Comparing Characterization Methods for Investigation High-Temperature Bending Behavior of Melted Thermoplastic Prepreg using DMA and Rheometer

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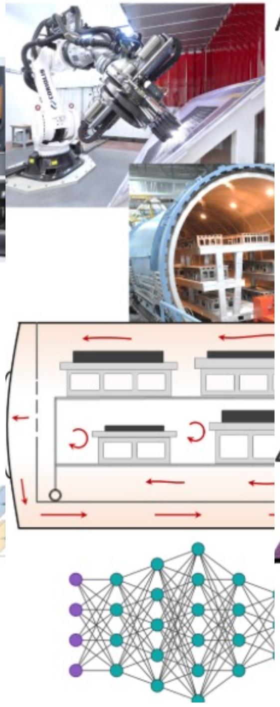
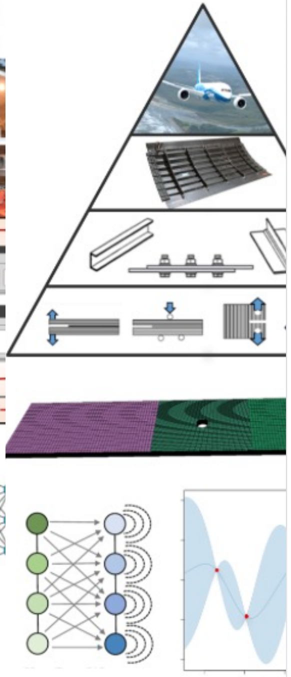
PI: Prof. Navid Zobeiry

Accelerated Material Testing and Discovery

Smart Manufacturing



Accelerated Qualification and Certification



Degradation, End-of-life, and Recycling

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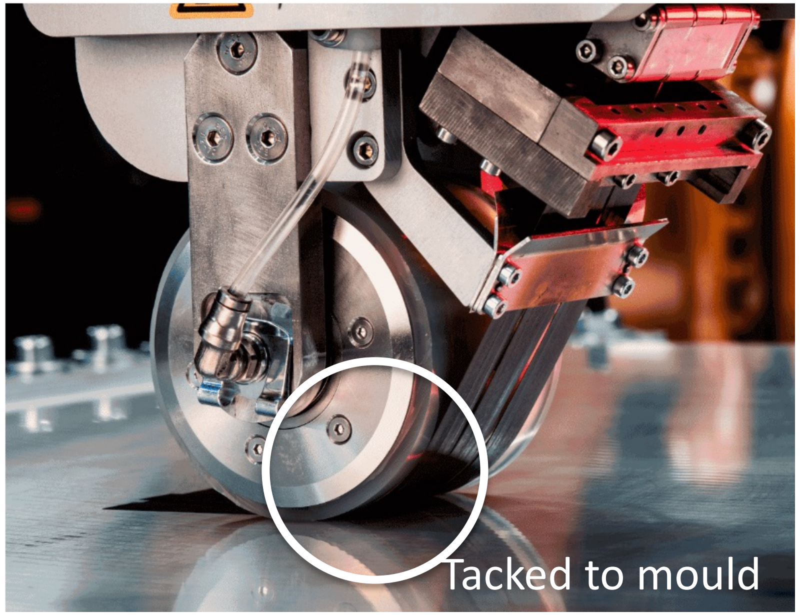
Background

- Prepreg bending is key deformation mechanism during automated fiber placement (AFP) and hot drape forming

- Prepreg's bending response strongly depend on

- Temperature
- Loading rate



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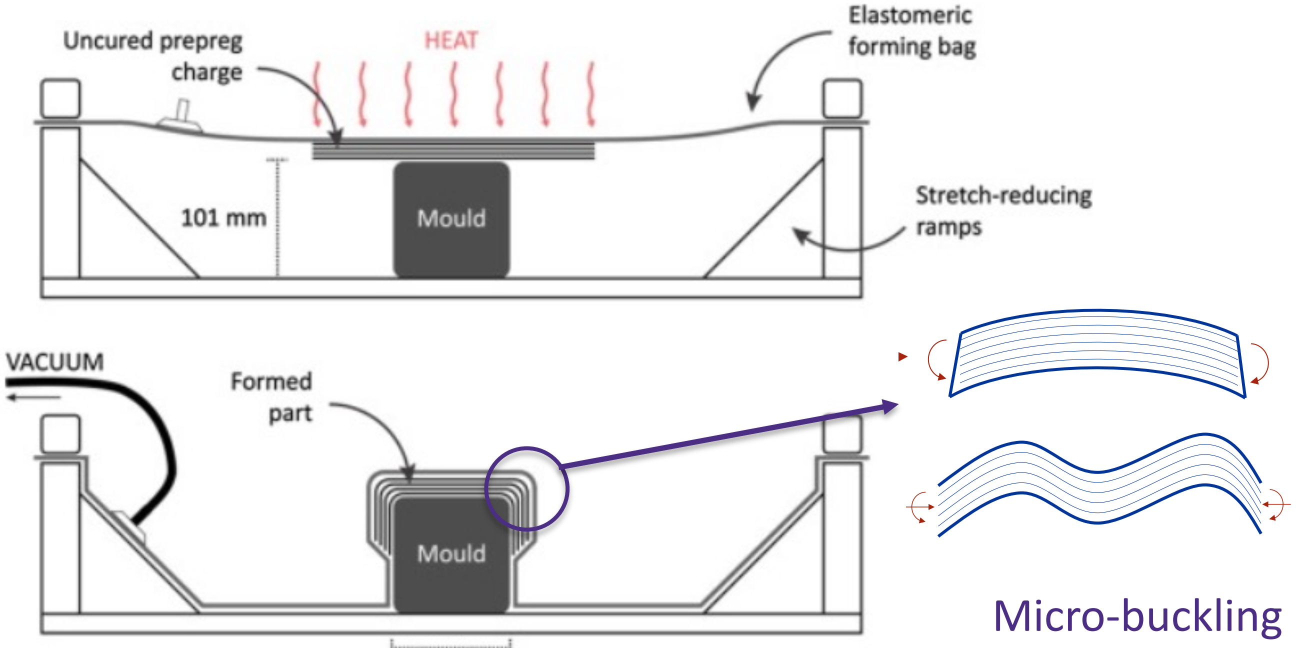

Farnand et al. 2017

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Convergent's Pure Bending Fixture

Relative work have done with rheometer by Convergent Manufacturing Technologies for thermoset prepreg

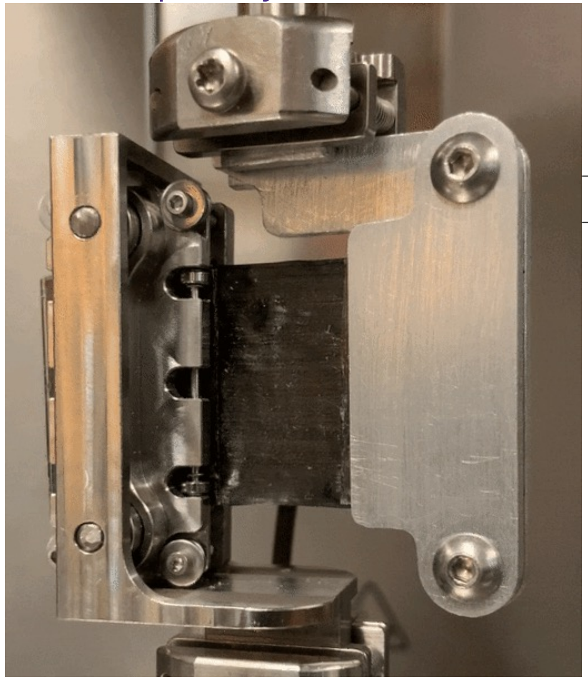
Key features:

- Double roller design:
  - Minimizing frictional and membrane effects
  - Providing pure bending moment
- Fixed sample length
- Vertical configuration
  - To eliminate the effect of gravity
- Large to small bending radii
  - To reproduce realistic processing conditions

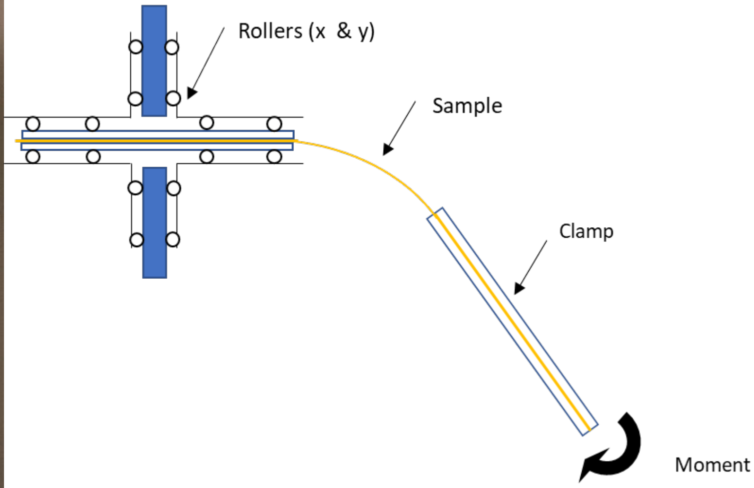
Fully definable test conditions:

- Temperature
- Bending Rate
- Bending Angle and Radius of curvature
- Loading/Relaxation/Unloading

Pure Bending fixture
inspired by Sachs (2014)



Top View
schematic of fixture



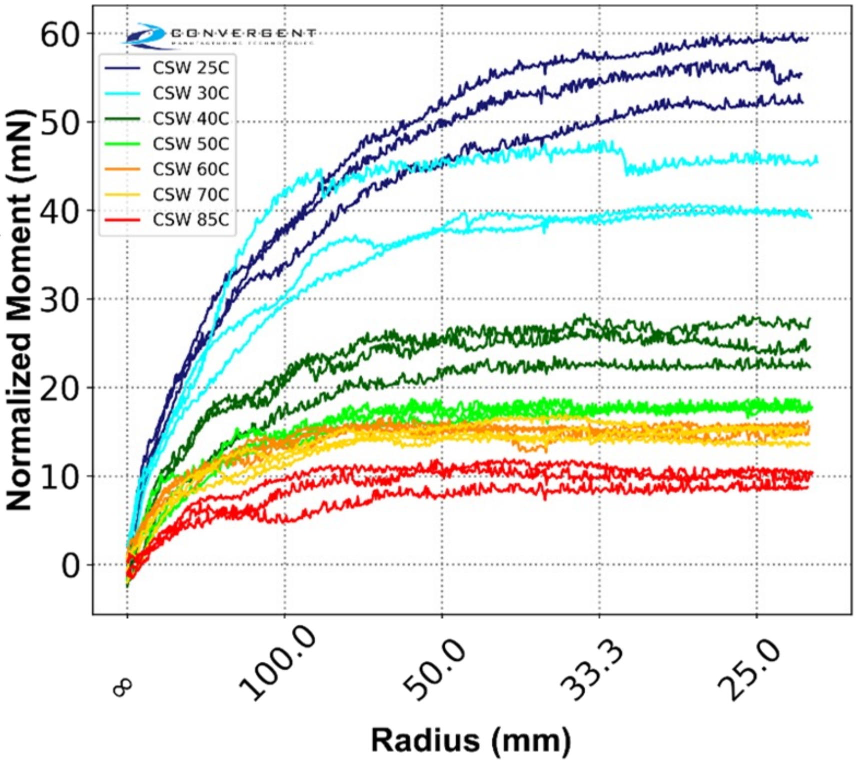
*Lane et al. 2023

Convergent test data for a thermoset prepreg

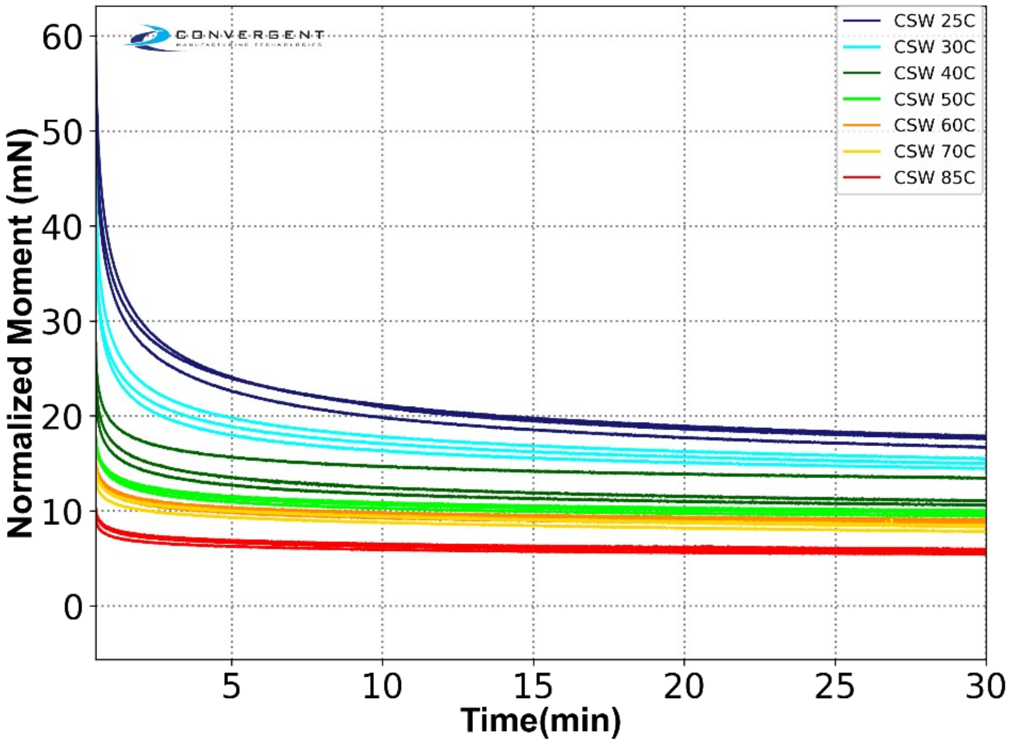
- Loading stiffness decrease with temperature increase

- Relaxation happens earlier with temperature increase

Loading



Relaxation



*Lane et al. 2023

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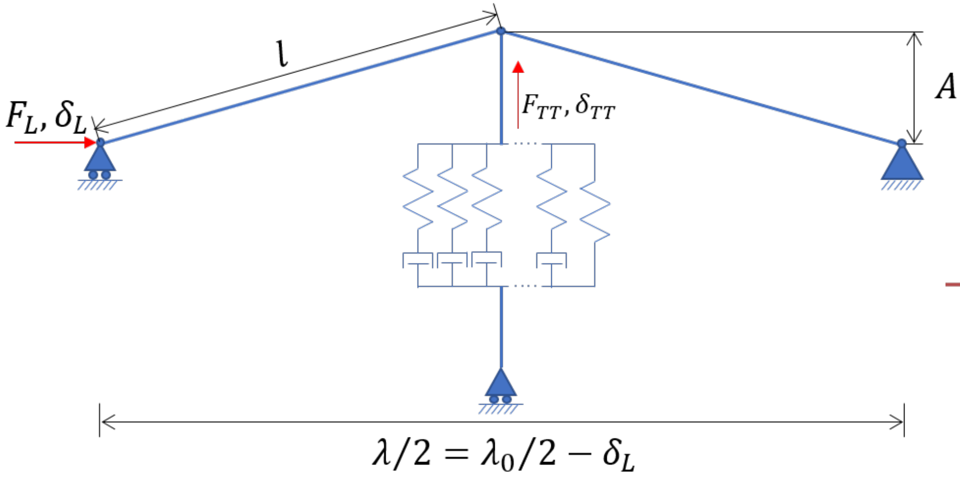
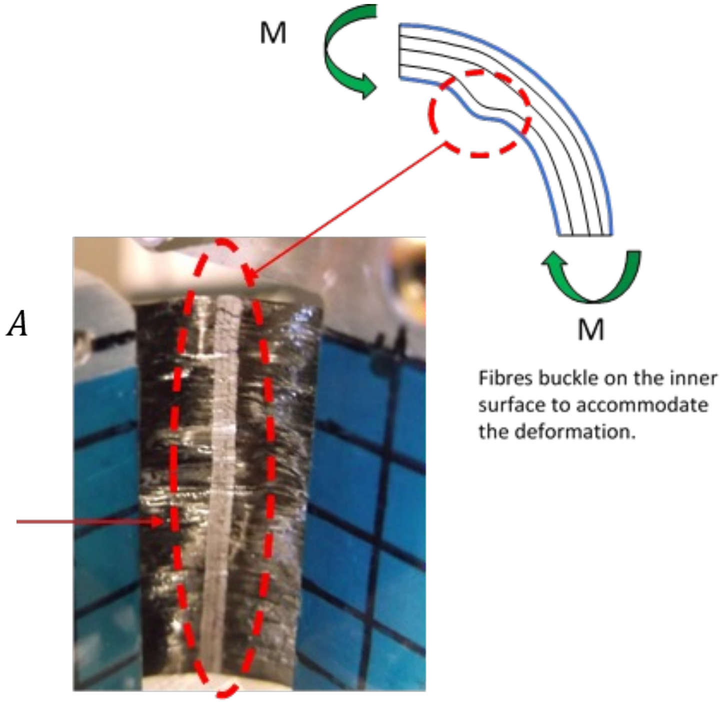
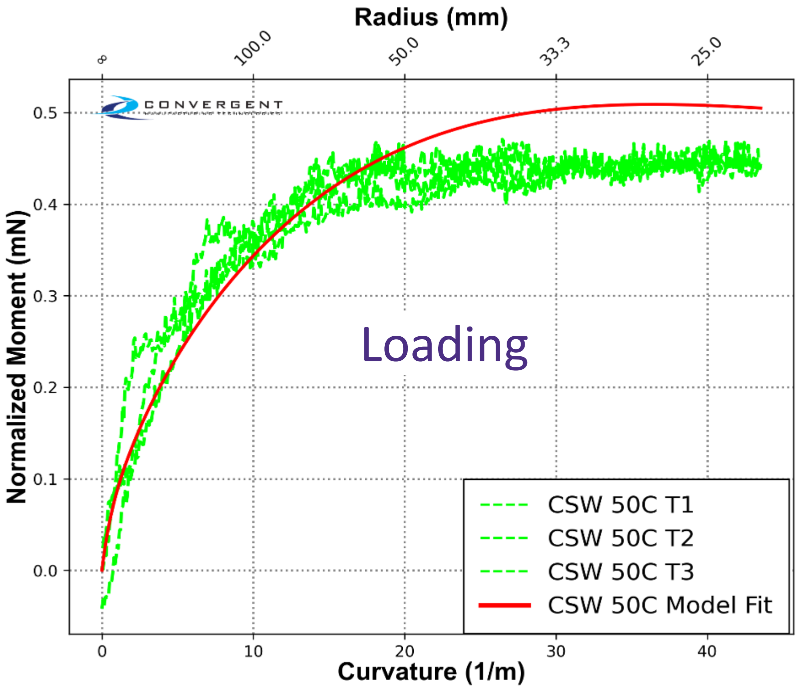
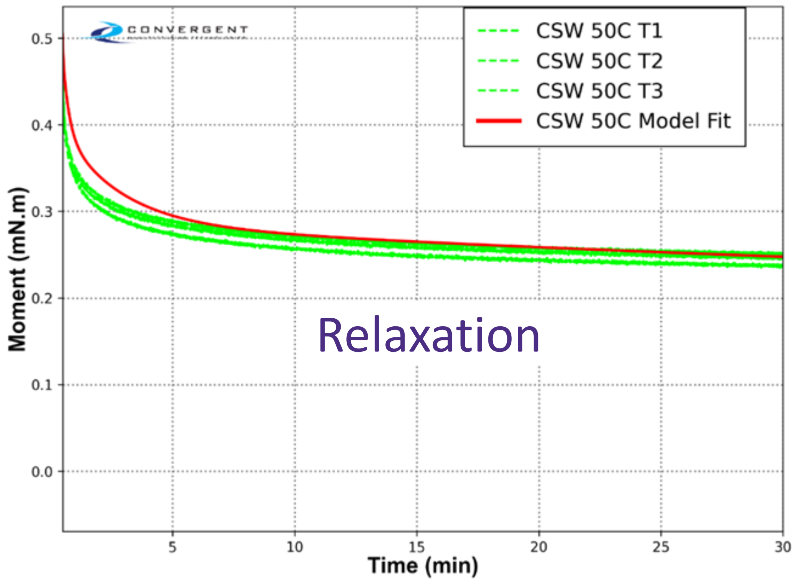
Convergent’s Bending Constitutive Model

- Fiber micro buckling is observed in bent samples
- This inspired a non-linear viscoelastic model that is represented as a hinge on a viscoelastic bed









*Silva et al. 2023

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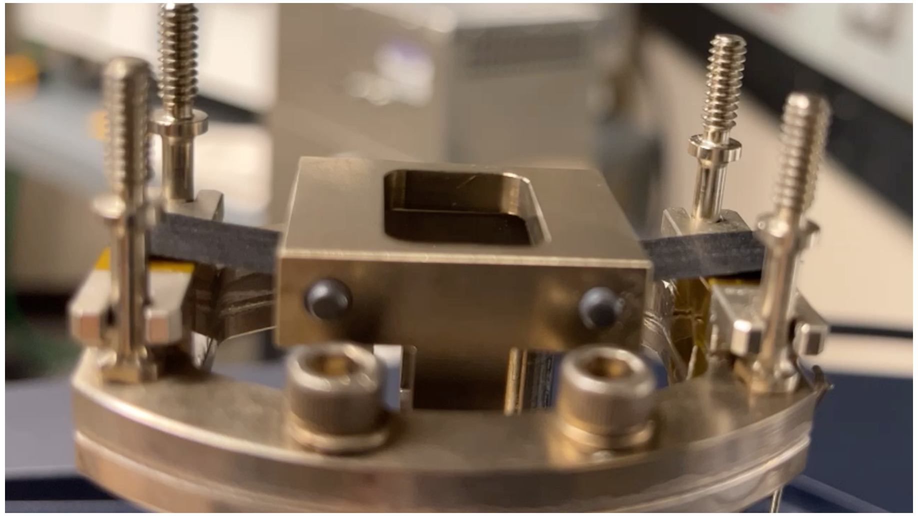
DMA Bending Method Development

Dynamic Mechanical Analysis (DMA)

- built-in bending test capability and control
  - Temperature
  - Strain Rate
- Measure viscoelastic properties
  - Dynamic test
  - Relaxation test
  - Creep test
- In this research, we use DMA TA 850 to develop a new test method

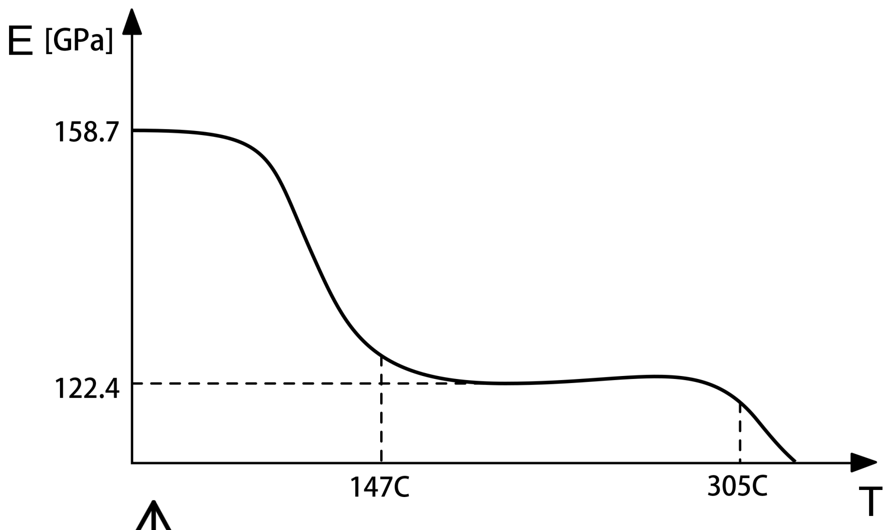


Material

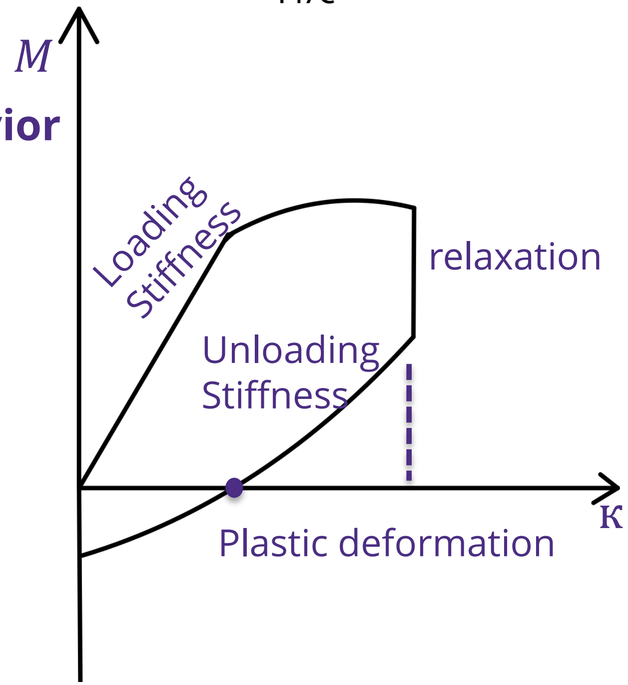
'TORAY'
Toray Advanced Composites

Property of Toray TC1225 LMPAEK	Standard Value
Fiber areal weight (FAW)	145 g/m^2 (4.28 oz/yd^2)
Resin content by weight (RC)	34%
Consolidated ply thickness (CPT)	0.14mm (0.0054 in.)
Glass Transition Temperature (T_g)	147 ℃ (296.6 °F)
Melting Temperature (T_m)	305 ℃ (581 °F)

Transition Temperature



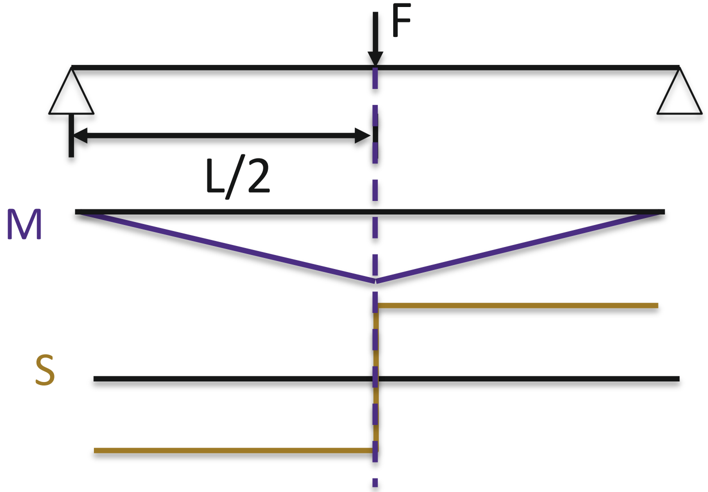
Nominal bending behavior



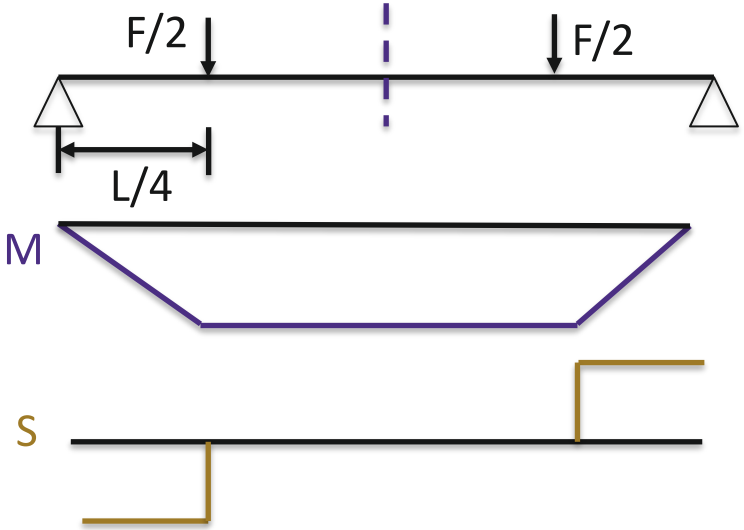
Test Methods

3-point bending/ 4-point bending schematic with moment & shear force distribution

- Non-pure bending moment with shear force
- Plastic hinge caused at contact point



- Isolate pure bending moment
- Constant curvature

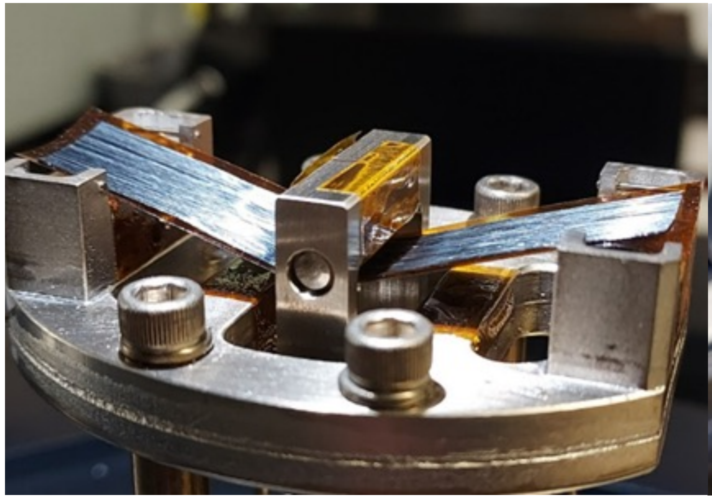
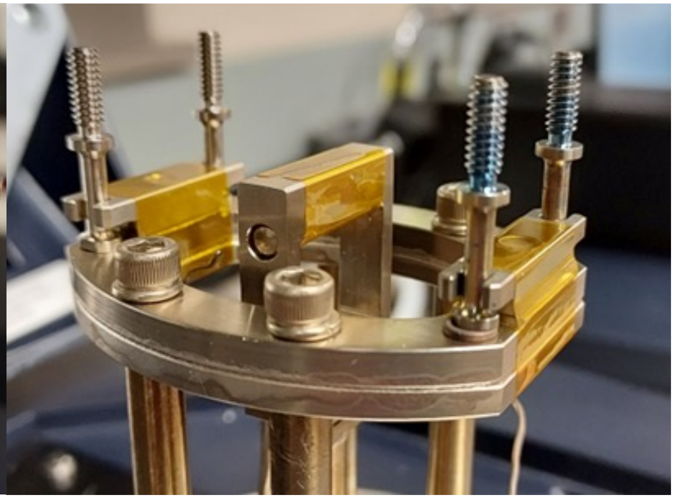


DMA Tests

- 3-point bending outer fixture

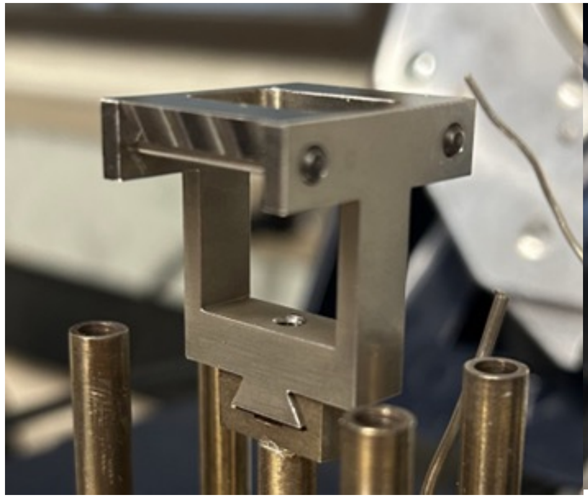
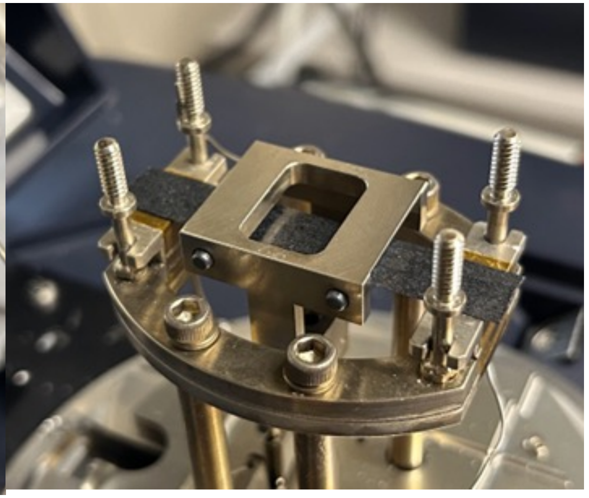
\- roller outer fixture could not support

\- customized clamp outer fixture with no span length change

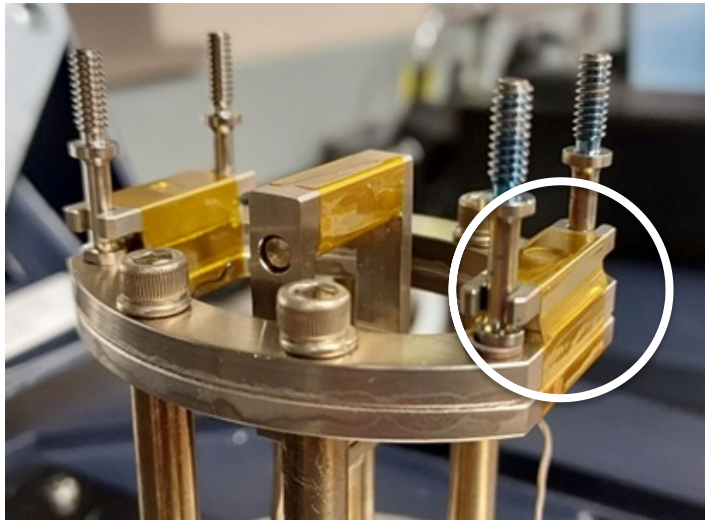
- Developed customized 4-point bending fixture

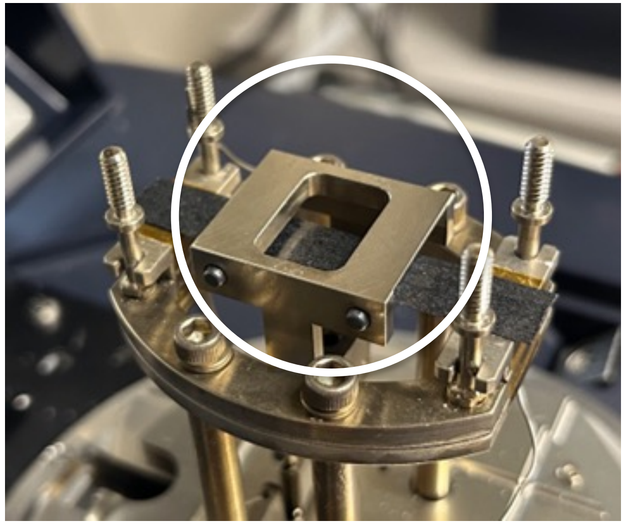
\- To better isolate pure bending moment

Final Fixtures

- Custom 4-point bending fixture
- Dual flat clamp outer fixture with Kapton tape
- Release agent applied on contact points





Bending Calculation

According to bending theory, while neglected gravity, the beam deflection can be described by

$$EI\frac{d^2y}{dx^2} = M = \frac{F}{2} * x - \frac{F}{2} * \left(x - \frac{L}{4}\right) - \frac{F}{2} * \left(x - \frac{3L}{4}\right) \qquad (1)$$

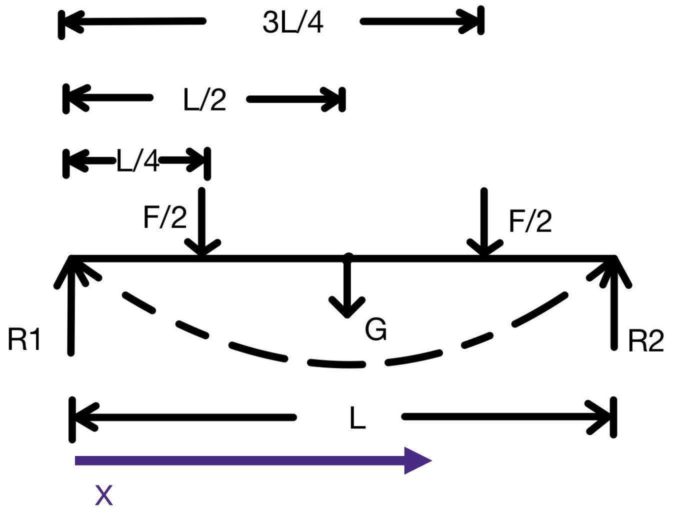
As a viscoelastic material, Pseudo viscoelastic *cure hardening instantaneously linear elastic* (CHILE) approach can be applied and the initial Euler-Bernoulli beam equation can be transformed to

$$dM = E'(\theta)I \times d\kappa \qquad (2)$$

Final equations at $\frac{L}{4}$ can be reached to approximate the melt bending behavior of the material :

$$M = \frac{FL}{8} \qquad (3)$$

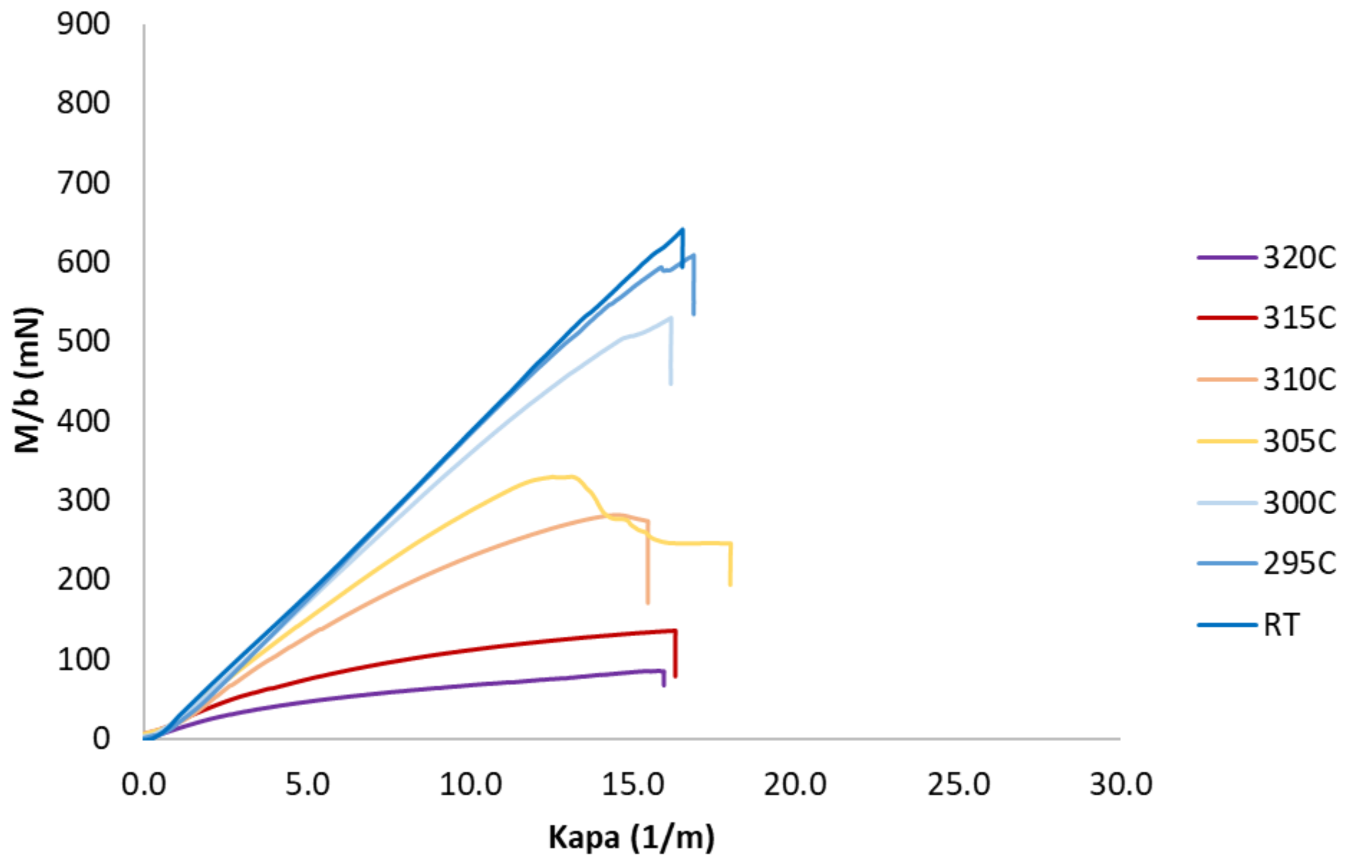
$$\kappa = \frac{12y}{L^2} \qquad (4)$$



Where R is reaction force;
F is load; G is gravity;
E is Modulus;
L is span length of specimen;
b is width of specimen;
E' is instantaneous elastic modulus;
I is second moment of area;
y is deflection;
x is assumed distance

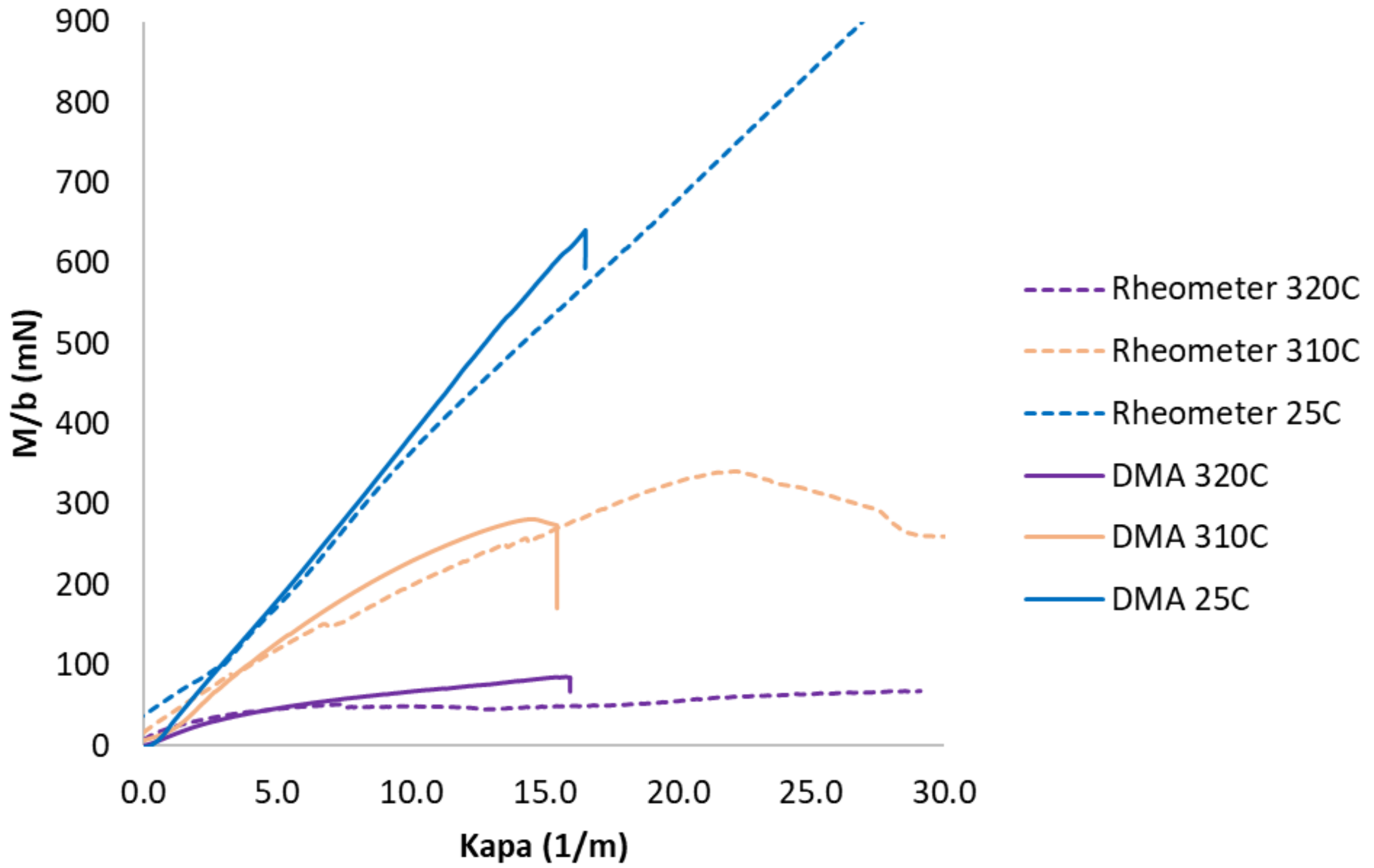
DMA Results

- Data has been processed via the previously shown method
- Minimal change in bending rigidity up to about 300°C
- Notable stiffness drop at 305°C
- A softening response at 305°C
- Significant stiffness drop at 310°C



Data Comparison

- Pure bending fixture in Rheometer allows tighter radius for testing
- Both methods indicate melting point around 305°C to 310°C
- Similar temperature-dependent rigidity behavior (Relaxation not include) is shown by both methods
- Attributed to buckling of fibers on compressive side of sample



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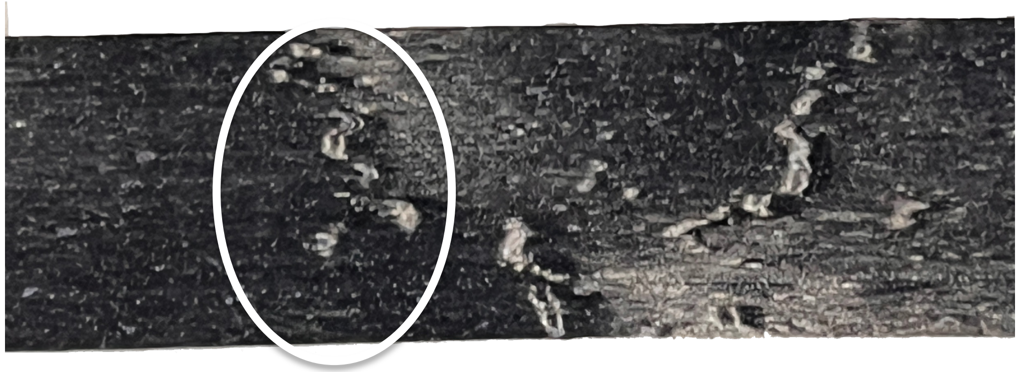
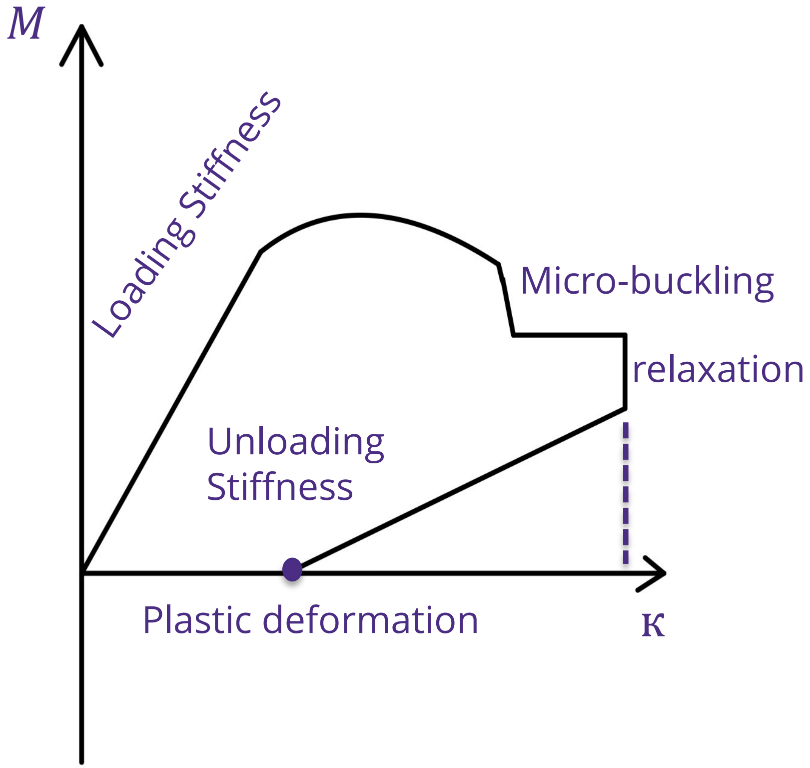
Material Behavior and Limitation of DMA

- During the bending process, micro-buckling can happen before relaxation (aligns with previous Convergent 's work)
  - Higher displacement
  - Higher applied load
- Curvature is limited to around 20 m^{-1}





Conclusions

- The developed 4-point bending fixture successfully isolates pure bending better than 3-point bending fixture
- Despite differences in loading application, sample geometry, and data reduction approach, similar results were obtained using both the Rheometer and DMA
- DMA test can characterize rigidity behavior
- DMA test has a minimum test radius around 5cm

Acknowledgement

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THANKS FOR COMING!
Any Questions?