TA Instruments – Waters LLC

Materials Characterization by Dynamic Mechanical Analysis

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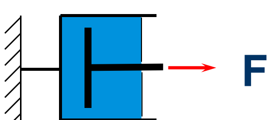
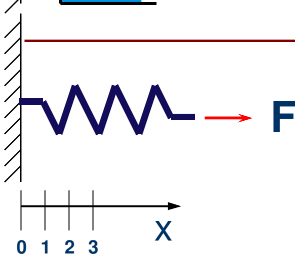
Rheology: The study of the flow and deformation of matter



Flow: Fluid Behavior; Viscous Nature

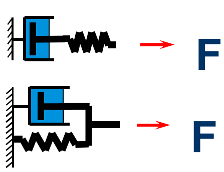
$F = F(v); F \neq F(x)$



**Deformation: Solid Behavior
Elastic Nature**

$F = F(x); F \neq F(v)$

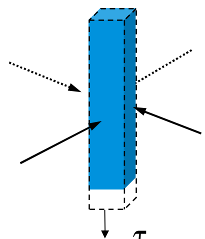
We discussed these concepts in the Rheology section of the workshop.



Viscoelastic Materials: Force depends on both Deformation and Rate of Deformation and vice versa.

Tensile Deformation

Young's Modulus



$$E = \frac{\tau}{\varepsilon}$$

Deformation Parameters
L_0 = Initial Length (m)
L = Stretched Length (m)
ε = Elongational Strain, $(L/L_0) - 1$ (unitless) (Engineering Strain)

- Strain is the amount of deformation normalized for the type of deformation and the dimensions of the specimen.

Force Parameters
T = Tensile force (Newtons)
w_0 = Initial Width (m)
t_0 = Initial Thickness (m)
τ = Tensile Stress, $T/(w_0 * t_0)$ (Pa)

Conversions:
Machine → Rheological
Displacement → Strain
Force → Stress

- Stress is the amount of force normalized for the type of deformation and the dimensions of the specimen.

Elongational Properties
$E = \tau/\varepsilon$ (Pa) Modulus
$D = \varepsilon/\tau$ (1/Pa) Compliance

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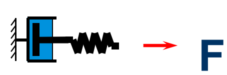
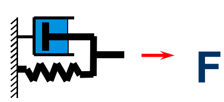
UNIDIRECTIONAL TYPES OF TESTS ON THE DMA

- TRANSIENT
  - Stress Relaxation
    - Deformation applied instantaneously ⇒ Force measured as a function of time
    - Deformation (mm) converted to Strain (ε), Force (N) to Stress (τ)
    - Stress (τ)/Strain(ε) = Modulus (E)
  - Creep
    - Force applied instantaneously ⇒ Deformation measured as a function of time
    - Force to Stress (τ), Deformation converted to Strain (ε)
    - Strain (ε)/Stress (τ) = Compliance (D)





- PRACTICAL
  - Strain Ramp
    - Strain increased linearly with time or, optionally, exponential with the RSA-G2
  - Iso-Strain
    - Strain held constant as temperature is varied
  - Stress Ramp
    - Stress increased linearly or exponentially with time
  - Controlled Stress
    - Stress held constant as temperature is varied

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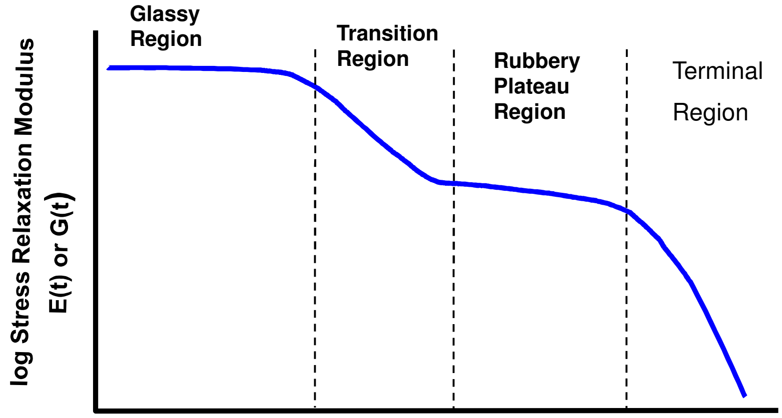
Stress Relaxation: Material Response



This would be the type of curve expected for an uncrosslinked polymer if given sufficient time.

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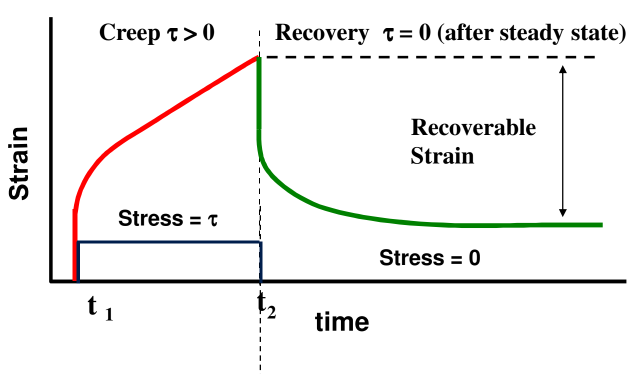
Creep Testing



The greater the elasticity, the greater the recovery.

With uncross-linked systems, strain increases indefinitely.
If you have reached steady state flow, you can calculate the viscosity and the recoverable compliance.
With cross-linked systems, there is a limiting strain.

Reference: Mark, J., et.al., Physical Properties of Polymers ,American Chemical Society, 1984, p. 102.

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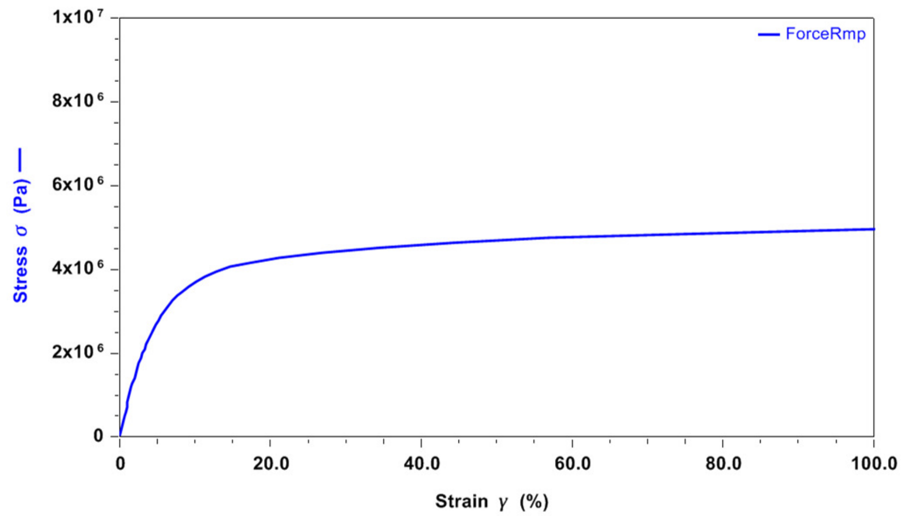
Polyethylene Stress Ramp (or Strain Ramp)



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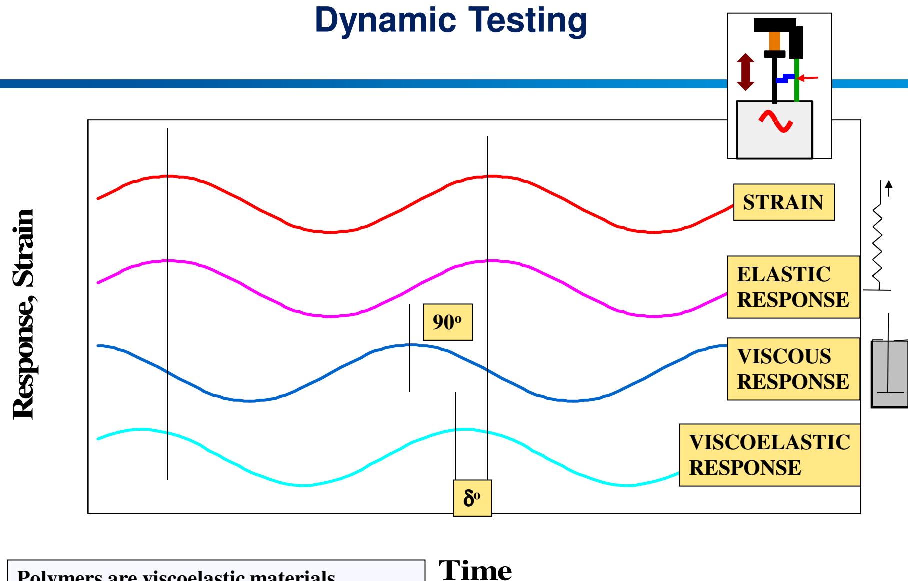
Dynamic Testing



Polymers are viscoelastic materials.
Both components – viscosity and elasticity – are important.

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Dynamic Rheological Parameters

Parameter	Shear	Elongation	Units
Strain	$\gamma = \gamma_0 \sin(\omega t)$	$\varepsilon = \varepsilon_0 \sin(\omega t)$	---
Stress	$\sigma = \sigma_0 \sin(\omega t + \delta)$	$\tau = \tau_0 \sin(\omega t + \delta)$	Pa
Storage Modulus (Elasticity)	$G' = (\sigma_0/\gamma_0)\cos\delta$	$E' = (\tau_0/\varepsilon_0)\cos\delta$	Pa
Loss Modulus (Viscous Nature)	$G'' = (\sigma_0/\gamma_0)\sin\delta$	$E'' = (\tau_0/\varepsilon_0)\sin\delta$	Pa
Tan δ	G''/G'	E''/E'	---
Complex Modulus	$G^* = (G'^2+G''^2)^{0.5}$	$E^* = (E'^2+E''^2)^{0.5}$	Pa
Complex Viscosity	$\eta^* = G^*/\omega$	$\eta_E^* = E^*/\omega$	Pa-sec

We will be mainly concerned with the Elongation column in this table.

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Dynamic Oscillatory Testing Methods

- Frequency Sweep
- Strain Sweep
- Stress Sweep
- Temperature Sweep
- Temperature Ramp
- Time Sweep
- Temperature Sweep (Multifrequency)
- Fatigue Test

Most common sequence
- Strain sweep at 1 Hz to find the “sweet spot” for testing and the Linear Viscoelastic Region (LVR)
- Temperature ramp at 1 Hz and 3 C/min using amplitude from strain sweep testing.

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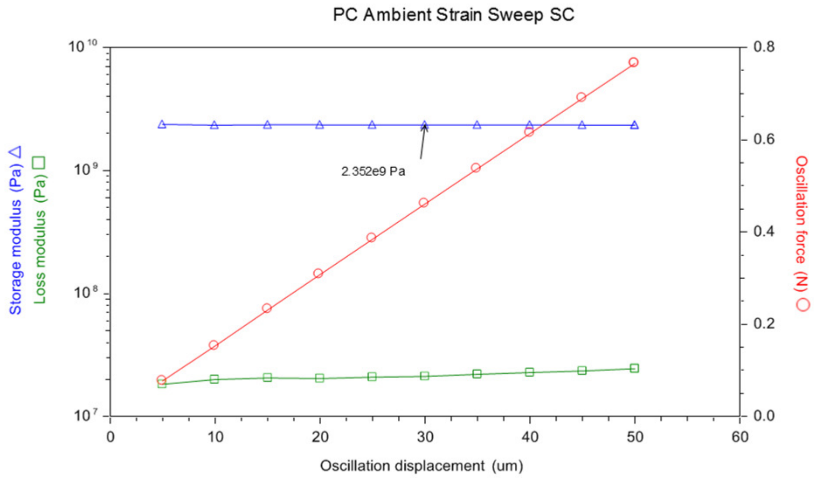
Dynamic Strain Sweep



The material shows a nice Linear Viscoelastic Region (LVR).
The oscillation force at 30 microns is about 0.4 N, which is definitely in the sweet spot for our DMA's.
We aim for a storage modulus of 2350 MPa at room temperature with polycarbonate.

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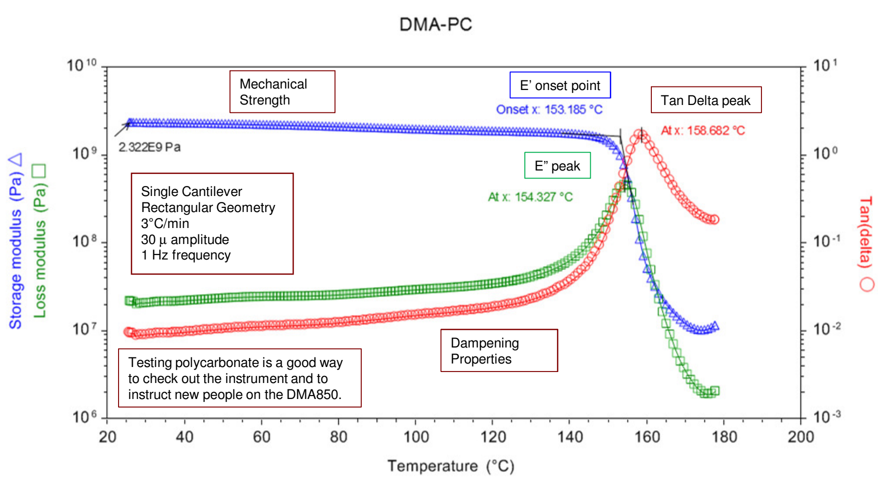
Polycarbonate Testing on the DMA 850



This is the main test performed on DMA instruments.

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DMA INSTRUMENTATION

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DMAs from TA Instruments

RSA G2

Controlled Strain
SMT

DMA 850

Controlled Stress
CMT

ARES G2
and DHR

DMA mode
(oscillation)

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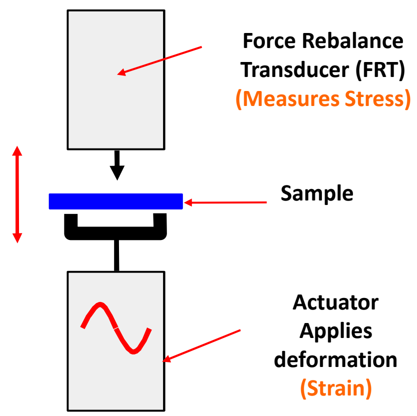
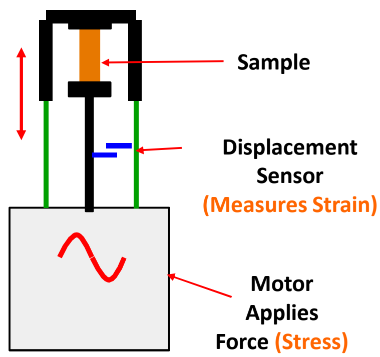
DMAs from TA Instruments

RSA G2
Controlled Strain
SMT – Separate Motor & Transducer



DMA 850
Controlled Stress
CMT – Combined Motor & Transducer



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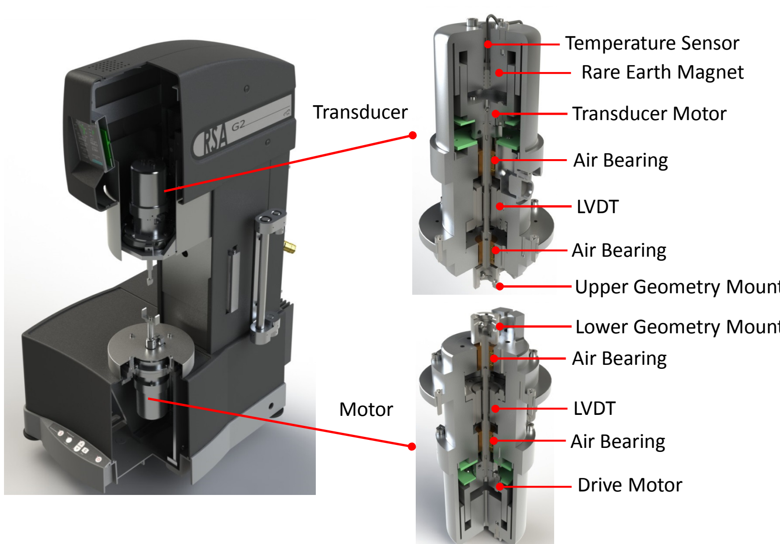
RSA G2: Schematic Dual Head Design



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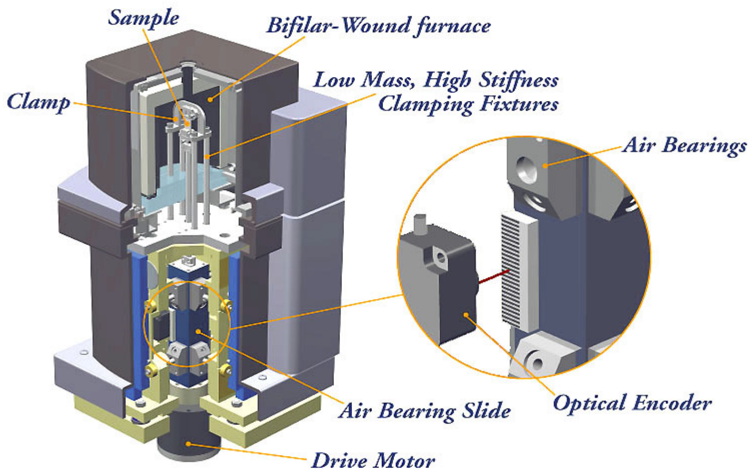
DMA Q850: Schematic



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DMA Specifications

	RSA G2	Q800	ARES G2 DMA	DHR DMA (optional)
Max Force	35N	18N	20N	50N
Min Force	0.0005N	0.0001N	0.001N	0.1N
Frequency Range	1e-5 to 628 rad/s (1.6e-6 to 100 Hz)	0.01 to 1250 rad/s (1.6e-3 to 200 Hz)	6.3e-5 to 100 rad/s (1.0e-5 to 16 Hz)	6.3e-5 to 100 rad/s (1.0e-5 to 16 Hz)
Dynamic Deformation Range	+/- 0.05 to 1,500mm	+/- 0.5 to 10,0000mm	+/- 1 to 50 mm	+/- 1 to 100 mm
Control Stress/Strain	Control Strain (SMT)	Control Stress (CMT)	Control Strain (CMT)	Control Stress (CMT)
Heating Rate	0.1°C to 60°C/min	0.1°C to 20°C/min	0.1°C to 60°C/min	0.1°C to 60°C/min
Cooling Rate	0.1°C to 60°C/min	0.1°C to 10°C/min	0.1°C to 60°C/min	0.1°C to 60°C/min

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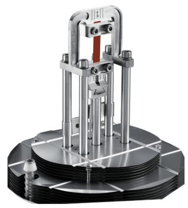
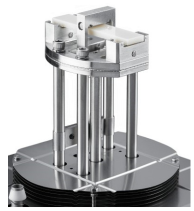
Clamps for DMA850

S/D Cantilever

Film/Fiber Tension

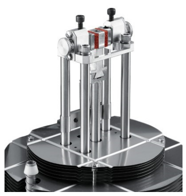


3-Point Bending

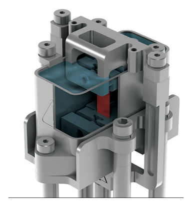


Compression

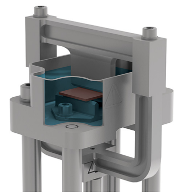
Shear Sandwich



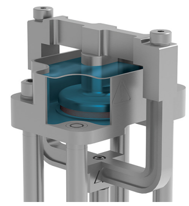
Submersible Tension



Submersible Bending



Submersible Compression



The standard size S/D cantilever clamp is included with the purchase of the DMA 850.

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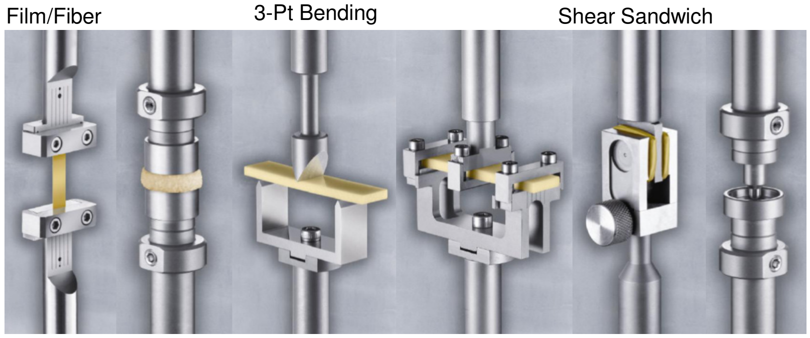
Clamps for RSA G2

Film/Fiber   3-Pt Bending   Shear Sandwich



Compression   Cantilever   Contact Lens

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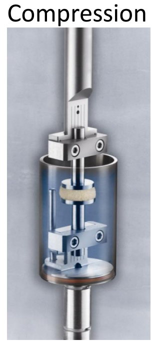
RSA G2 Immersion Clamps

Immersion clamp kit offers 3 geometries with temperature control from -10 to 200 °C in the FCO.

Tension

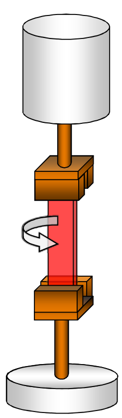
Compression



3 Point Bending

Tension: Up to 25 mm long, 12.5 mm wide and 1.5 mm thick.
Compression: 15 mm in diameter; maximum sample thickness is 10 mm.
Three Point Bending: includes interchangeable spans for lengths of 10, 15, and 20 mm. Maximum sample width is 12.5 mm and maximum thickness is 5 mm.

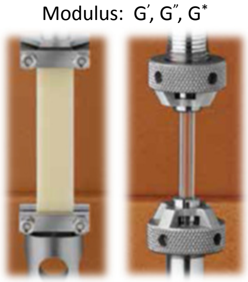
Torsion and DMA Measurements on Rheometers



- Torsion and DMA geometries allow solid samples to be characterized in a temperature controlled environment
  - DMA functionality is standard with ARES G2 and optional DHR

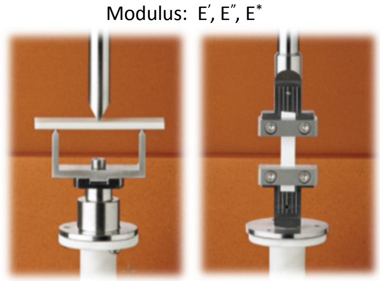
$$E = 2G(1 + \nu) \qquad \nu : \text{Poisson's ratio}$$

Modulus: G', G'', G^*



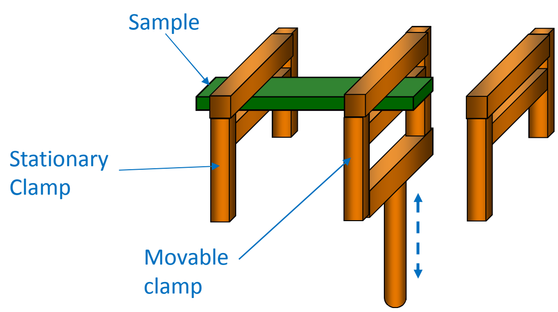
Rectangular and cylindrical torsion

Modulus: E', E'', E^*



DMA 3-point bending and tension (Cantilever not shown)

DMA: Single Cantilever Clamp



- Best general purpose mode (thermoplastics); used the most for reasonably stiff specimens on DMA 850
- Preferred mode over dual cantilever for most neat thermoplastics (unreinforced), except elastomers
- Clamping torque is important

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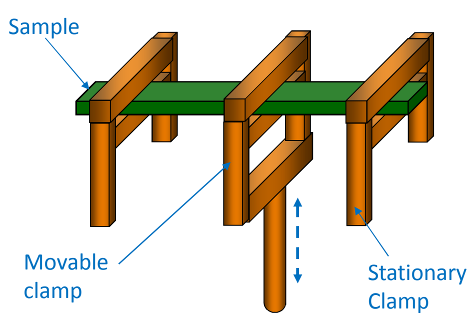
DMA: Dual Cantilever Clamp



- Highly damped materials can be measured
- Best mode for evaluating the cure of supported materials

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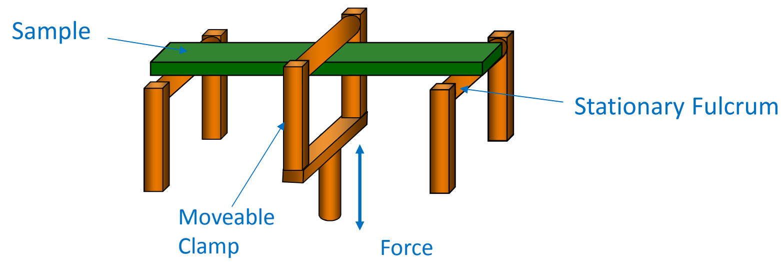
DMA: 3 Point Bend Clamp



- Best mode for measuring medium to high modulus materials
- Conforms with ASTM standard test method for bending
- Purest deformation mode since clamping effects are eliminated
- Most common clamp for flexural testing on RSA-G2

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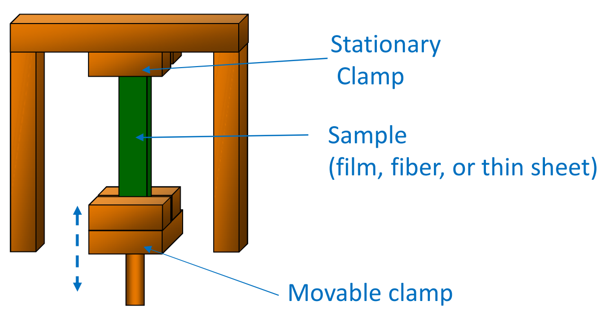
DMA: Film and Fiber Tension Clamp



- Best mode for evaluation of thin films and fibers
  - bundle or single filaments
- Small samples of high modulus materials can be measured
- TMA-like constant force and force ramp measurements
  - aka. mini-tensile tester
- Force track and constant force control

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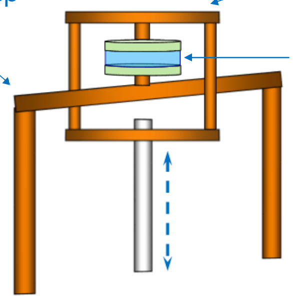
DMA: Compression Clamp



- Good mode for low to medium modulus materials (gels,elastomers)
- Materials must provide restoring force (support necessary static load)
- Options for expansion & penetration measurements

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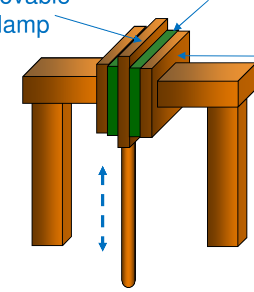
DMA: Shear Sandwich Clamp



- Square sample configuration provides pure shear deformation
- Provides *Shear Moduli: G*, G', G" & G(t)*
- Good for evaluating highly damped soft solids such as gels and adhesives & elastomers > Tg
- Can be used for high viscosity melts and resins

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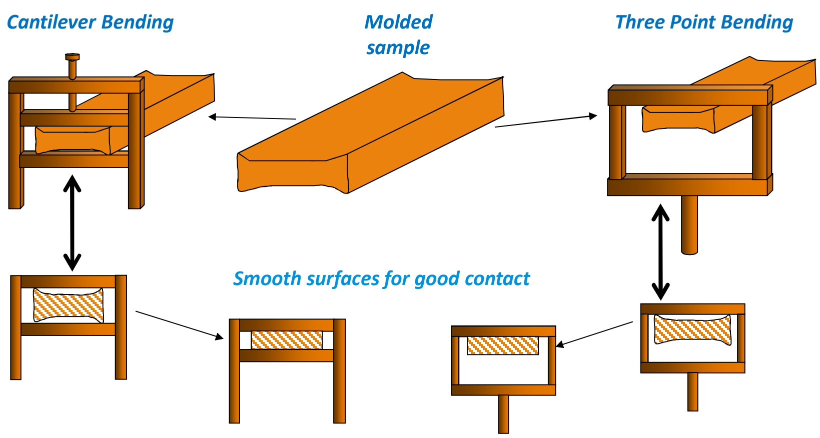
Preparing Samples – The Importance of Shape

Shape: Molded samples are often not flat. May lead to poor contact in Cantilever and Three Point Bend Clamps. Sand samples smooth.



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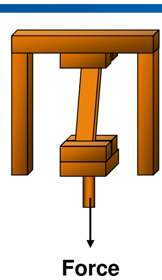
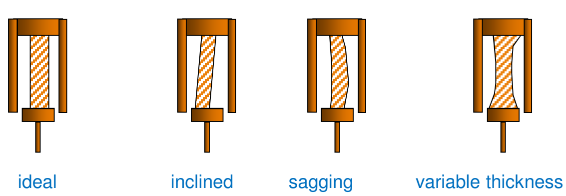
Alignment in Tension Mode



If sample buckles during Oscillation. Modulus will be artificially low.

- Buckling during loading causes serious errors as buckled areas do not “feel” the force or deformation
- Buckling can be the result of non-uniform stretching, or crooked loading of a film.
- Observe film from edge while oscillating to verify goodness of load.
- If sample is buckling, reload a new sample.



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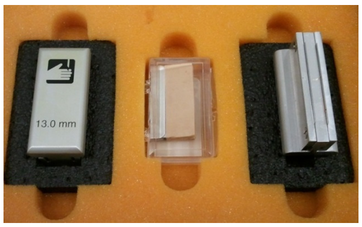
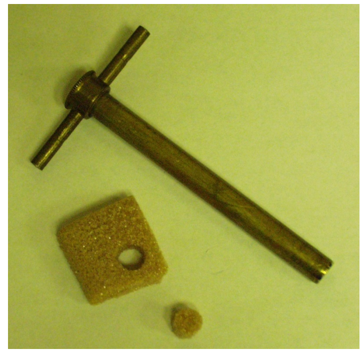
Some Sample Prep Tools

Parallel Razor
Blade Cutter



Good for Films and
Sheets of rubber.

Cork Borer



Good for stiff foams and
Sheets of rubber.

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Choose the Correct Clamp for Testing

Sample Dimension

- Films and fibers: tension clamps
- Bars and cylinders: bending clamps
- O-rings and tablets: compression and/or shear

Deformation Mode:

- E [tension, compression and bending]
- G [shear]

Sample Stiffness:

- Machine range fixed: **100 - 10, 000,000 N/m**. Stiffness of sample related to its dimensions [L, w, t]. Stiffness may limit sample size to below clamp maximum.

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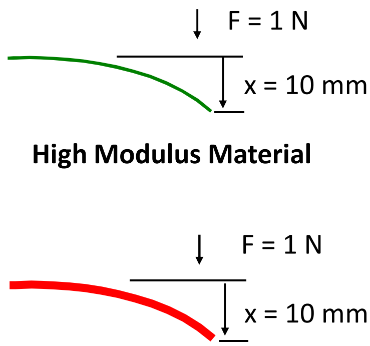
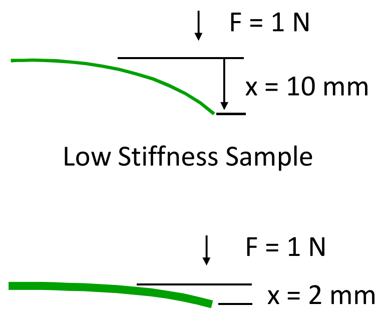
Sample Stiffness and Material Modulus

Thick and Thin Samples Can Have The Same Stiffness



Low Modulus Material

Thick and Thin Samples That Have The Same Modulus



High Stiffness Sample

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Changing Sample Stiffness

Clamp Type	To Increase Stiffness…	To Decrease Stiffness…
Tension Film	Decrease length or increase width. If possible increase thickness.	Increase length or decrease width. If possible decrease thickness.
Tension Fiber	Decrease length or increase diameter if possible.	Increase length or decrease diameter if possible.
Dual/Single Cantilever	Decrease length or increase width. If possible increase thickness. Note: L/T ≥ 10	Increase length or decrease width,, If possible decrease thickness. Note: L/T ≥ 10
Three Point Bending	Decrease length or increase width. If possible increase thickness.	Increase length or decrease width. If possible decrease thickness.
Compression – circular sample	Decrease thickness or Increase diameter.	Increase thickness or decrease diameter.
Shear Sandwich	Decrease thickness or Increase length and width.	Increase thickness or decrease length and width.

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DMA Clamping Guide

Sample	Clamp	Sample Dimensions
High modulus metals or composites	3-point Bend Dual Cantilever Single Cantilever	L/T> 10 if possible
Unreinforced thermoplastics or thermosets	Single Cantilever	L/T >10 if possible
Brittle solid (ceramics)	3-point Bend Dual Cantilever	L/T>10 if possible
Elastomers	Dual Cantilever Single Cantilever Shear Sandwich Tension	L/T>20 for T<Tg L/T>10 for T<Tg (only for T> Tg) T<2 mm W<5 mm
Films/Fibers	Tension	L 10-20 mm T<2 mm
Supported Systems	8 mm Dual Cantilever	minimize sample, put foil on clamps

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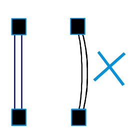
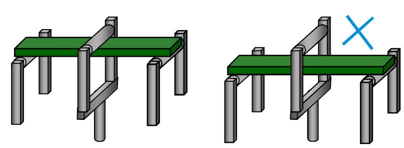
Some Clamps Require an Offset (Static) Force



Good Bad

Tension



Good Bad

3-pt Bend

1. With the tension clamp, one wants to avoid the buckling of the specimen that is shown with the tension specimen on the right.
2. With the 3-pt bend clamp, one wants to avoid the loss of contact of the center clamp with the specimen that is shown with the 3-pt bend specimen on the right. The same principle applies to the compression clamp.

Clamps without offset force:	Clamps with offset force:
Single Cantilever Dual Cantilever Shear Sandwich	Tension Film Tension: Fiber 3-Point Bend Compression Penetration

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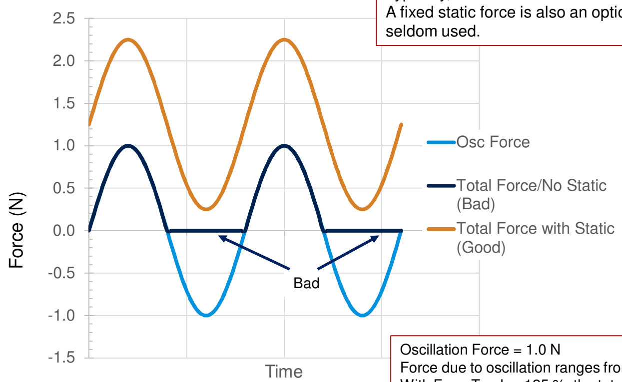
Waveforms with and without Static Force



Typically, the static force is 1.25x the oscillation force. A fixed static force is also an option, although less seldom used.

Oscillation Force = 1.0 N
Force due to oscillation ranges from -1.0 to +1.0 N
With ForceTrack = 125 %, the total Force will range from 0.25 N to 2.25 N.
Note that this reduces the available oscillation force to 8 N with the DMA 850 and 15.6 N on the RSA-G2.

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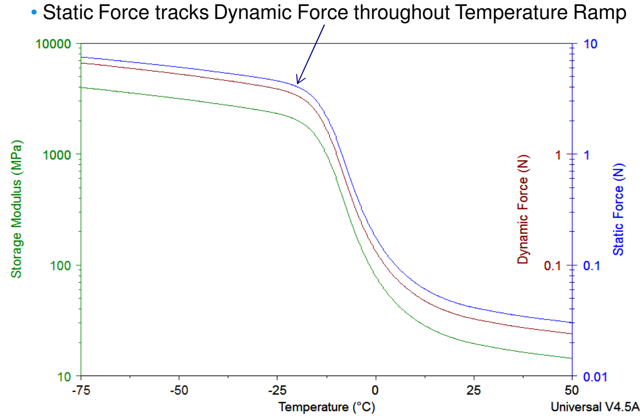
Temperature Ramp with Force Track

- Static Force tracks Dynamic Force throughout Temperature Ramp



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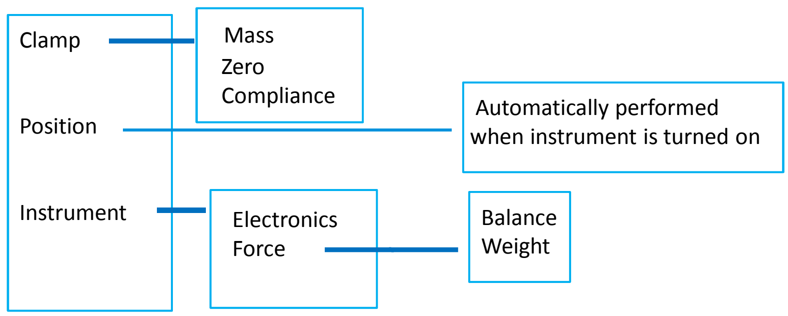
Q850 Flow Chart of Calibration Procedures



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DMA Calibrations and Compliance Tables

Clamp	Mass	Zero	Compliance
Dual/Single Cantilever	X		X
3 Point Bend	X		X
Tension Film	X	X	X
Compression/Penetration	X	X	X
Shear Sandwich	X		
Specialty Fiber	X	X	

Clamp	Typical Compliance in µm/N
Single Cantilever	≤ 0.8
Dual Cantilever	≤ 0.2
3 Point Bend	≤ 0.6
Tension Film	≤ 0.5
Compression	≤ 0.6
Specialty Fiber	N/A
Shear Sandwich	N/A

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RSA-G2 Instrument Calibration

Calibration Tasks and Recommended Intervals

Calibration Task	Calibration Interval
Upper Fixture Mass Calibration	Mandatory: During geometry creation (is a part of geometry configuration)
Force Calibration	Suggested: Monthly. Mandatory: Following transducer replacement.
Phase Angle and Modulus Check	Suggested: Monthly Mandatory: Following actuator or transducer replacement.
Gap Temperature Compensation	Suggested: As required by the experiment.

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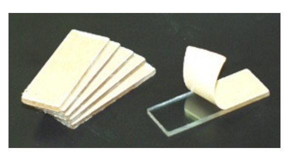
DMA Confidence Check - Polycarbonate

- Load Polycarbonate (L ≈ 17.5, w ≈ 12.85, t ≈ 0.8mm)
  - DMA 850: Single Cantilever; 20-30 micrometer amplitude
  - RSA-G2: 3-pt bend; 0.04% Strain

  - 1 Hz
  - 3 C/min

- Storage Modulus at Room Temperature
  E' = 2.35 GPa (2350 MPa) +/- 5%
- Tan Delta at Room Temperature
  Tan δ < 0.01

- Transition Temperature
  Tan δ peak from 155-160℃ @ 1Hz, 3-5℃/min
  E" peak will be about 5℃ lower



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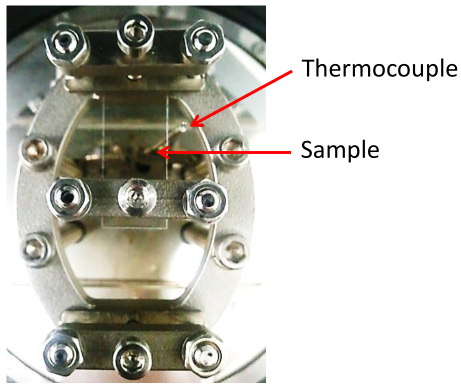
Mounting the Sample

- Finger tighten the sample in position and then 'Lock' movable shaft to align clamp before tightening with torque wrench. Tighten to 8-10 in·lbs torque.



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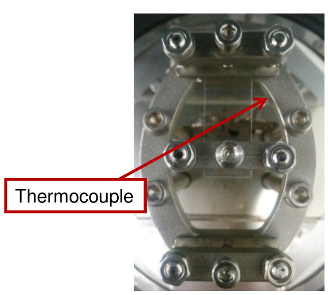
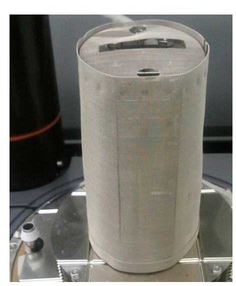
Temperature Ramp Results from Polycarbonate

- Transition Temperature:
  - Tan d peak from 155-160 °C @ 1Hz, 3-5 °C/min
  - E" peak will be about 5 °C lower





Note: Thermocouple position and sample or thermocouple shields can affect temperature results from a temperature ramp. The shields are recommended especially when the ACS chiller is used.

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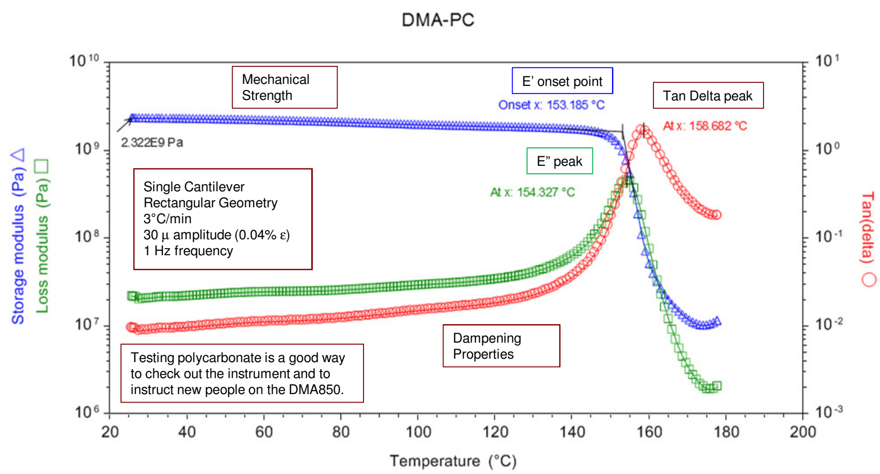
Polycarbonate Testing on the DMA 850



This is the main test performed on DMA instruments.

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APPLICATIONS

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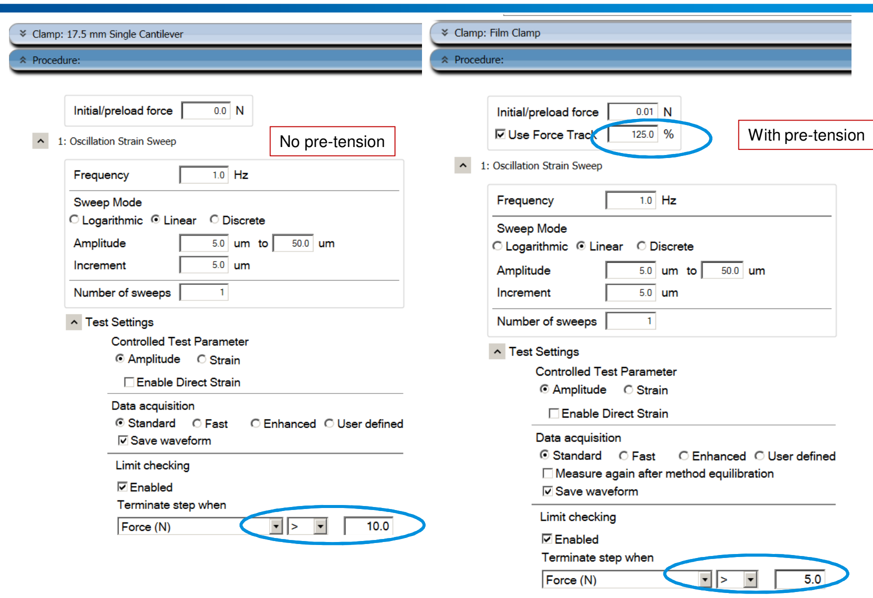
Dynamic Strain Sweep – DMA 850



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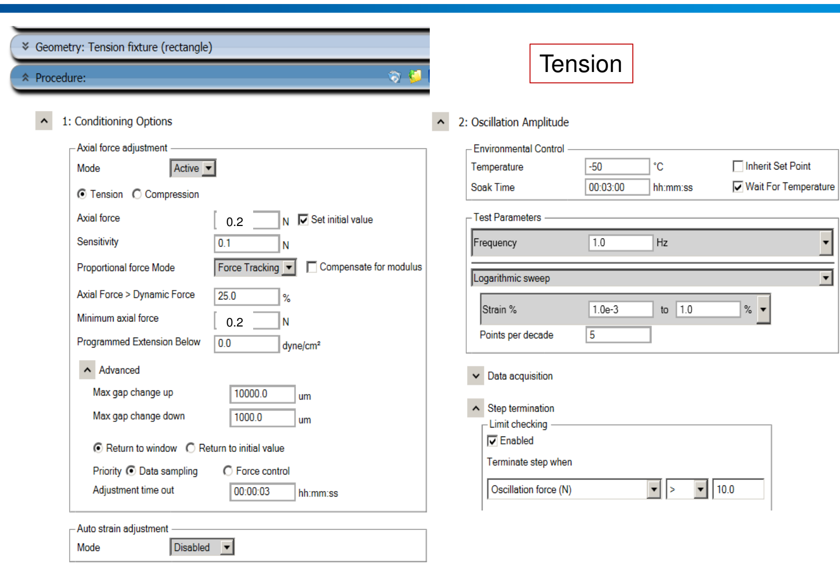
Programming Strain Sweep on RSA G2



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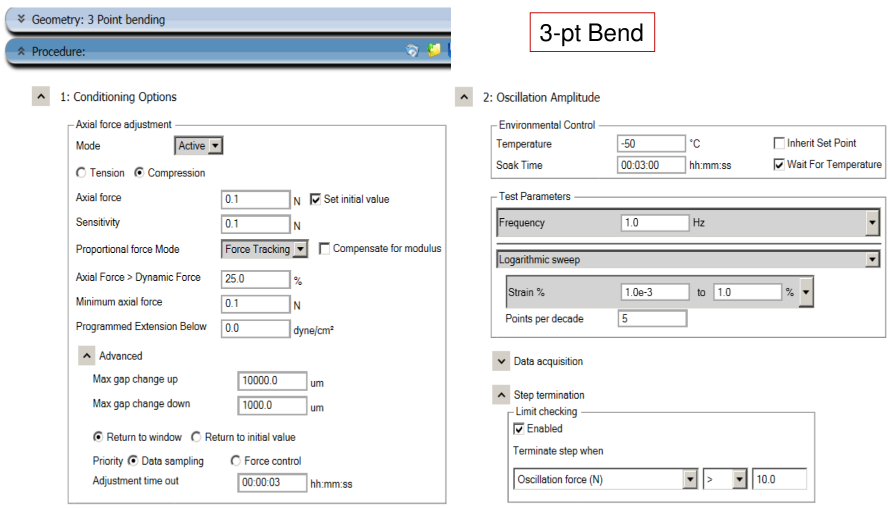
Programming Strain Sweep on RSA G2



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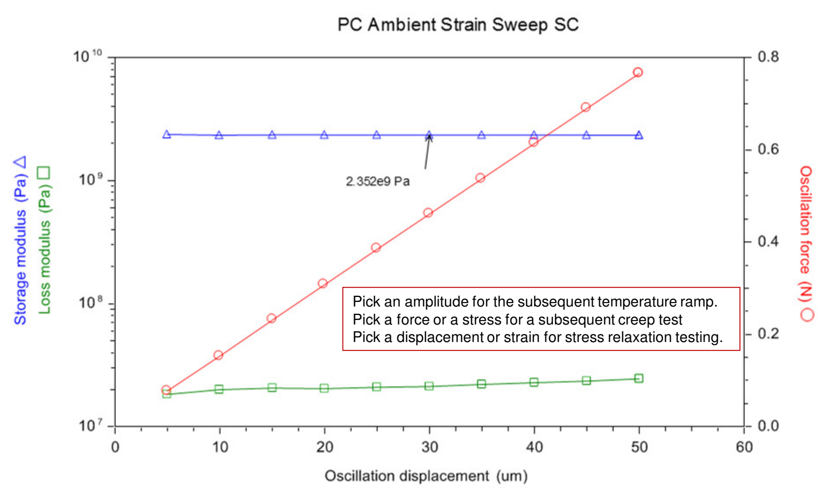
Dynamic Strain Sweep



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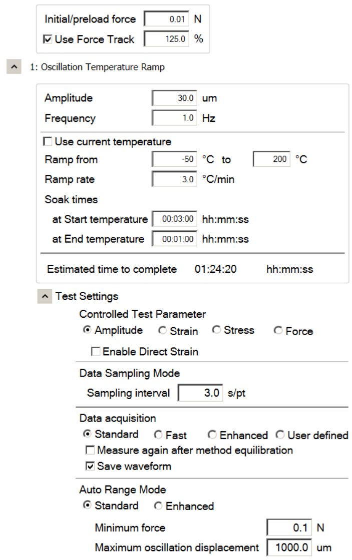
Dynamic Temperature Ramp – DMA 850



With the DMA 850, you can use either Trios Express or Trios Unlimited. Express is more basic. Unlimited gives you more options.
I usually run with Unlimited.

This is one way to do a temperature ramp.
One would enter the proper amplitude/strain and temperature range.
In the last section here, we set a minimum oscillation force and a maximum oscillation displacement.
You can also use Enable Direct Strain in the procedure.

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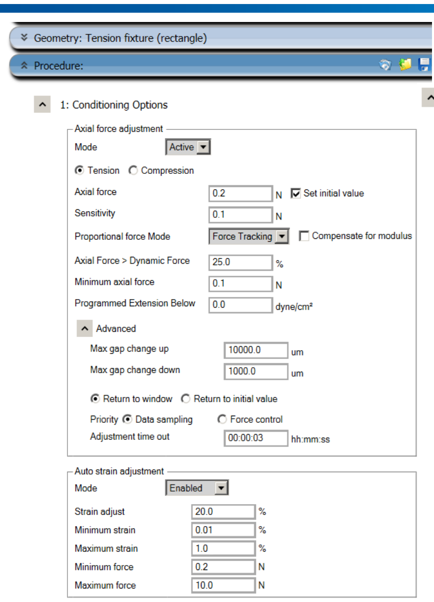
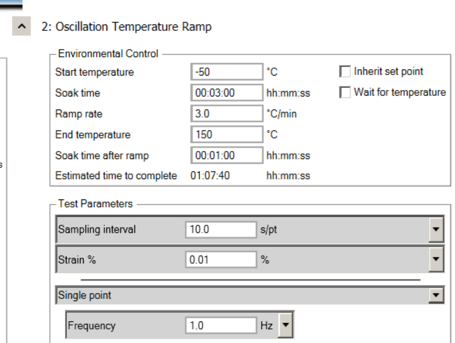
Programming Temperature Ramp on RSA G2





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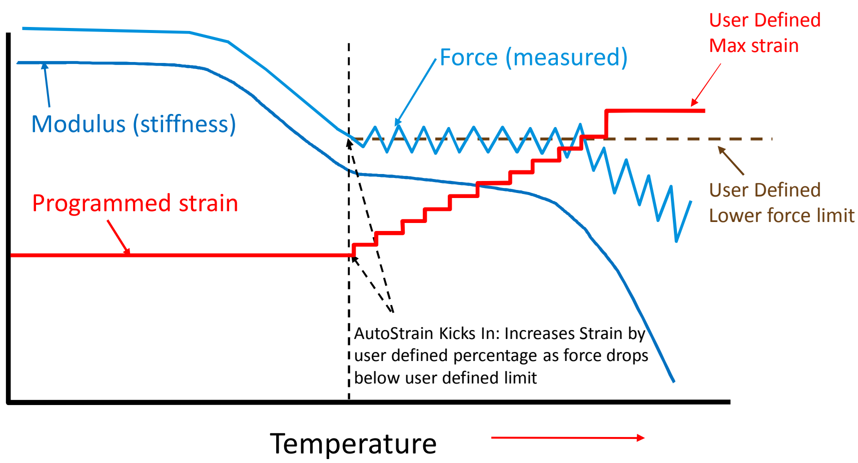
Auto-Strain on RSA G2

Over temperature range covered, force falls below user defined lower limit in strain controlled DMA.



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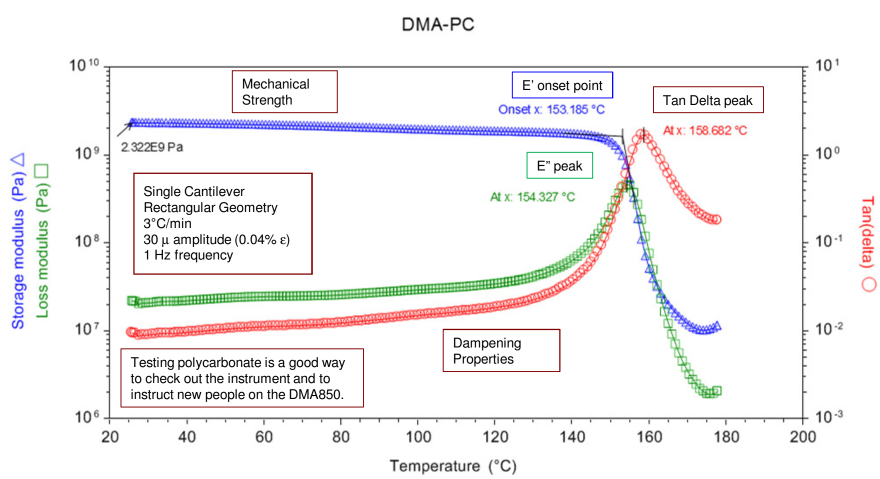
Polycarbonate Testing on the DMA 850



This is the main test performed on DMA instruments.

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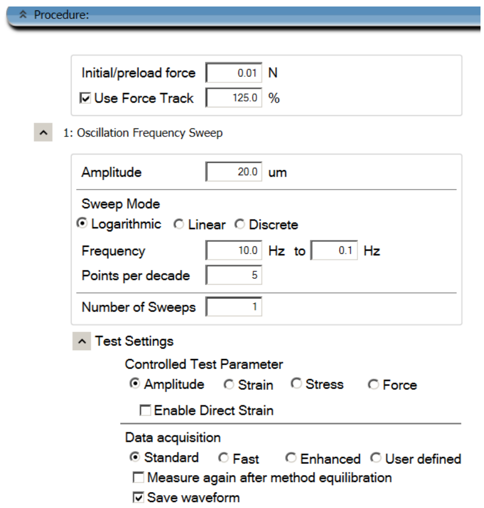
Frequency Sweep: DMA 850



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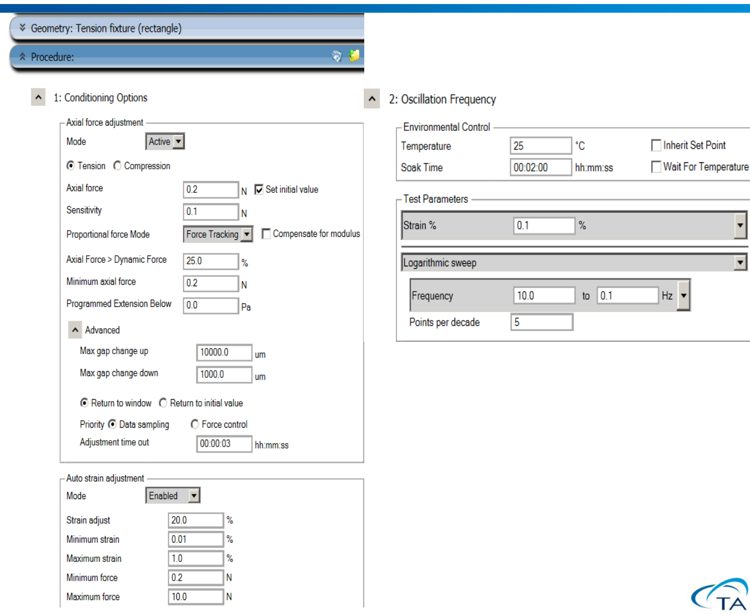
Frequency Sweep: RSA-G2



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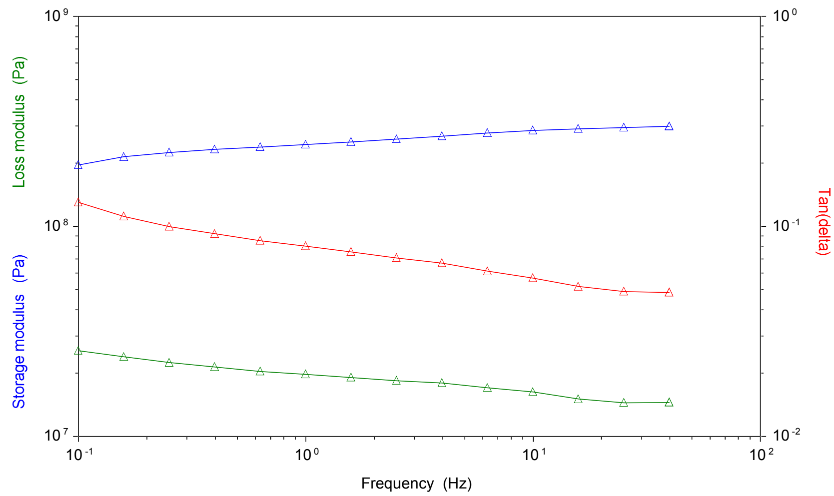
Frequency Sweep



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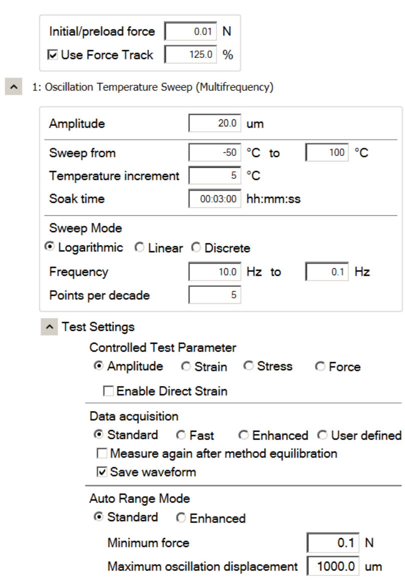
Dynamic Temperature/Frequency Sweep – DMA 850



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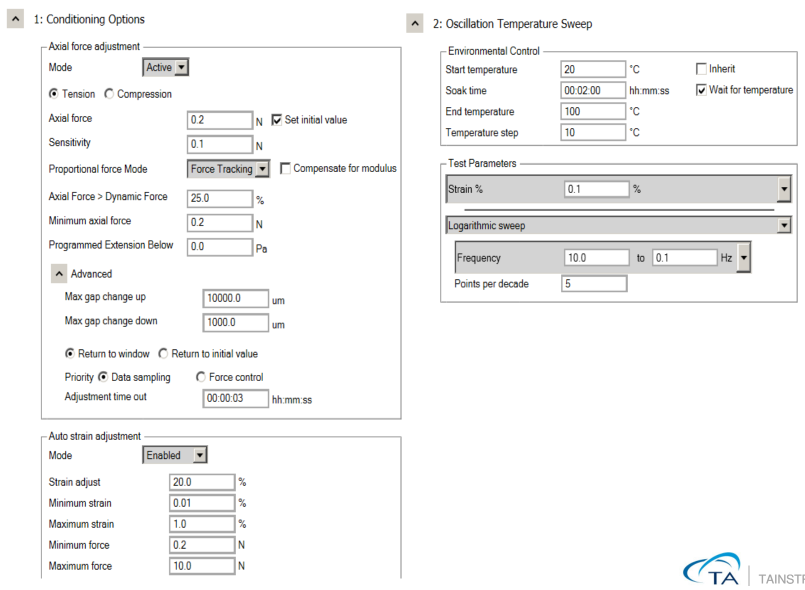
Temperature/Frequency Sweep – RSA-G2



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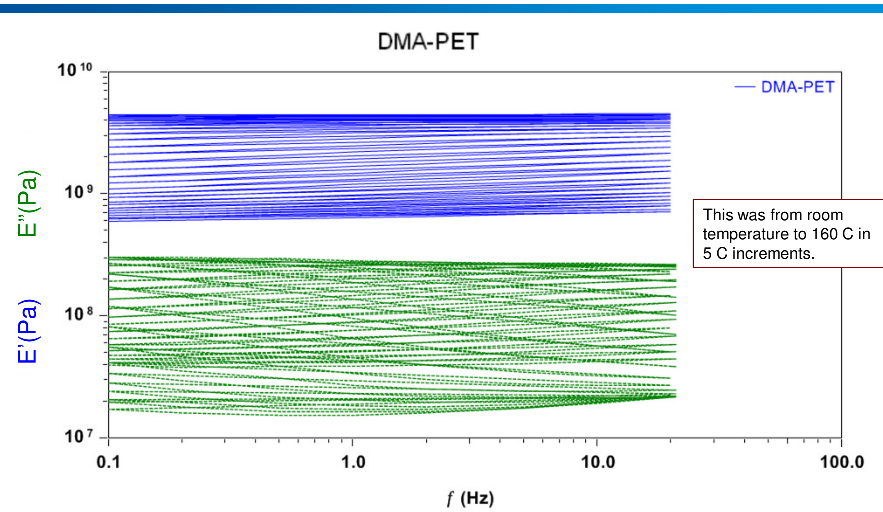
Temperature/Frequency Sweep



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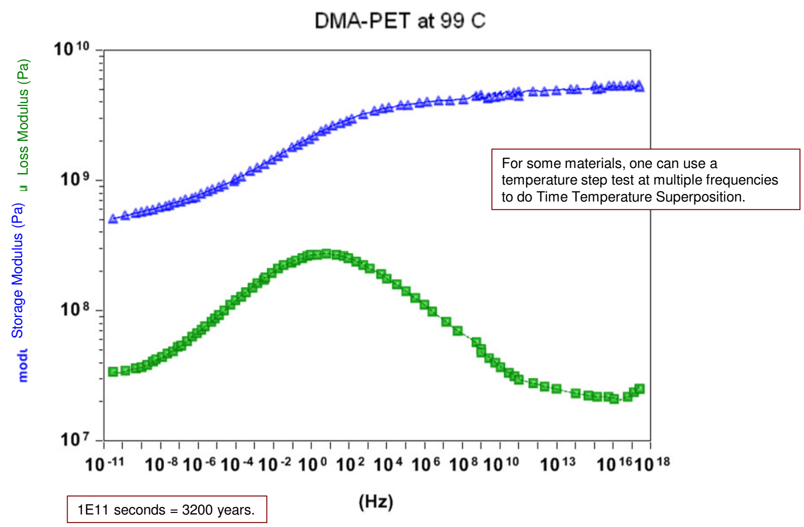
Frequency/Temperature Sweep – Time Temperature Superposition



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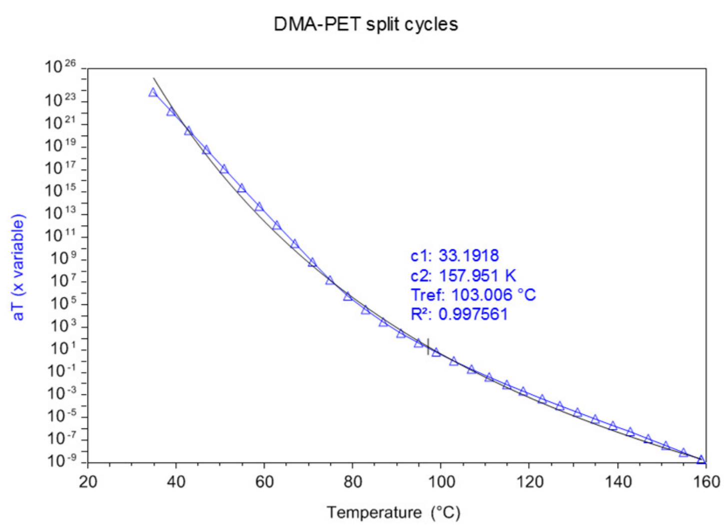
Shift Factors from TTS



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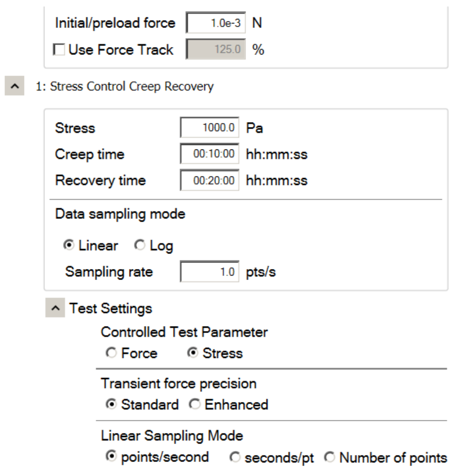
Creep Testing: DMA 850



This is straightforward.
It is more complex with the RSA-G2

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Creep Testing on the RSA-G2

Steps needed to do a creep test on the RSA-G2

1. Perform a strain sweep to find the Linear Viscoelastic Region
2. Use the Conditioning > Controlled Stress to calculate the PID constants.
3. Perform the creep test.

The sample chosen was a foam material that was readily available. The compression clamp was used.

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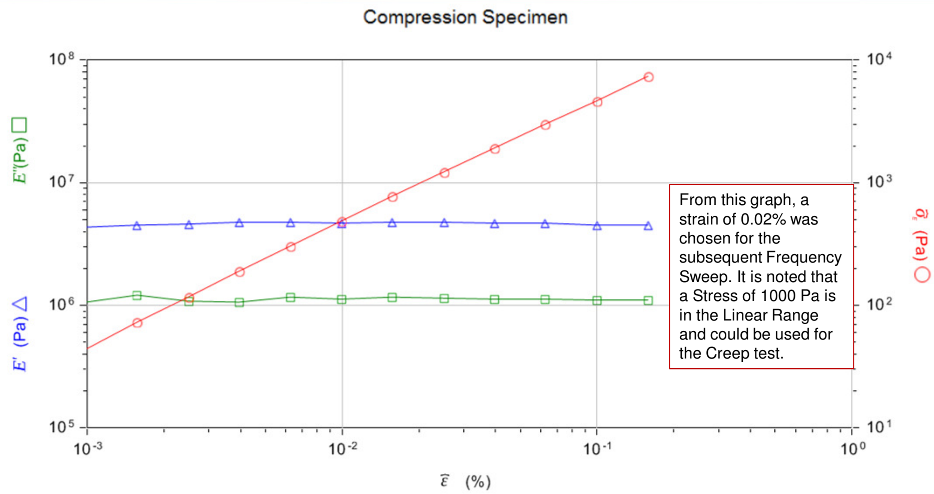
Graph of Preliminary Strain Sweep Test



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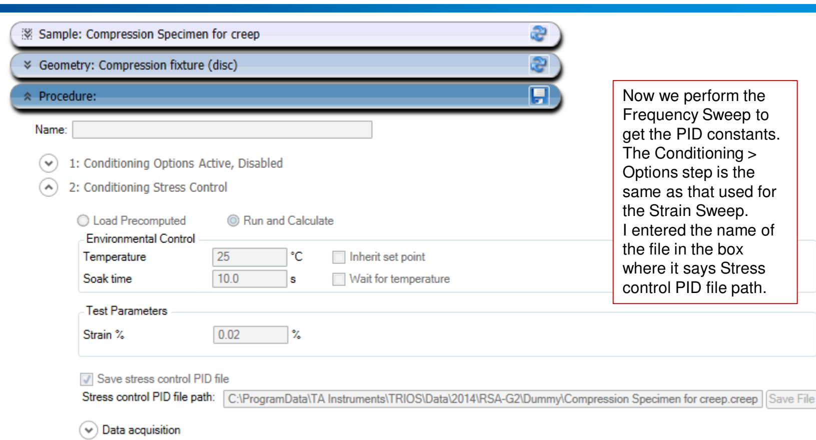
Frequency Sweep to Get PID Constants



Now we perform the Frequency Sweep to get the PID constants. The Conditioning > Options step is the same as that used for the Strain Sweep.
I entered the name of the file in the box where it says Stress control PID file path.

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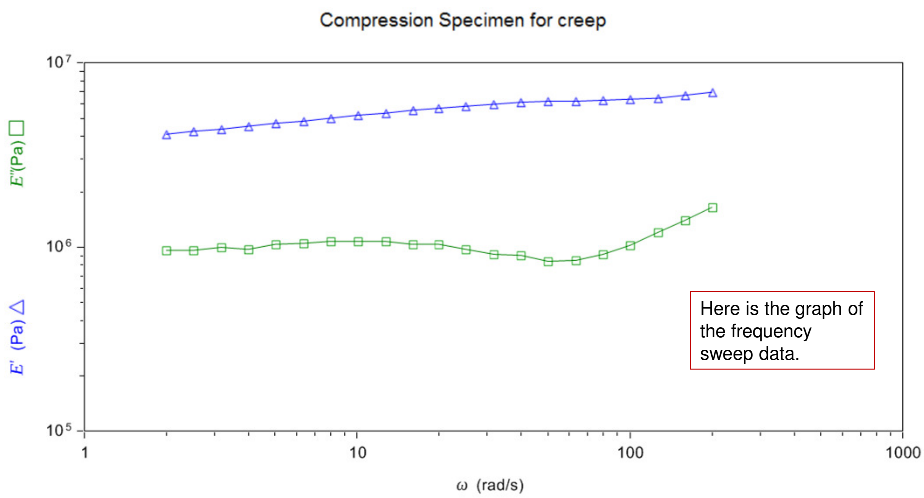
Frequency Sweep to Get PID Constants



Here is the graph of the frequency sweep data.

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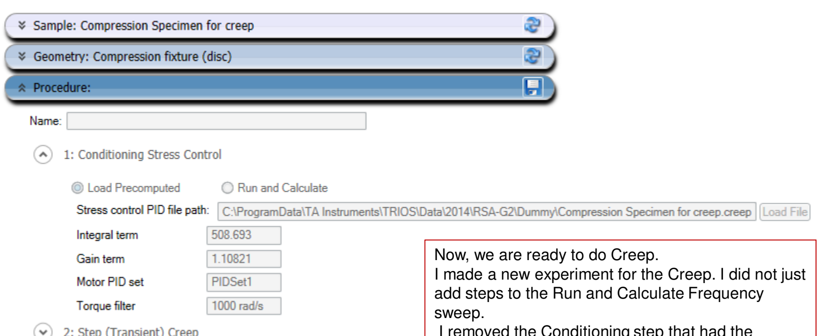
Actual Creep Test on RSA-G2



Now, we are ready to do Creep.
I made a new experiment for the Creep. I did not just add steps to the Run and Calculate Frequency sweep.
I removed the Conditioning step that had the Preload Axial Force.
We changed the command in Conditioning Stress Control to Load Precomputed.
We select the PID file path from our last run. Note the values for the Integral term and the Gain term.
I also manually raised the RSA-G2 head so that it was just touching the specimen. The force was right around 0.0 g.

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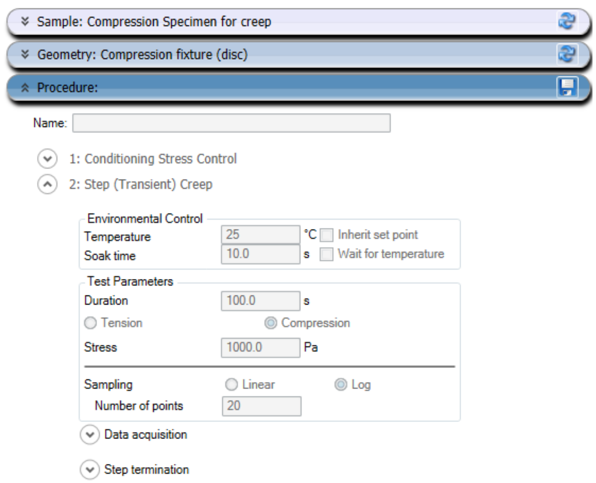
Actual Creep Test



Here is the Creep procedure I designed.

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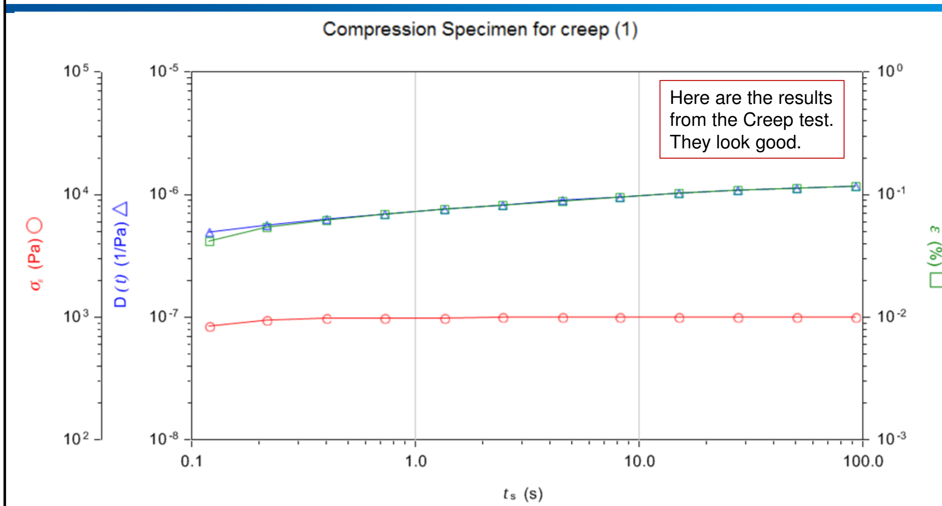
Creep Test on RSA-G2



Here are the results from the Creep test. They look good.

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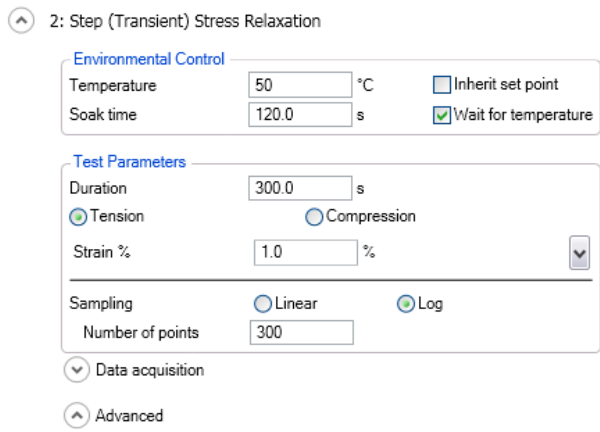
Programming Stress Relaxation on a RSA-G2



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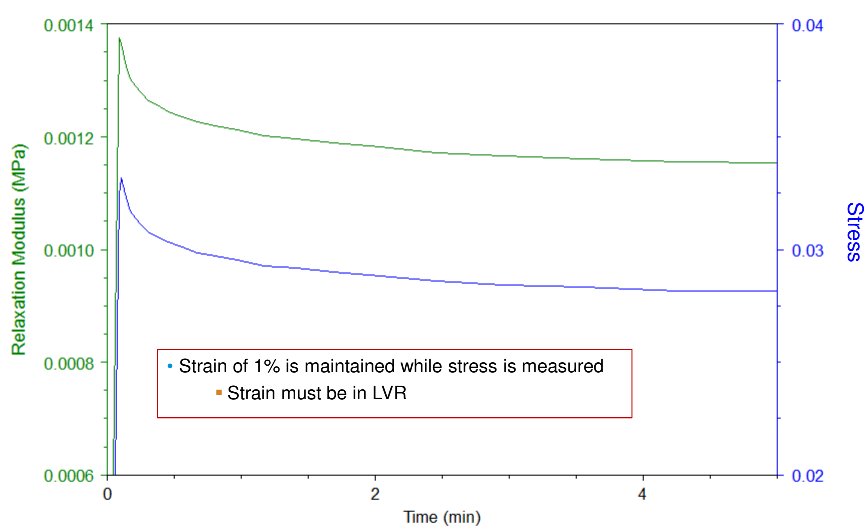
Stress Relaxation on Silicone Foam



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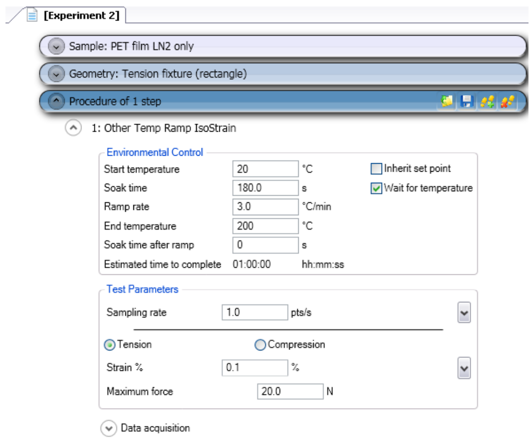
Programming Iso-strain Testing on a RSA-G2

- Hold strain constant and measure sample shrinking force



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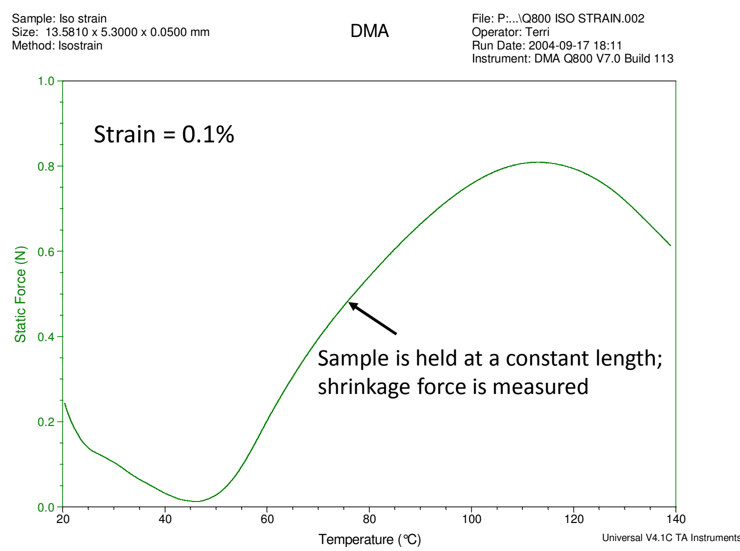
PVC Based Film - IsoStrain



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Polymer Structure-Property Characterization

- Glass transition
- Secondary transitions
- Crystallinity
- Molecular weight/cross-linking
- Phase separation (polymer blends, copolymers,...)
- Composites
- Aging (physical and chemical)
- Curing of networks
- Orientation
- Effect of additives

Turi, Edith, A, Thermal Characterization of Polymeric Materials, Second Edition, Volume I., Academic Press, Brooklyn, New York, P. 489.

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The Glass Transition

- "The glass transition is associated with the onset of long-range cooperative segmental mobility in the amorphous phase, in either an amorphous or semi-crystalline polymer."
- Any factor that affects segmental mobility will affect T_g, including…
  - the nature of the *moving segment*,
  - chain stiffness or steric hindrance
  - the free volume available for segmental motion

Turi, Edith, A, Thermal Characterization of Polymeric Materials, Second Edition, Volume I., Academic Press, Brooklyn, New York, P. 508.

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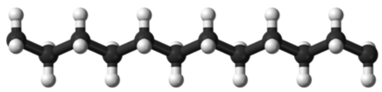
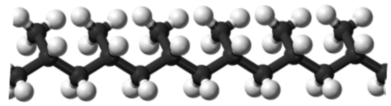
Chemical Composition of Polymers

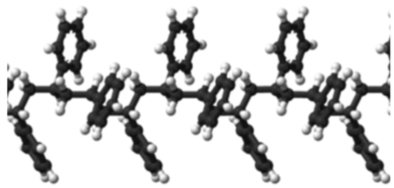
- Polymers are long chains of repeating units (monomers)
- The chemical composition determines mechanical properties, and the temperature where transitions occur



Polyethylene T_g = -128° C



Polypropylene T_g = -20° C



Polystyrene T_g = 100 ° C

"Introduction to Polymer Viscoelasticity," 2nd Edition. Aklonis, John J; MacKnight, William J. Wiley-Interscience

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Dynamic Mechanical Analysis of Tg

- DMA provides a higher sensitivity to Tg than DSC, because it directly measures changes in mechanical and viscoelastic properties as a function of temperature.
- Materials whose glass transitions cannot be resolved by DSC can often be measured easily in DMA
  - Semi-crystalline materials with low amorphous content
  - Composites in which the polymer weight fraction is small
  - Glass Transitions that occur over a wide range, or overlap with other thermal events
- Because DMA is based on mechanical properties, the Glass Transition measurement is particularly relevant to characterizing materials for their end-use properties

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Glass Transition E' Onset, E" Peak, and Tan δ Peak

- **Storage Modulus E' Onset**:
  - Occurs at lowest temperature, relates to mechanical failure
- **Loss Modulus E" Peak:**
  - Occurs at middle temperature
  - Related to the physical property changes
  - Reflects molecular processes - the temperature at the onset of segmental motion
- **Tan δ Peak:**
  - Occurs at highest temperature; Used historically in literature
  - Measure of the "leatherlike" midpoint between the glassy and rubbery states
  - Height and shape change systematically with amorphous content.

Turi, Edith, A, Thermal Characterization of Polymeric Materials, Second Edition, Volume I., Academic Press, Brooklyn, New York, P. 980.

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The Glass & Secondary Transitions

–Glass Transition - Cooperative motion among a large number of chain segments, including those from neighboring polymer chains

–**Secondary Transitions**
–Local Main-Chain Motion - intramolecular rotational motion of main chain segments four to six atoms in length
➢Side group motion with some cooperative motion from the main chain
➢ Internal motion within a side group without interference from side group.
➢ Motion of or within a small molecule or diluent dissolved in the polymer (e.g. plasticizer.)

Turi, Edith, A, Thermal Characterization of Polymeric Materials, Second Edition, Volume I., Academic Press, Brooklyn, New York, P. 487.

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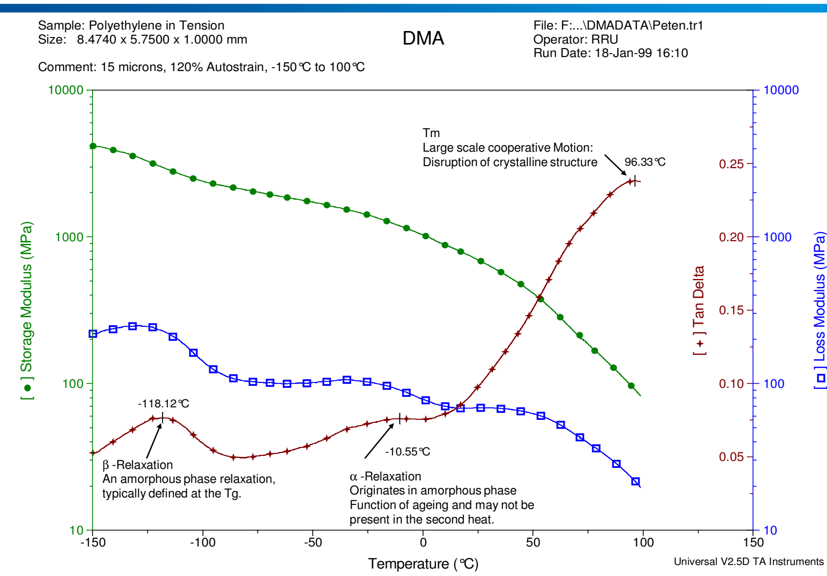
LDPE: Primary and Secondary Transitions



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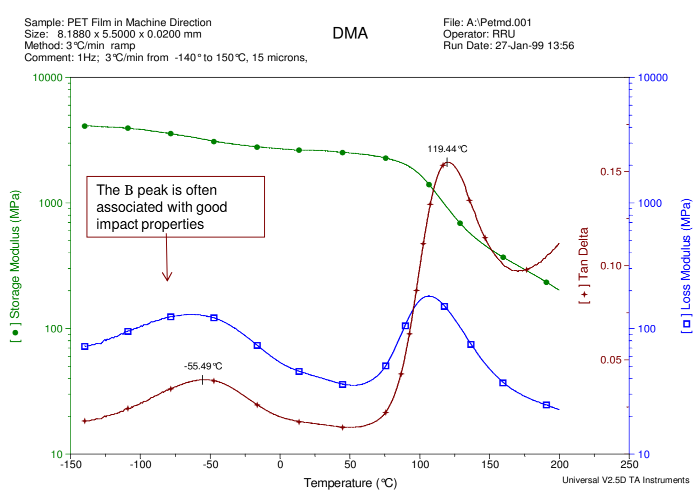
Primary and Secondary Transition in PET Film



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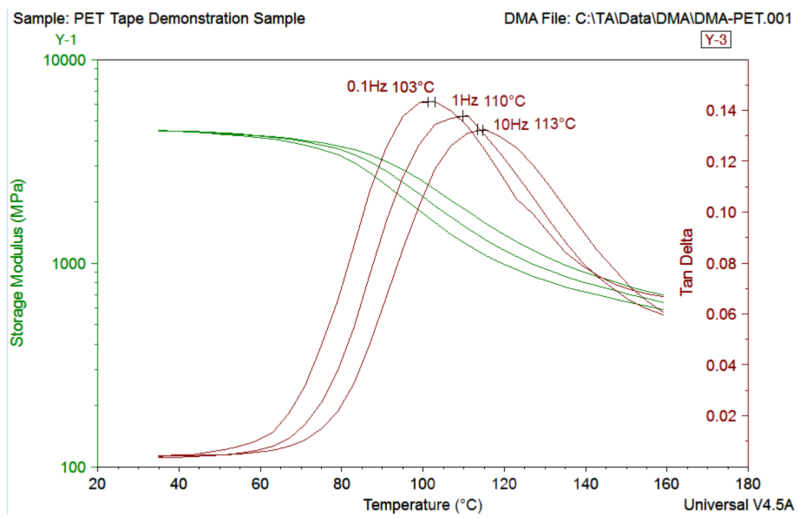
PET Film: Effect of Frequency on Tg



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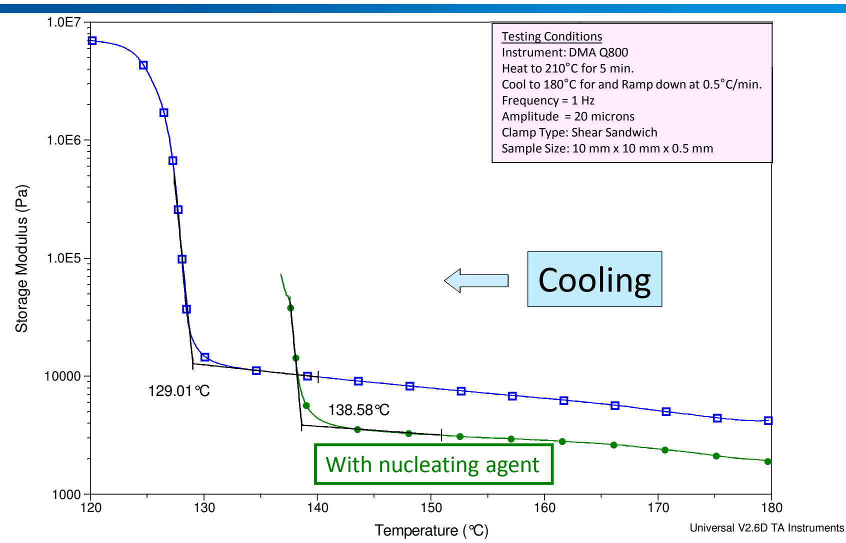
Polypropylene - Onset of Crystallization



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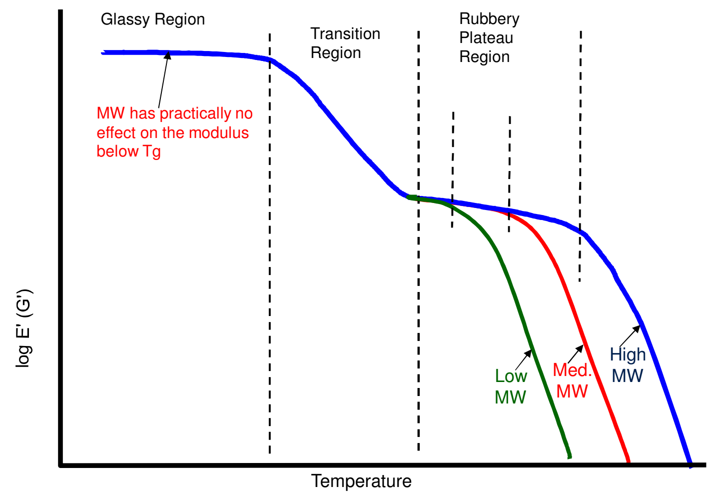
Molecular Structure - Effect of Molecular Weight



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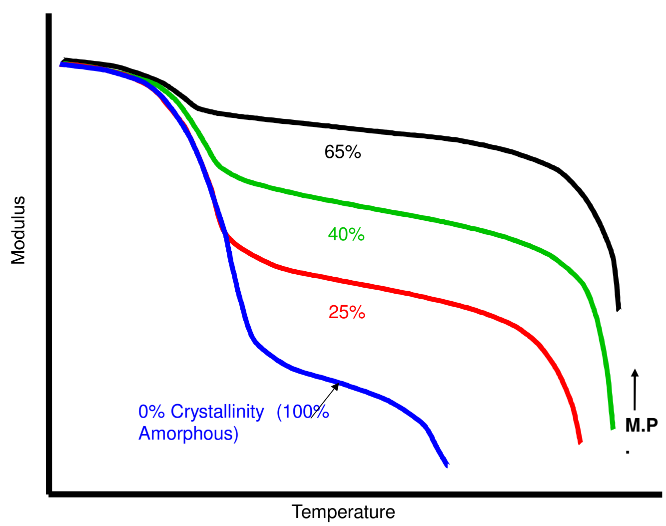
Effect of Crystallinity



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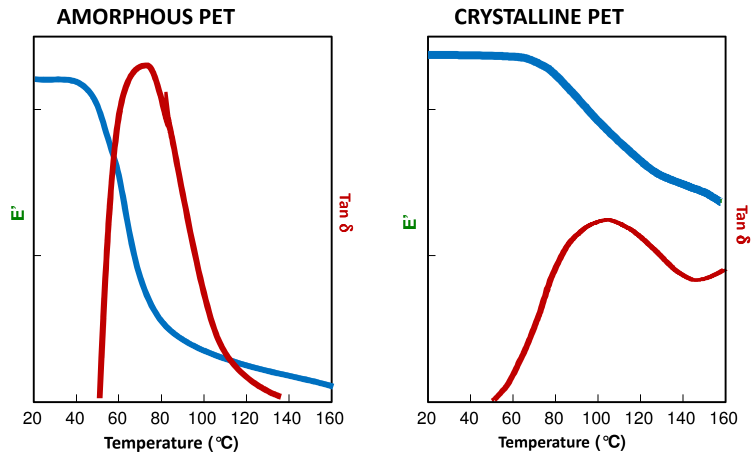
Effect of % Crystallinity on Glass Transition



Redrawn with permission from Thompson and Woods, Trans. Faraday Soc., 52, 1383 (1956)

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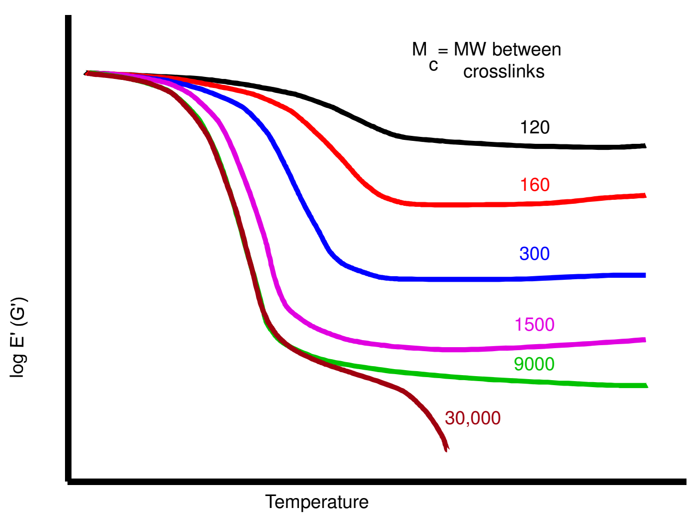
Effect of Crosslinking



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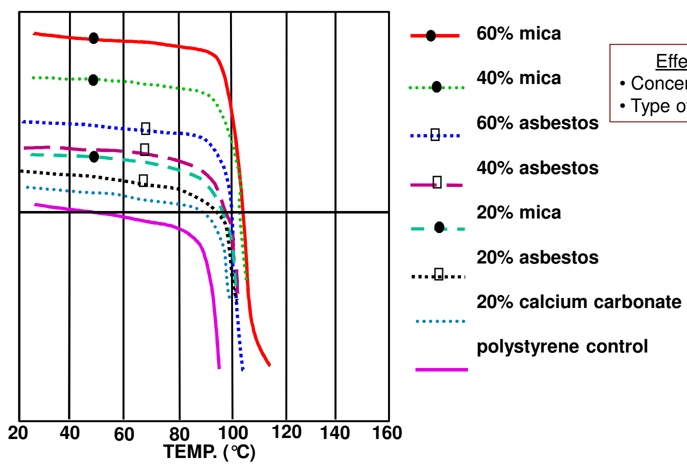
Effect of Filler on Modulus



Effects
- Concentration
- Type of filler

Nielson, L. E., Wall, R. A., and Richmond, P. G., **Soc. Plastics Eng. J.**, **11**, 22 (1966)

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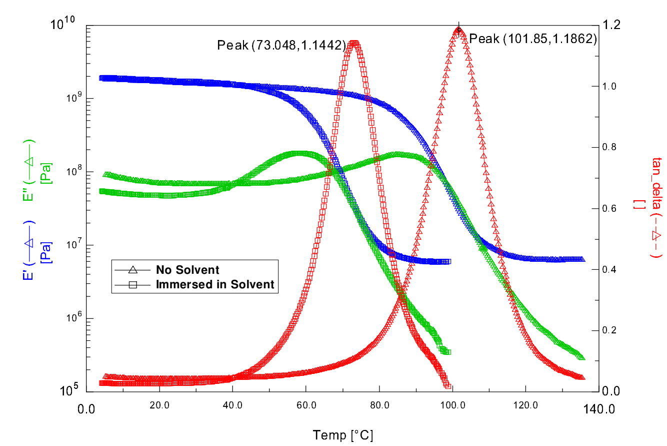
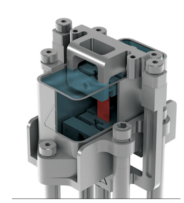
Effect of Moisture

- Automotive coating measured under dry vs. wet conditions





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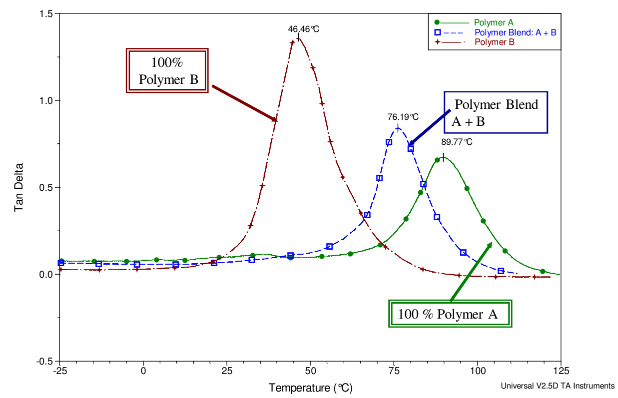
Polymer Blend - Aerospace Coating



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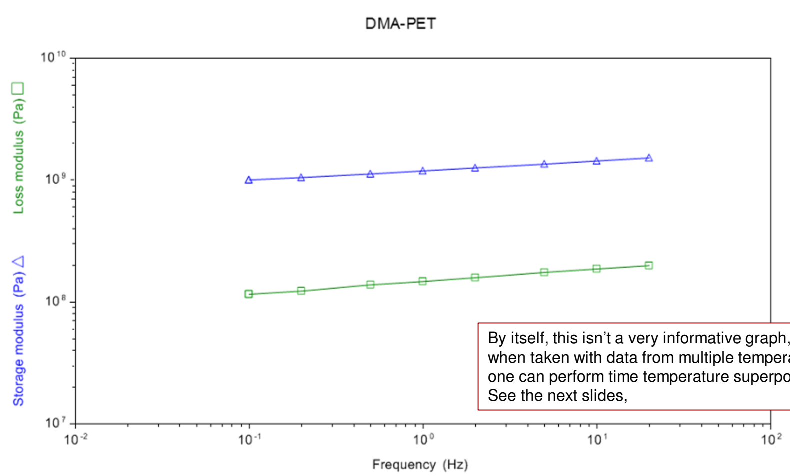
Dynamic Frequency Sweep



By itself, this isn't a very informative graph, but, when taken with data from multiple temperatures, one can perform time temperature superposition. See the next slides,

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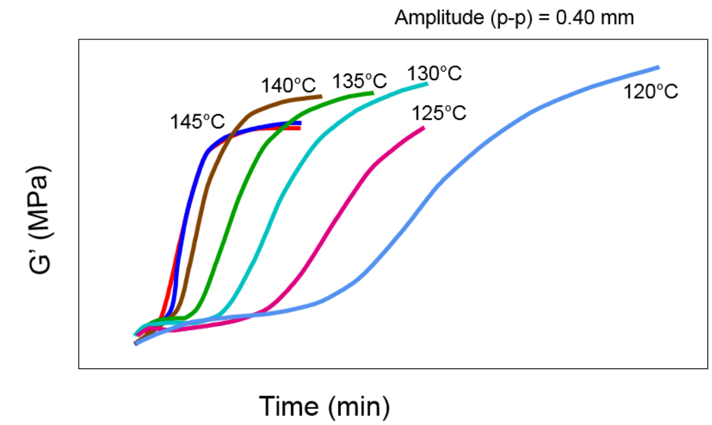
Isothermal Cure of Tire Compound: Effect of Curing Temperature



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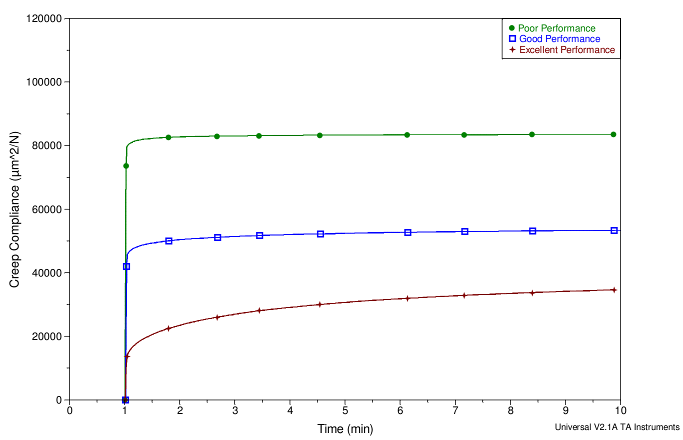
Creep on Packaging Films used in Thermoforming



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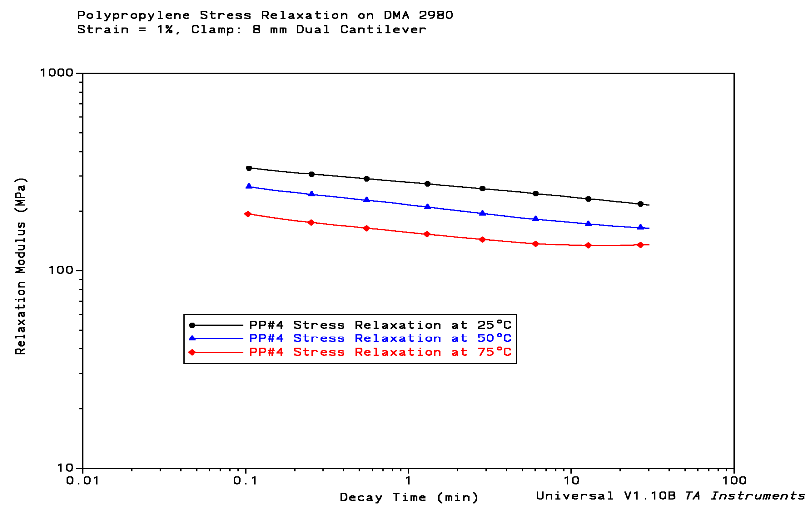
DMA: Stress Relaxation on Polypropylene



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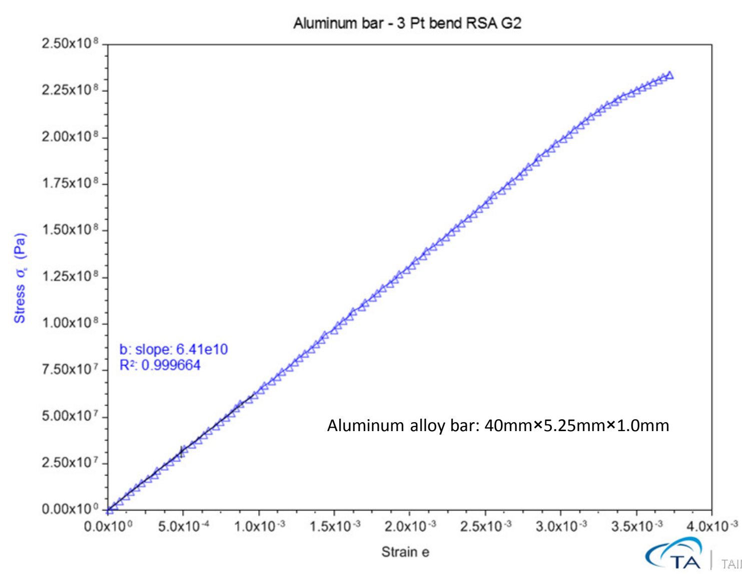
Other (Axial) – RSA G2

Constant Linear Rate: 0.1mm/min, 2 mm max gap change



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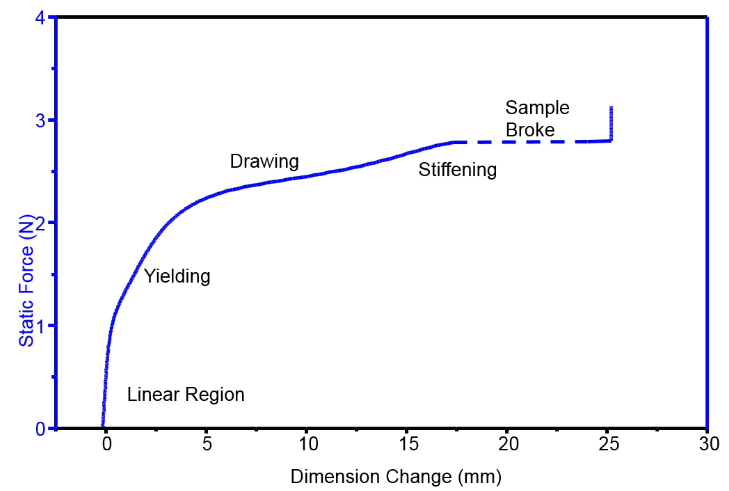
Stress-Strain Experiment (Ramped Force) Polyethylene Film 4 mm



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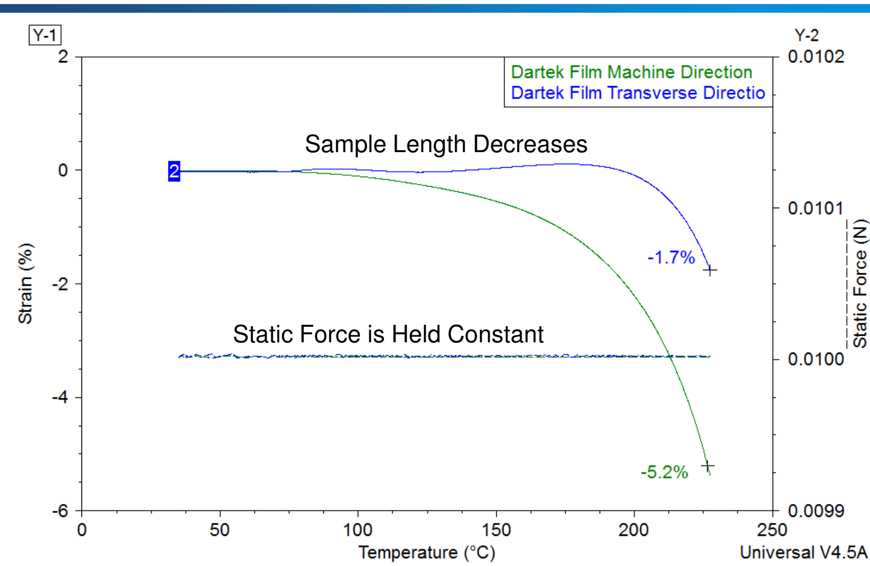
Iso-Force Temp Ramp- Shrinkage of Oriented Film



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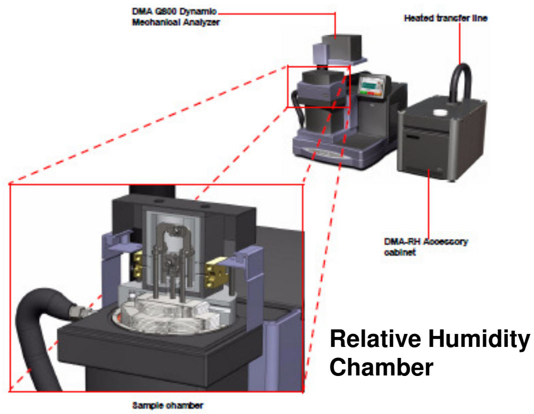
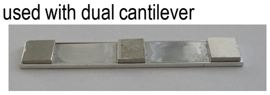
Other Accessories

- Relative Humidity Chamber
  (described later)
- Powder Kit for 35-mm Cantilever Clamp for Tg's from tan delta
- Low Friction 3-pt bend
- Penetration Clamp
- Glass Support Cloth



Relative Humidity Chamber

Powder clamp, used with dual cantilever



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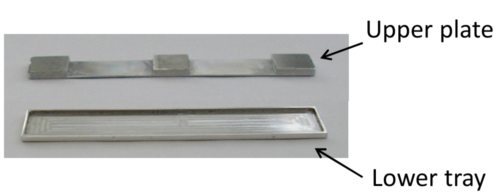
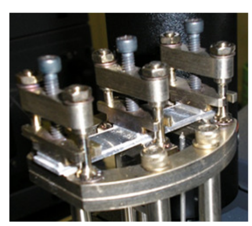
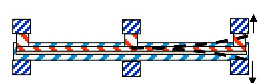
Powder Clamp

- Powder clamp measures thermal transitions in powders and is used with the standard 35 mm dual cantilever clamp





- Powder is placed in the lower tray
- Clamp will flex during measurements and contribution of the powder to the system is "magnified"
  - Use mesh or screen to aid in cleaning
  - Do not melt sample, cleaning will be difficult



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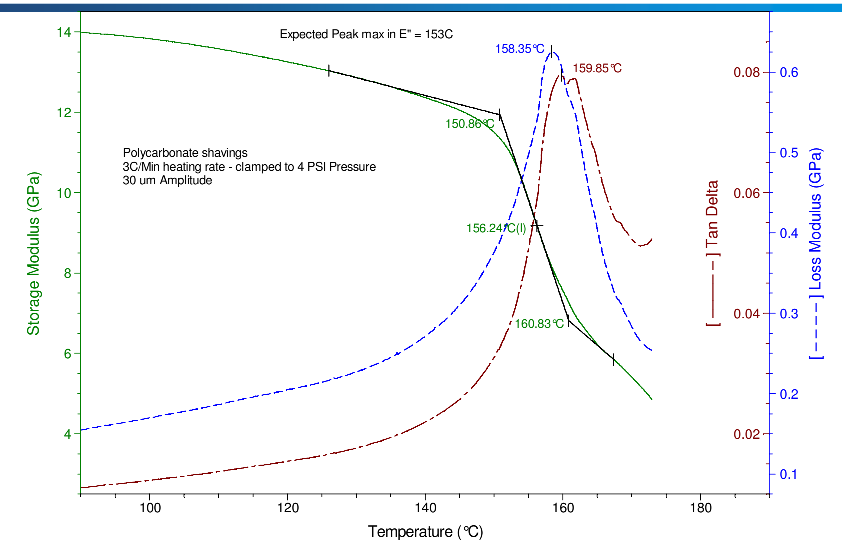
Polycarbonate Shavings



Note: Disregard values of modulus

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Humidity Option

This is the temperature/humidity chamber that was used to control the environment for this testing.

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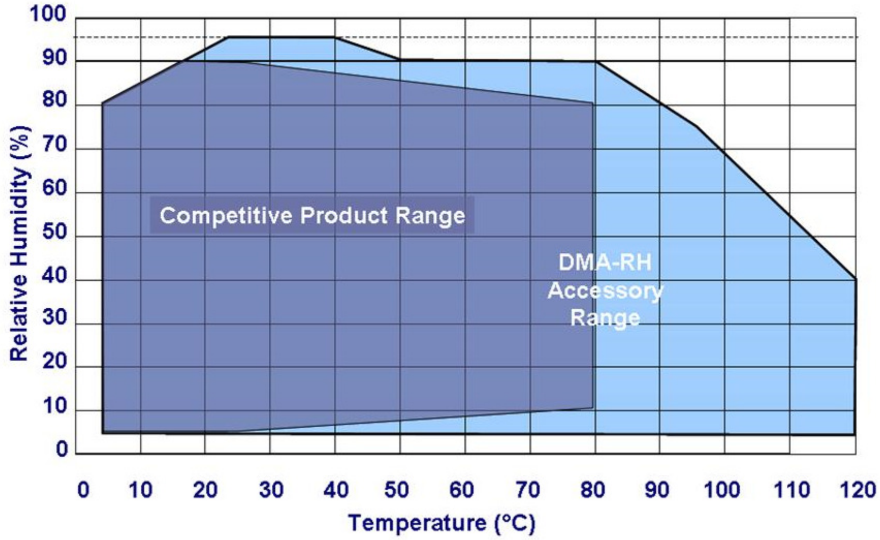
Q800: DMA-RH Operating Range



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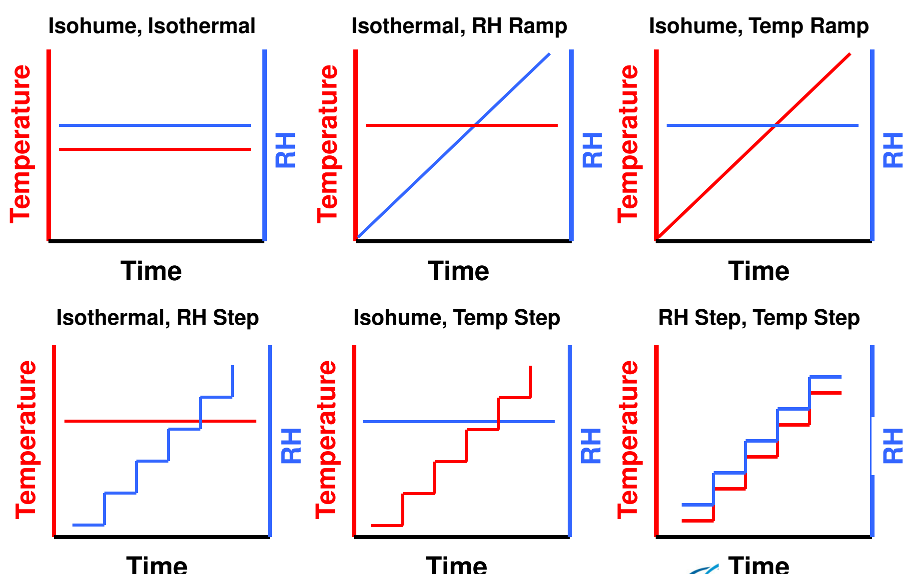
DMA-RH Experimental Options



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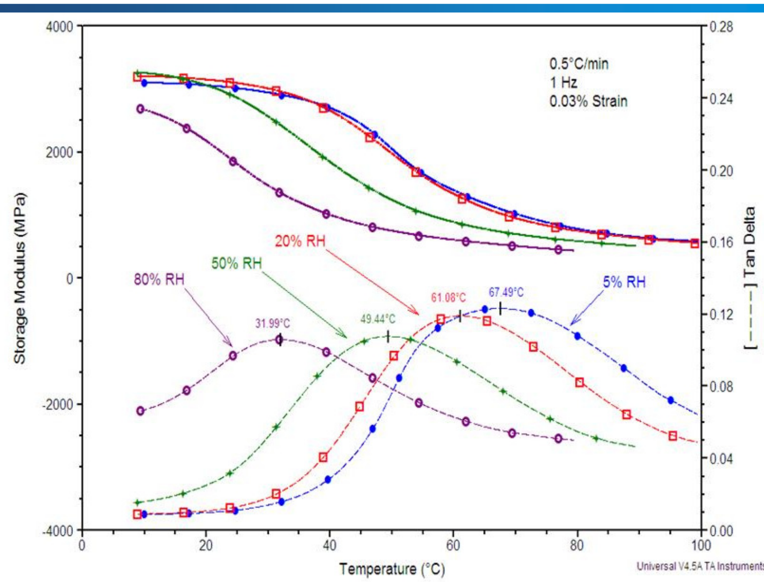
Analysis of Nylon 6: Isohume-Temperature Scans



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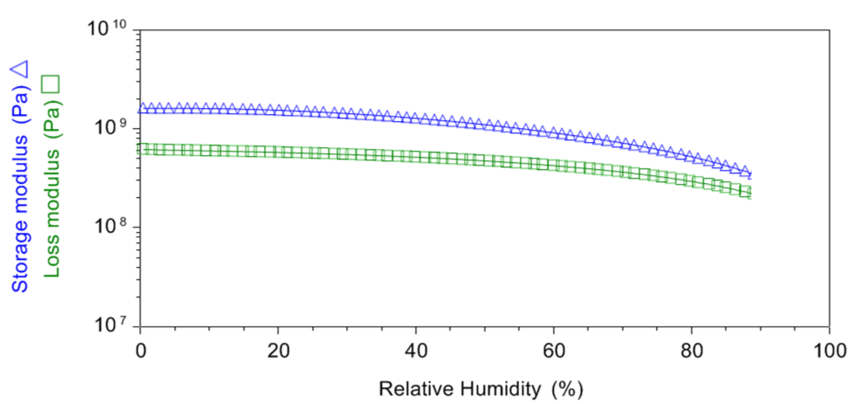
Dynamic Humidity Ramp



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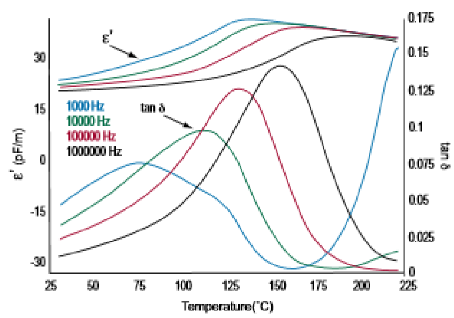
Dielectric Testing

Figure 16: DETA Temperature Ramp on PMMA



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RSA G2 Dielectric Accessory

- RSA G2 can be positioned as two instruments in one.
  - DMA/Solids Analyzer
  - Dielectric Analyzer

Attribute	Specification
Geometry	25 mm PP
Temperature System Compatibility	FCO, Force Convection Oven
ARES/RSA to DE Bridge Interface	IEEE Internal to Instrument
Temperature Range	-160° to 300°C

(LCR Meter)	Frequency	AC Test Signal (potential)
Agilent 4285A	75 kHz to 30 MHz	0.005 to 10 Volts
Agilent E4980A	20 Hz to 2 MHz	0.005 to 20 Volts

Agilent LCR Meter Model 4980A

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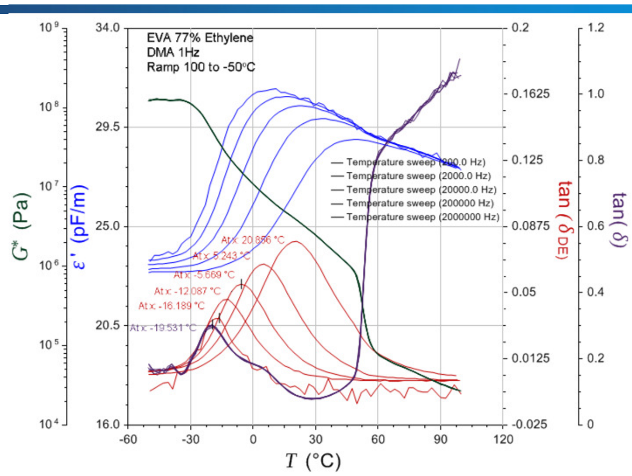
Relaxations in Ethylene Vinyl Acetate (EVA)



Temperature ramp from 100 to -50°C with dynamic mechanical response at 1Hz and simultaneous dielectric response at a frequency of:
200, 2000, 20000, 200000 and 2000000 Hz (Data collected on DHR rheometer)

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Need DMA HELP?!?

- Check the manuals, help and error help.
- Contact the TA Instruments Rheology Hotline
  - **302-427-4070** M-F 8-4:30 ET
  - Email rheologysupport@tainstruments.com
- Call the TA Instruments Service Hotline
  - **302-427-4050** M-F 8-4:30 ET
- Call your local Technical or Service Representative
- Visit our Website www.tainstruments.com for training videos, TA Tech tips, application notes and much more!

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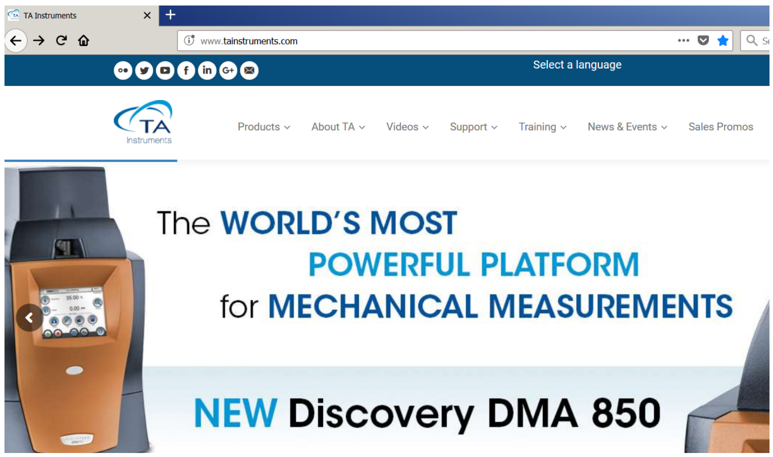
Website: www.tainstruments.com



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- Software Sorted by Instruments
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- Request a Feature

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- Premium Support Plan
- Plus Support Plan
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- Academic Support Plan
- ElectroForce Support Plans

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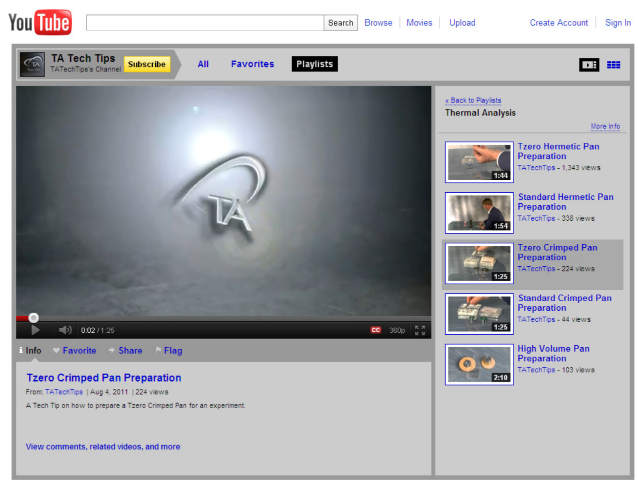
TA Tech Tips



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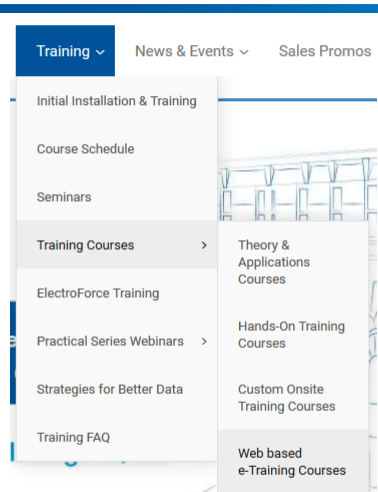
On Line Training



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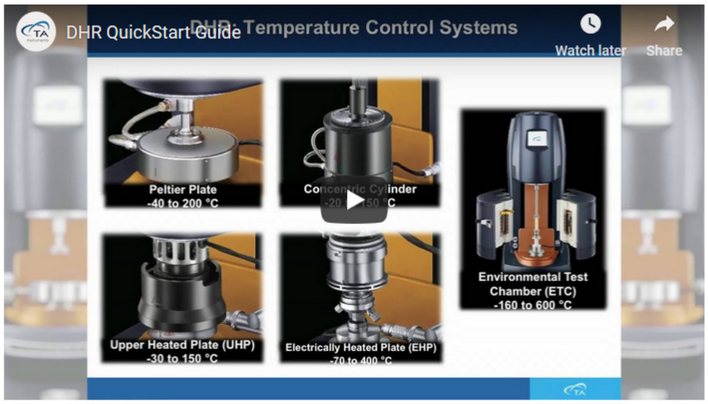
DHR Quick Start Guide



TRIOS QuickStart Guide – Basic Data Analysis Applications in Rheology

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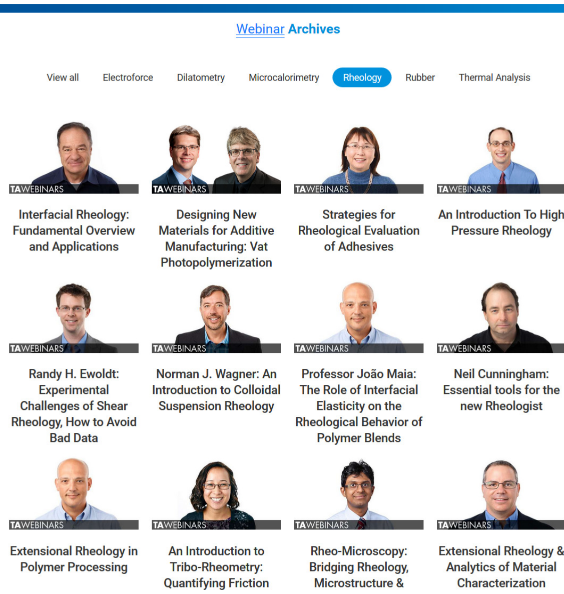
Sampling of Available Webinars



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