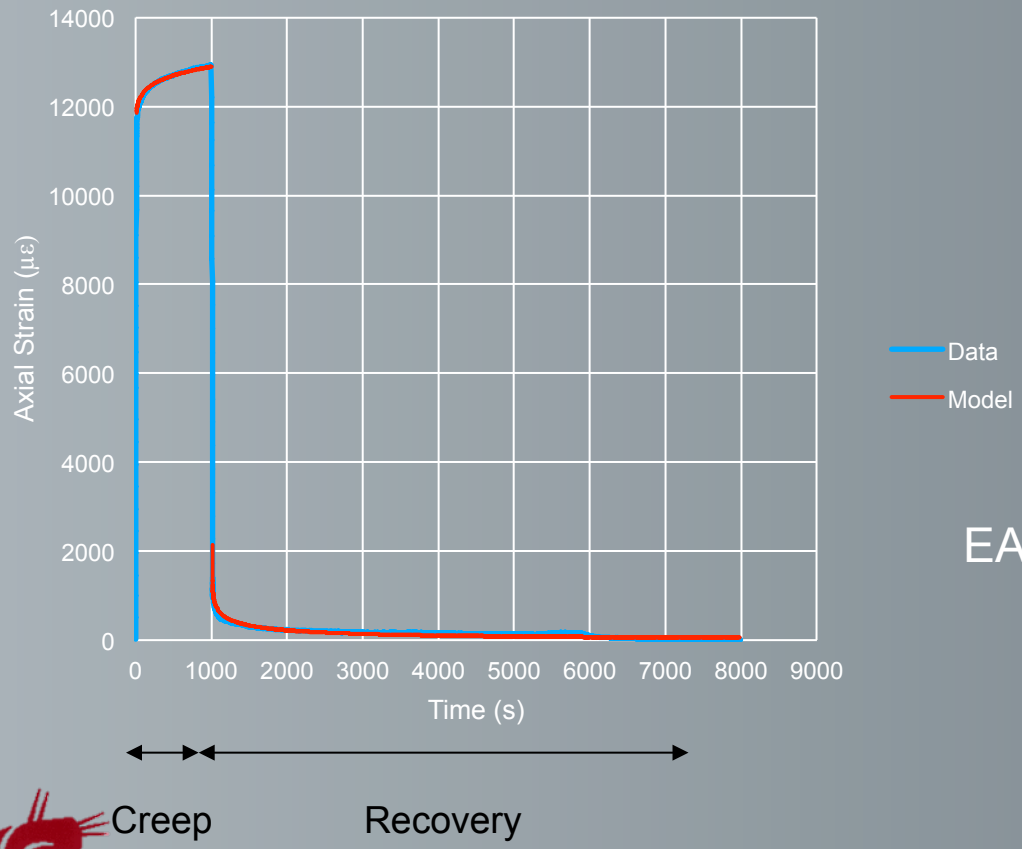
Neat Resin Creep Test

6” x 1” x 0.068” Coupons



Viscoelastic Properties of Adhesives

Creep Model



Creep:

$$\epsilon(t)=\sigma\downarrow 0\ [D\downarrow 0 + D\downarrow 1\ t\uparrow n\ ]$$

Recovery:

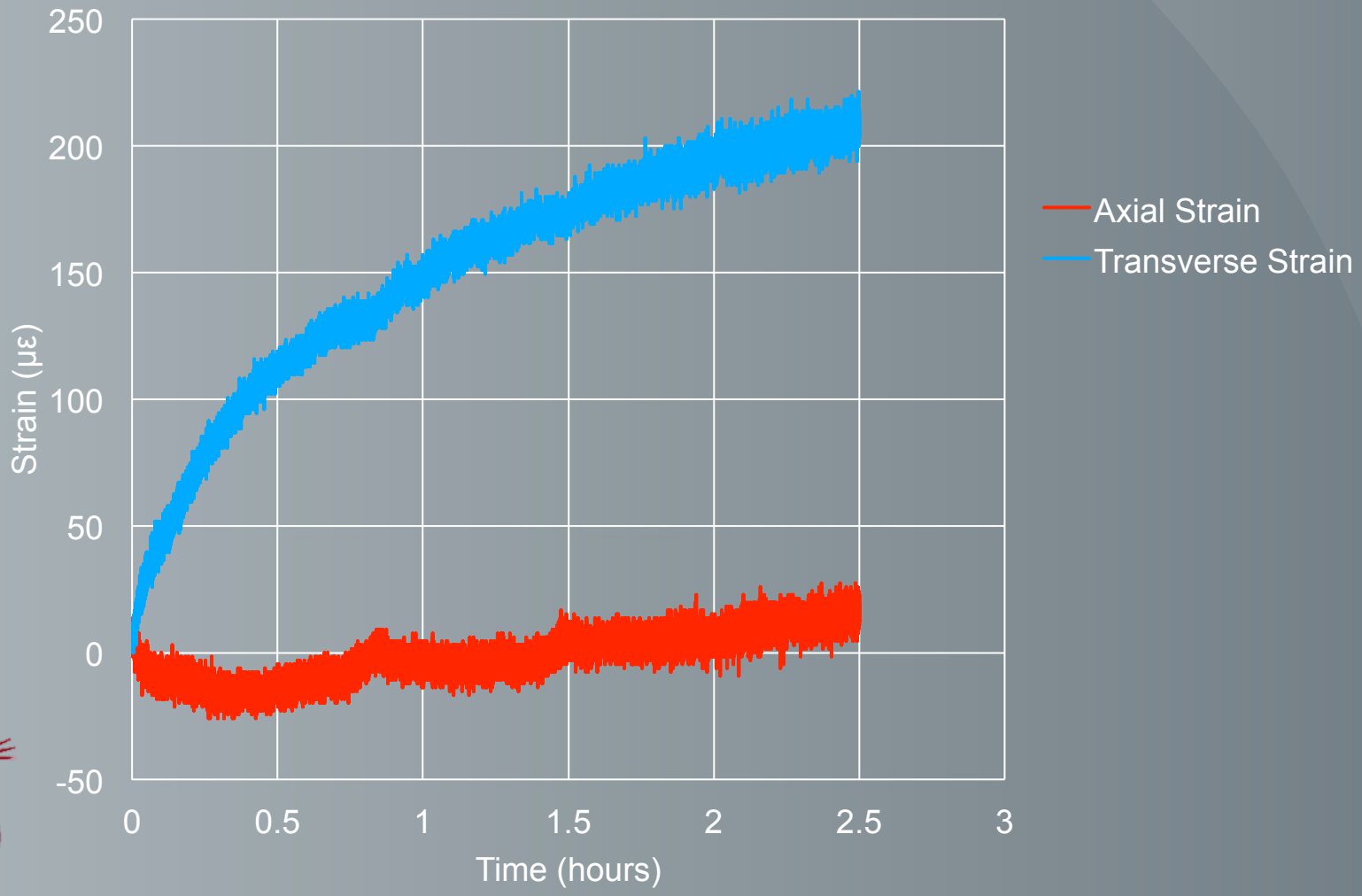
$$\epsilon(t)=\sigma\downarrow 0\ D\downarrow 1\ [t\uparrow n - (t - t\downarrow 0\ )\uparrow n\ ]$$

EA9696, $\sigma\downarrow 0 = 3{,}250\ psi$, $t\downarrow 0 = 1{,}000\ sec$

$D\downarrow 0 = 3.31$
$D\downarrow 1 = 0.25$
$n = 0.14$

Viscoelastic Properties of Adhesives

Creep Test Challenges



Next Steps

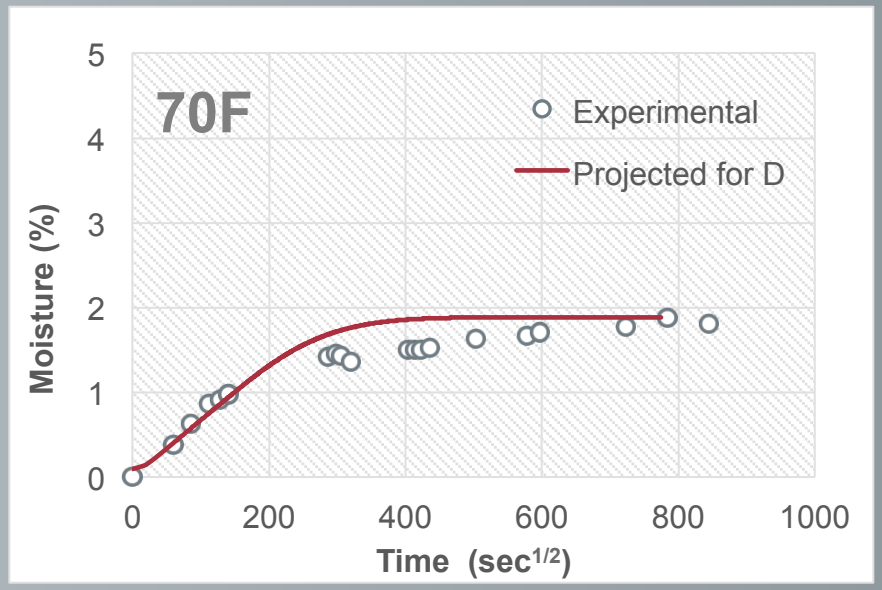
- Develop method to measure quasi-static transverse strain in neat resin coupons
- Viscoelastic characterization of EA9696 and FM377
- Develop method to measure cyclic strain of neat resin coupons
- Investigate environments leading to ratcheting behavior

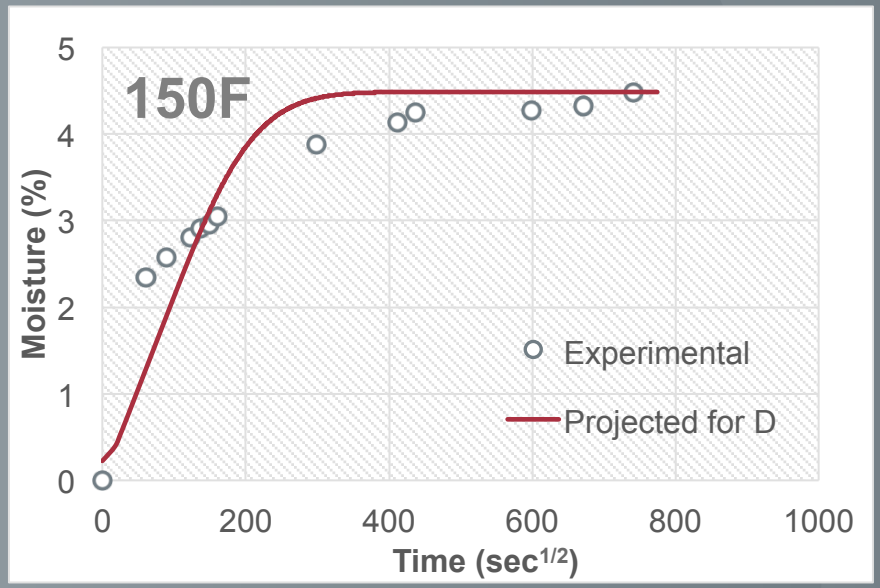
Environmental Effects on Adhesive Fatigue

- Adhesives lose strength and fatigue resistance in hostile environments.
- Changes threshold stress and crack growth rate.
- Temperature tends to have larger effect on crack growth rate than the threshold stress.
- Humidity tends to affect the threshold stress and crack growth rate.
- Temperature and humidity influence failure modes.

Diffusivity constant

- EA 9696
  - 0.008 inch thickness
  - immersed in water
  - 70 F, D = 1.8×10^{-10} in^2/s
  - 150 F, D= 3.2×10^{-10} in^2/s





Scope of Work

Adhesives
EA 9696
FM 300-2

Coupons
Double cantilever beam
Single lap shear
Scarf

Temperature
-5°C
30°C
65°C
100°C

Humidity
30%
60%
100%

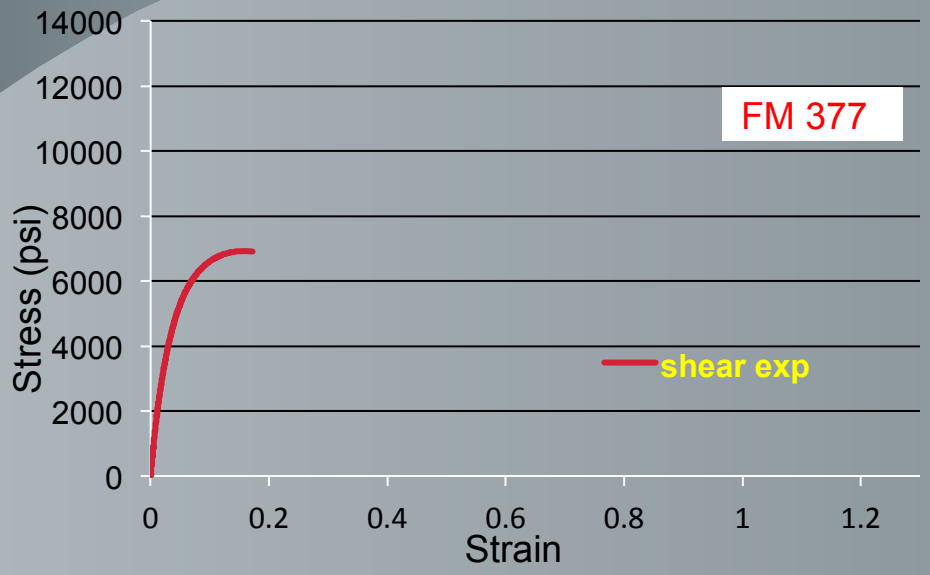
Next Steps

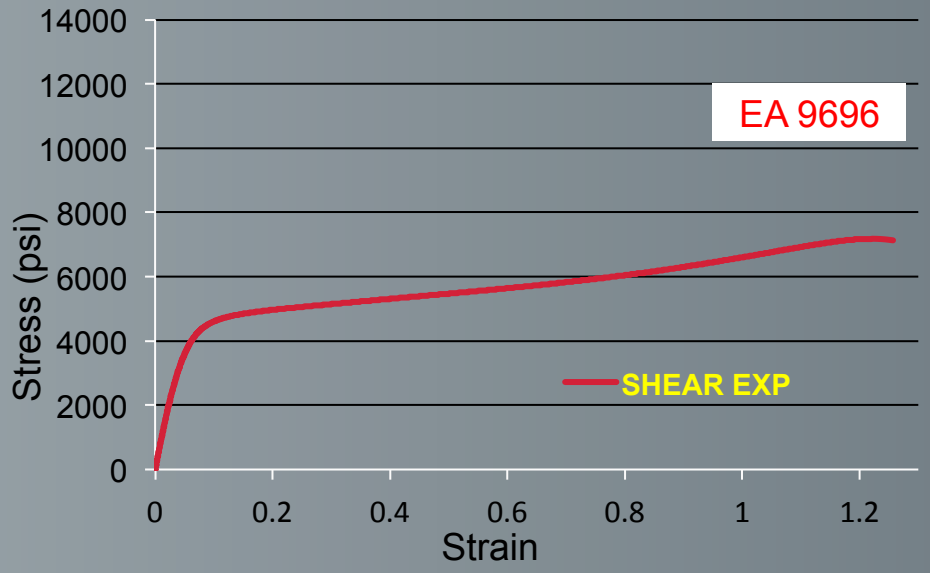
- Complete moisture diffusion studies
- Determine the effect of temperature on adhesive toughness
- Fabricate scarf coupons
- Compare the roll of temperature and adhesive on toughness in fatigue

Effect of toughness on adhesive fatigue (JCATI)

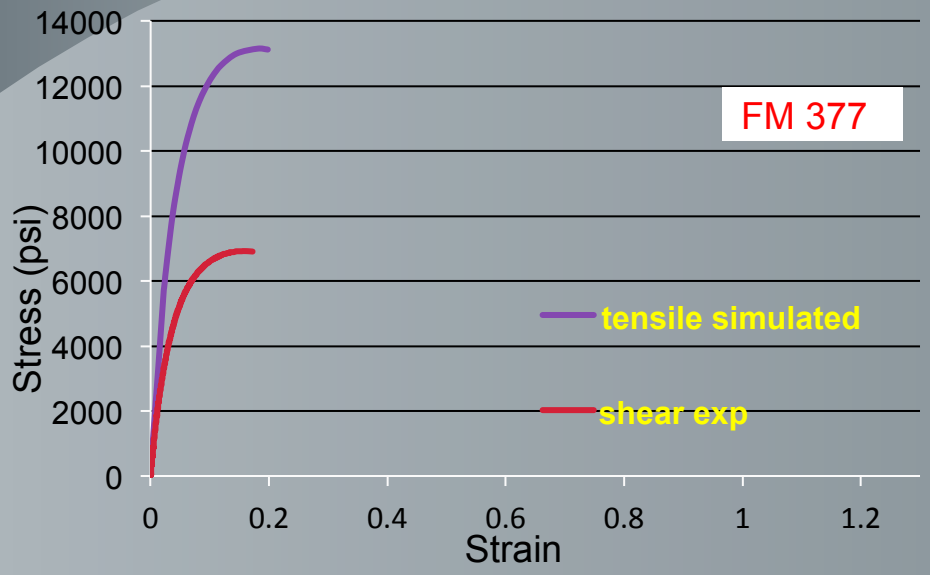
- Compare fatigue response of joints with varying toughness
  - Through adhesive properties
    - EA9696
    - FM377
  - Through adhesive thickness

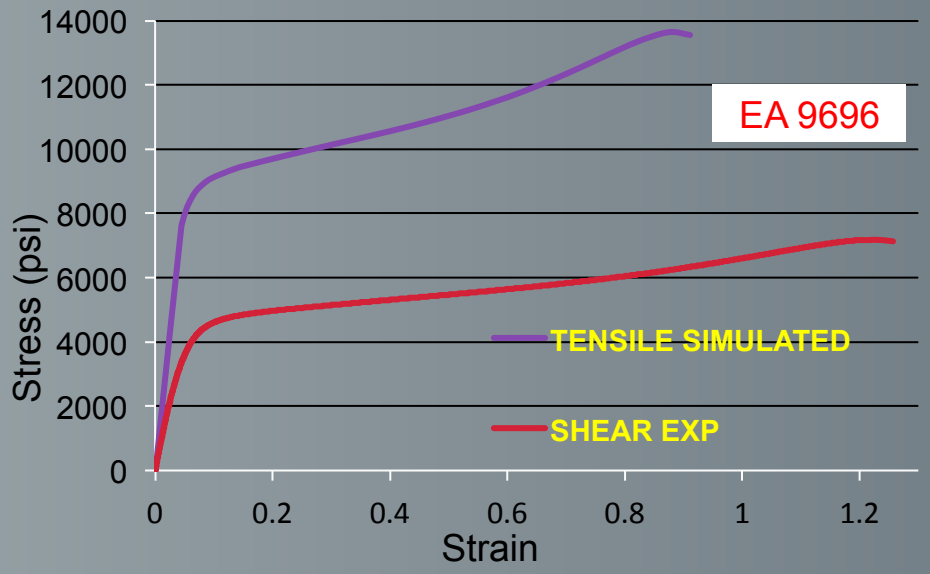
Experimental and simulated material properties



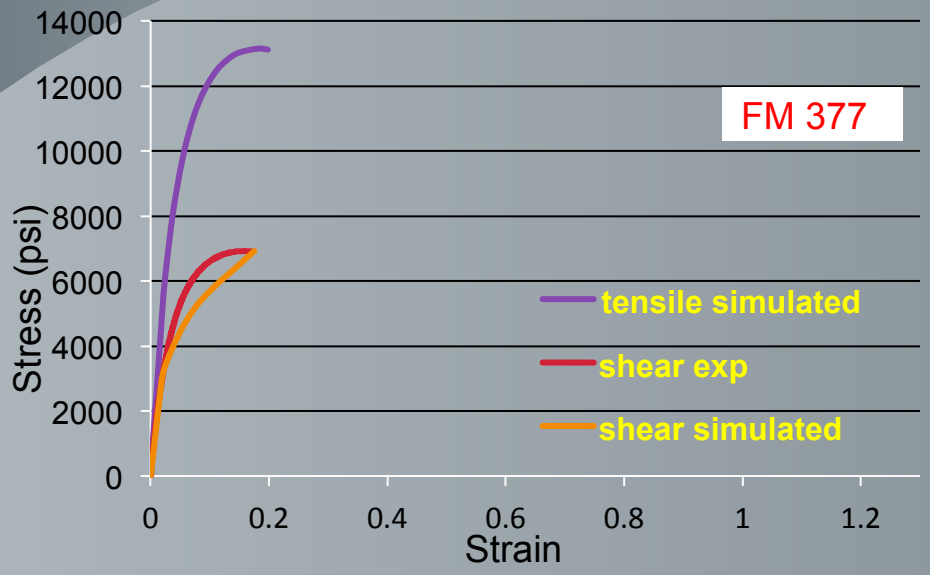


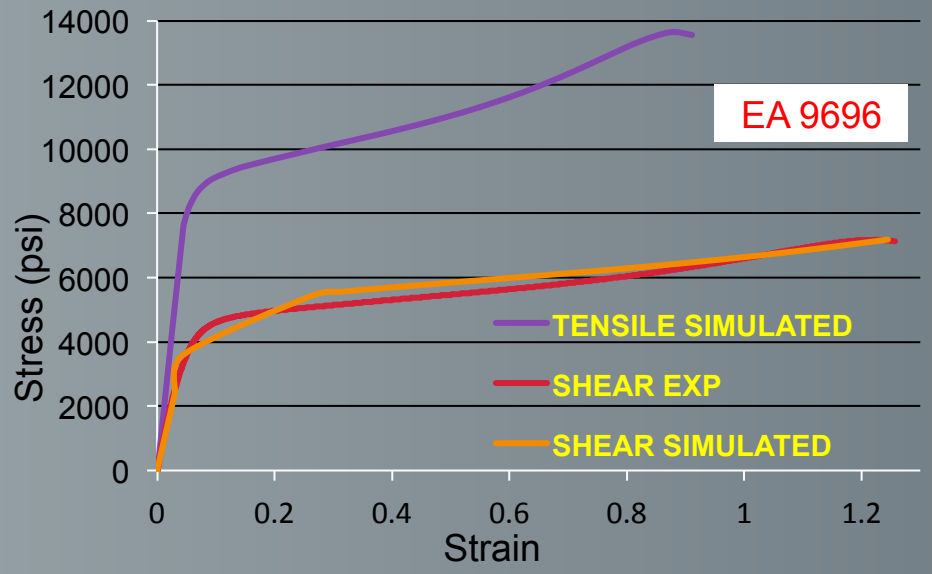
Experimental and simulated material properties



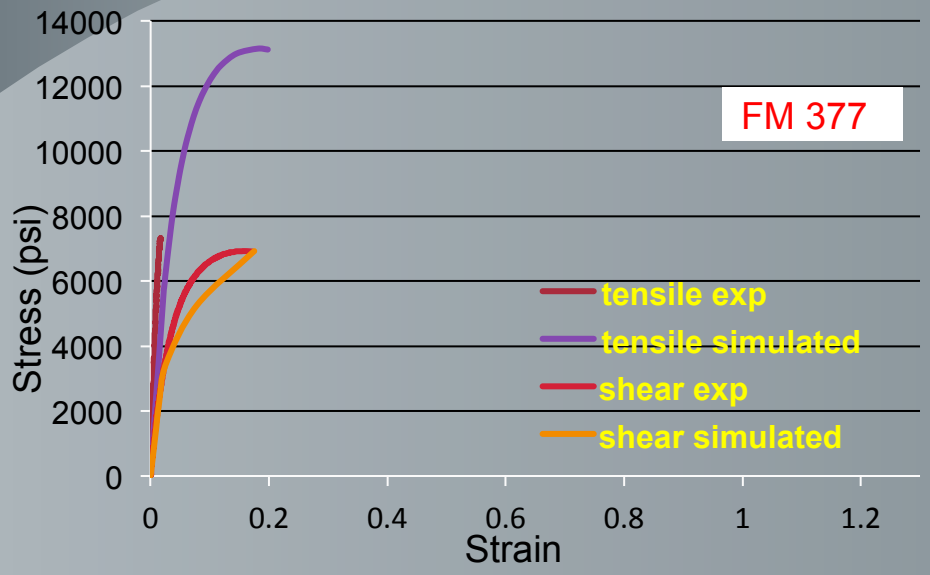


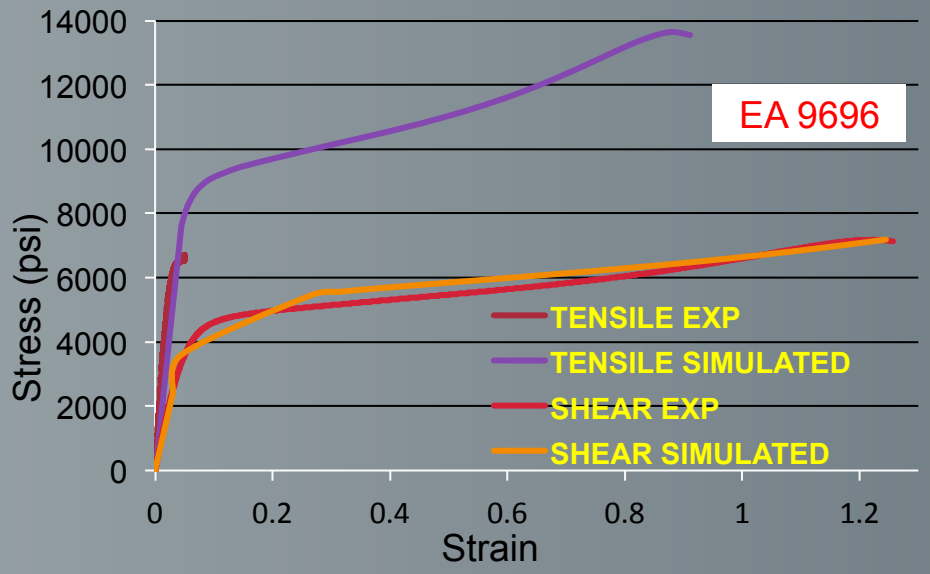
Experimental and simulated material properties





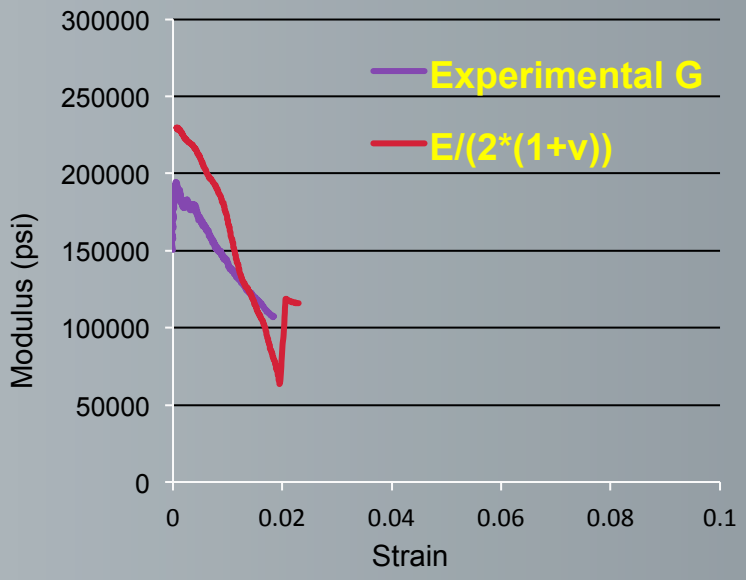
Experimental and simulated material properties

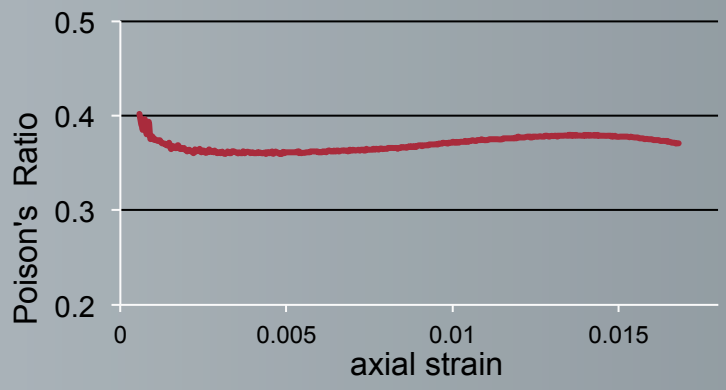




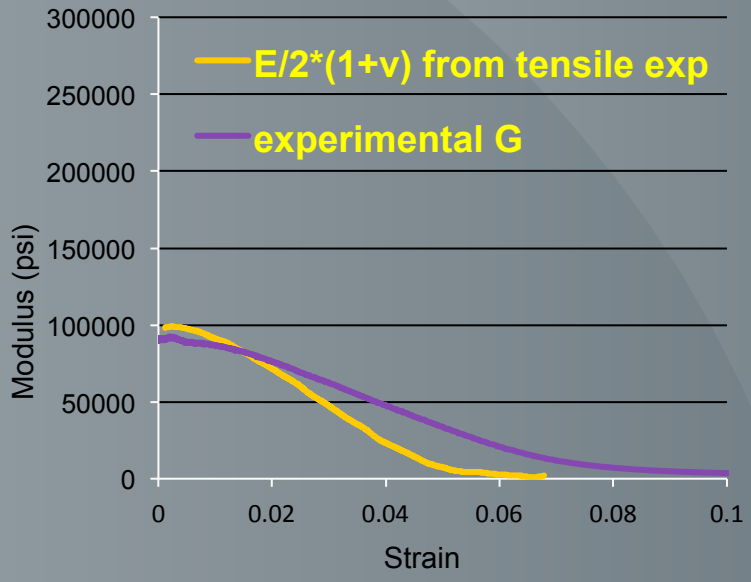
Adhesive Isotropy

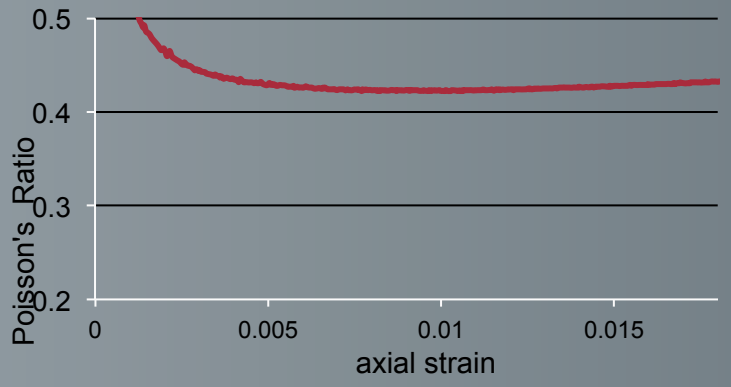
FM377





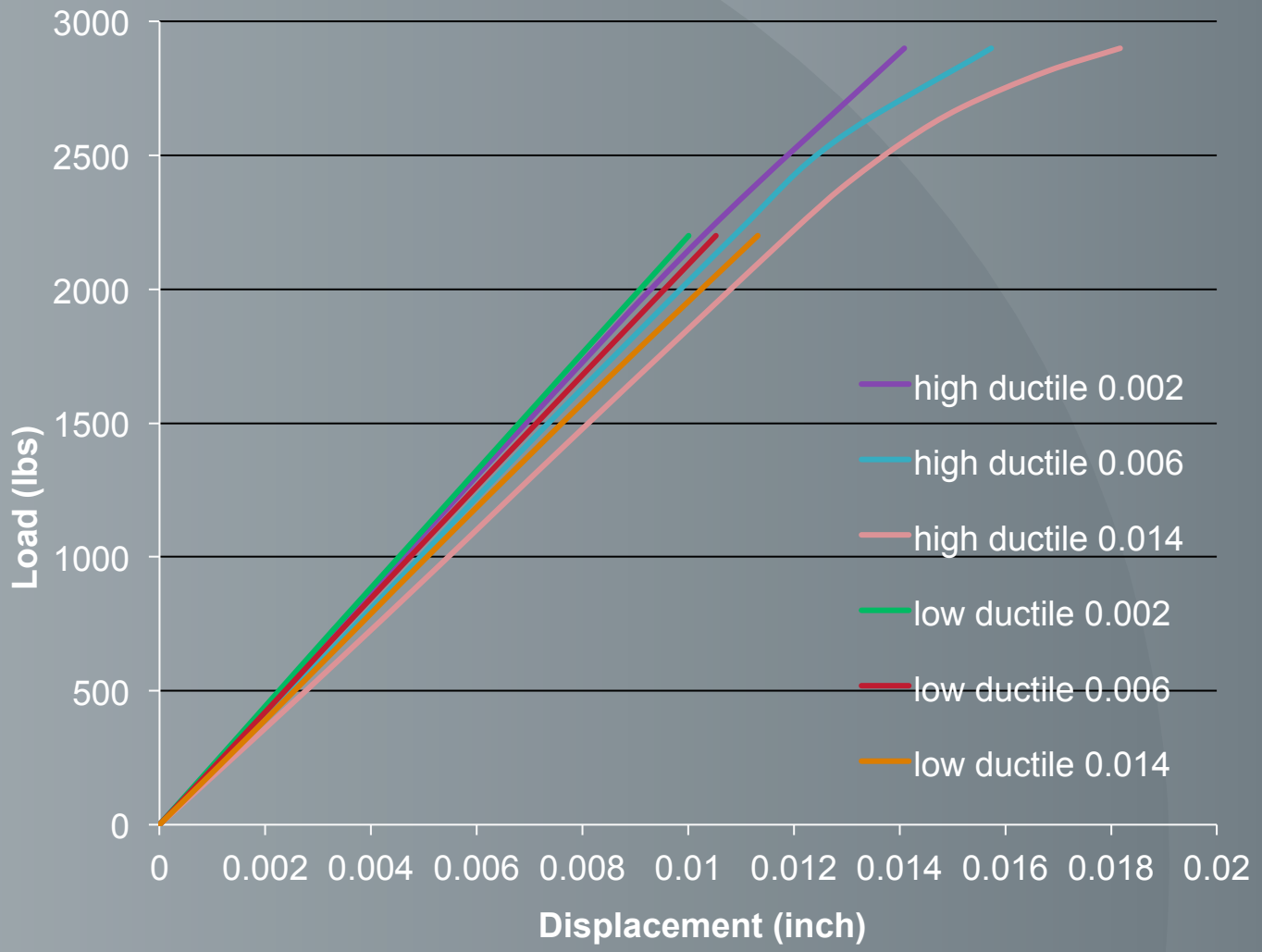
EA9696





Bond toughness increases with bondline thickness

- FEA simulation of Wide Area Lap Shear specimens
- High ductile sustains higher load
- Low ductile: lower load
- Both adhesives show longer elongation with thicker bonds



Next steps

- Complete adhesive isotropy study
- Fabricate coupons with varying thickness and adhesive toughness
- Compare the roll of joint toughness (from adhesive and adhesive thickness) on fatigue