DMA – RHEOLOGY OF SOLID-LIKE MATERIALS

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Topics in the Waters – TA Characterization Workshop

- Optimizing DSC and TGA Testing
- GPC Techniques and Applications
- Rheology from Liquids to Solids
- DMA – Rheology of Solid-Like Materials

We're approaching the finish line.
We're going to make it. ☺

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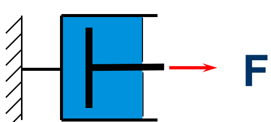
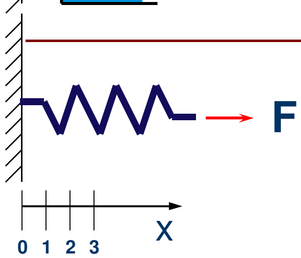
QUICK REVIEW OF RHEOLOGY

Rheology: The study of the flow and deformation of matter



Flow: Fluid Behavior; Viscous Nature

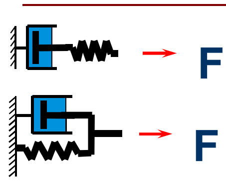
F = F(v); F ≠ F(x)



Deformation: Solid Behavior
Elastic Nature

F = F(x); F ≠ F(v)

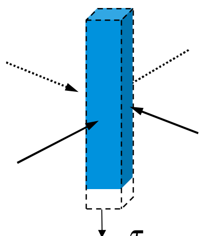
We discussed these concepts in the Rheology section of the workshop.



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

Rheological Parameters

FLUIDS TESTING

Parameter	Shear	Elongation	Units
Rate	$\dot{\gamma}$	$\dot{\varepsilon}$	Seconds^{-1}
Stress	σ	τ	Pascals
Viscosity	$\eta = \sigma/\dot{\gamma}$	$\eta_E = \tau/\dot{\varepsilon}$	Pascal-seconds

SOLIDS TESTING

Parameter	Shear	Elongation	Units
Strain	γ	ε	Unitless
Stress	σ	τ	Pascals
Modulus	$G = \sigma/\gamma$	$E = \tau/\varepsilon$	Pascals

We saw these parameters in the Rheology section.

Rheological Parameters

CREEP TESTING

Parameter	Shear	Elongation	Units
Stress	σ	τ	Pascals
Strain	γ	ε	Unitless
Compliance	$J = \gamma/\sigma$	$D = \varepsilon/\tau$	1/Pascals

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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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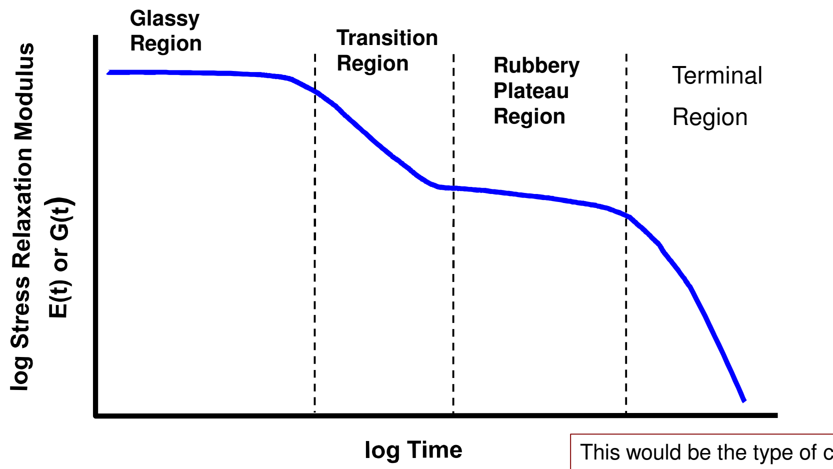
Stress Relaxation: Material Response



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

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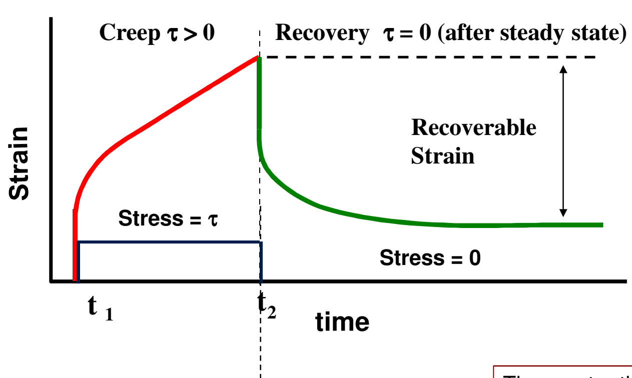
Creep Testing



The greater the elasticity, the greater the recovery.

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

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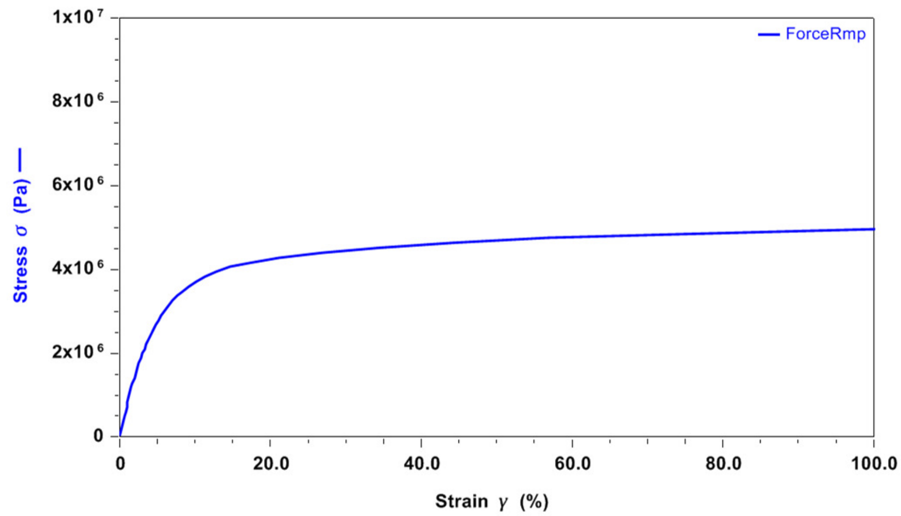
Polyethylene Stress Ramp



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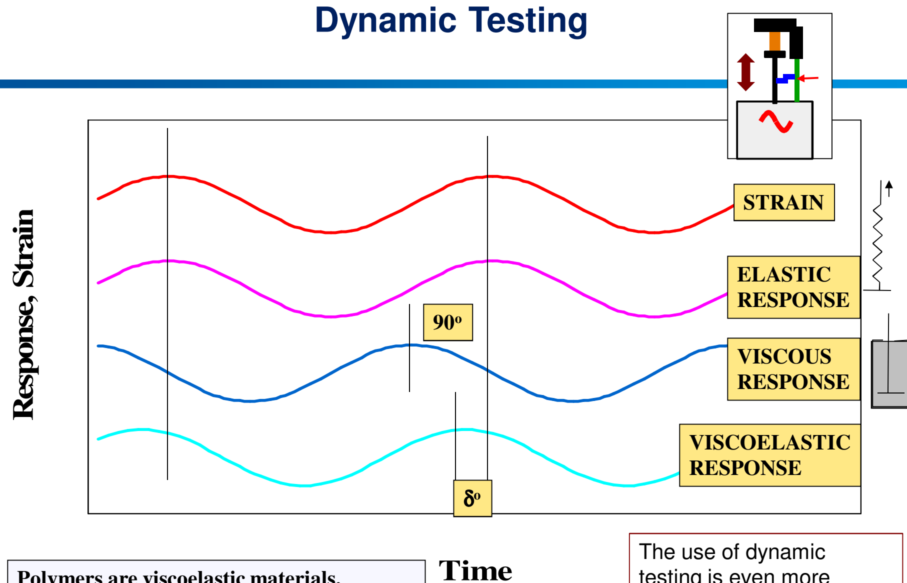
Dynamic Testing



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

The use of dynamic testing is even more prevalent with DMA than it is with rheometers.

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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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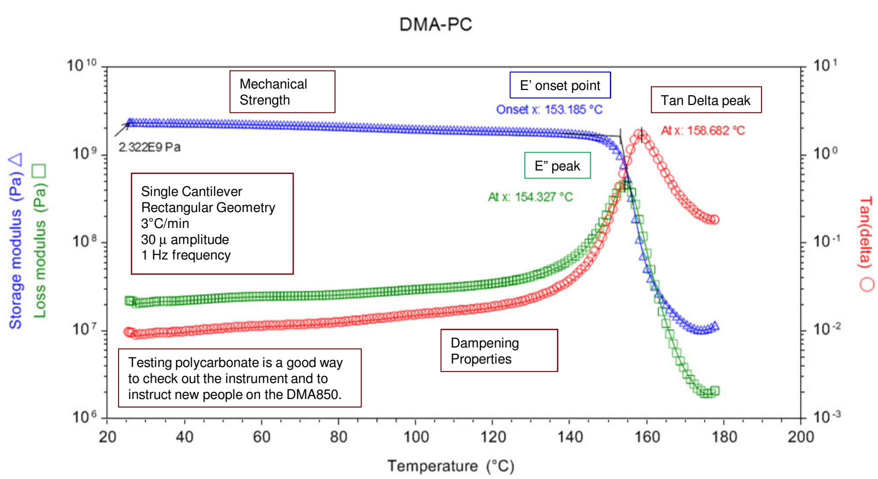
Polycarbonate Testing on the DMA 850



This is the main test performed on DMA instruments.

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E' Onset, E" Peak, and tan δ Peak

- **E' Onset**: Occurs at the lowest temperature - Relates to mechanical Failure
- **E" Peak:** Occurs at the middle temperature - more closely related to the physical property changes attributed to the glass transition in plastics. It reflects molecular processes - agrees with the idea of T_g as the temperature of the onset of segmental motion.
- **tan δ Peak:** Occurs at the highest temperature - used historically in literature - a good 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.

DMAs from TA Instruments

RSA G2

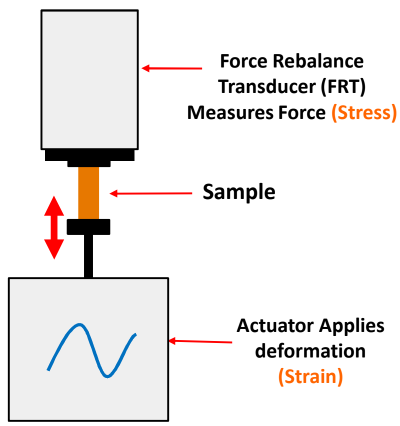
Discovery DMA850

ESG 3200

DMAs from TA Instruments

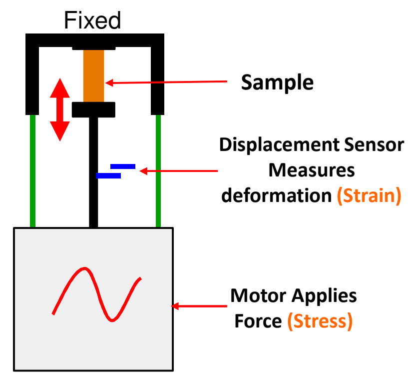
RSA G2

Separate Motor & Transducer



DMA850

Combined Motor & Transducer



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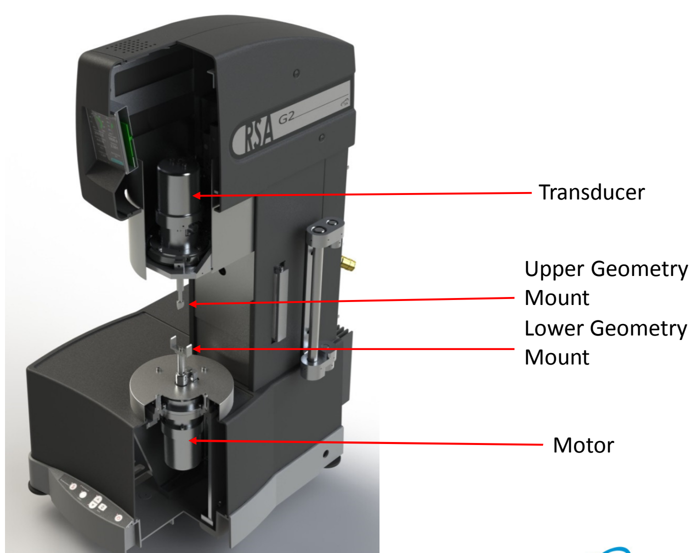
RSA G2: Schematic Dual Head Design



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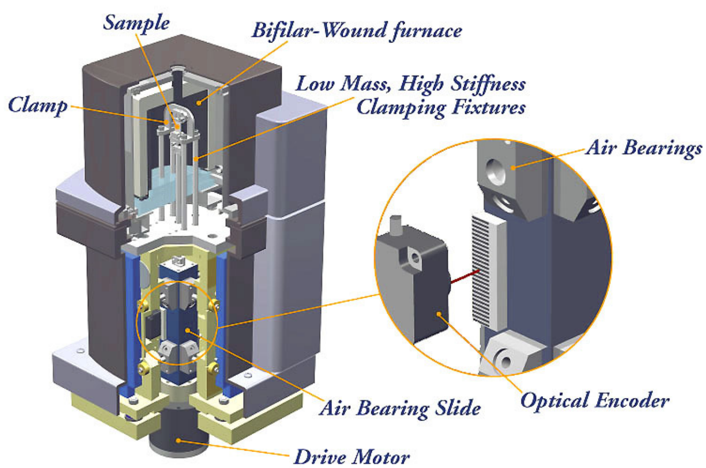
DMA850: Schematic



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DMA Specifications

	RSA G2	DMA850	Q800
Max Force	35 N	18 N	18 N
Min Force	0.0005 N	0.0001 N	0.0001 N
Displacement Resolution	1 nm	* 0.1 nm	1 nm
Frequency Range	2 x 10^{-6} to 100 Hz	* 1 x 10^{-4} to 200 Hz	1 x 10^{-2} to 200 Hz
Dynamic Deformation Range	± 5 x 10^{-5} to 1.5 mm	* ± 5 x 10^{-6} to 10 mm	± 5 x 10^{-4} to 10 mm
Temperature range	-150 to 600℃	-150 to 600℃	-150 to 600℃
Isothermal Stability	± 0.1	± 0.1	± 0.1
Heating Rate	0.1°C to 60°C/min	0.1°C to 20°C/min	0.1°C to 20°C/min
Cooling Rate	0.1°C to 60°C/min	0.1°C to 10°C/min	0.1°C to 10°C/min

* Denotes improvement by DMA 850 compared with Q800

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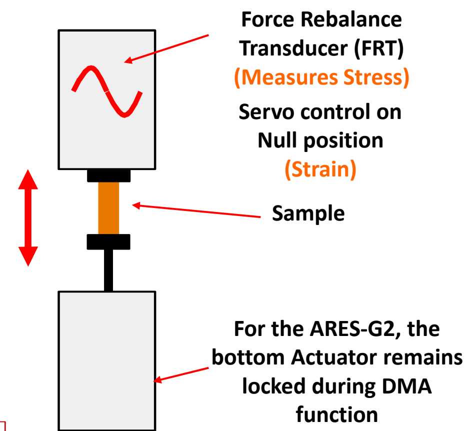
DMA Mode on DHR and ARES-G2

ARES G2 and DHR DMA Mode

Strain control & dynamic test only



With the rheometers in the linear DMA mode, both the DHR and ARES-G2 are CMT design.

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Specifications of the DHR-DMA and the ARES-G2 DMA

	DHR – DMA mode	ARES-G2 DMA mode
Motor Control	FRT	FRT
Minimum Force (N) Oscillation	0.1	0.001
Maximum Axial Force (N)	50	20
Minimum Displacement (µm) Oscillation	1.0	0.5
Maximum Displacement (µm) Oscillation	100	50
Displacement Resolution (nm)	10	10
Axial Frequency Range (Hz)	1×10^{-5} to 16	1×10^{-5} to 16

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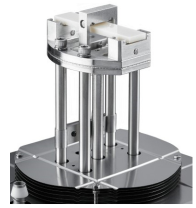
Clamps for DMA850

S/D Cantilever

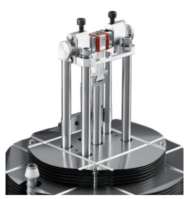
Film/Fiber Tension

3-Point Bending

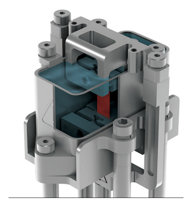


Compression

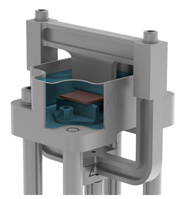
Shear Sandwich



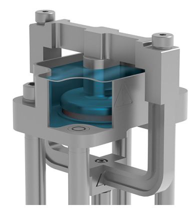
Submersible Tension



Submersible Bending



Submersible Compression



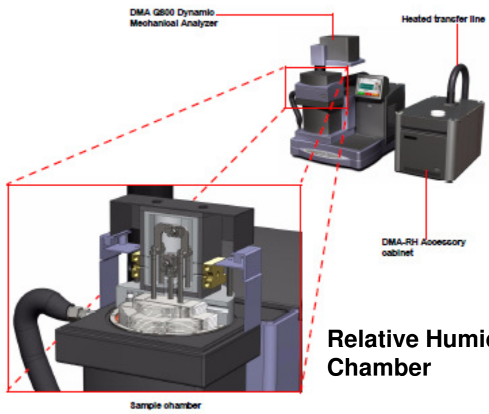
DMA 850 Sample Sizes

Dual/Single Cantilever	**L = 8/4 mm; W ≤ 15 mm; T ≤ 5 mm** **L = 20/10 mm; W ≤ 15 mm; T ≤ 5 mm** **L = 35/17.5 mm; W ≤ 15 mm; T ≤ 5 mm**
3-Point Bend	**L = 5, 10 or 15 mm; W ≤ 15 mm; T ≤ 7 mm** **L = 20 mm; W ≤ 15 mm; T ≤ 7 mm** **L = 50 mm; W ≤ 15 mm; T ≤ 7 mm**
Tension	**L = 5 to 30 mm; W ≤ 8 mm; T ≤ 2 mm** **L = 5 to 30 mm; 5 denier; D ≤ 0.8 mm**
Shear	**10 mm square; T ≤ 4 mm**
Compression	**15 and 40 mm diameter; T ≤ 10 mm**

For cantilever, 3-pt bend, and tension, these dimensions refer to length between clamps. Allow for an additional ~20 mm for the clamps.

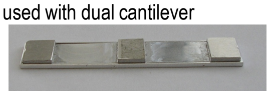
DMA 850 – Other Accessories

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



Relative Humidity Chamber

Powder clamp, used with dual cantilever



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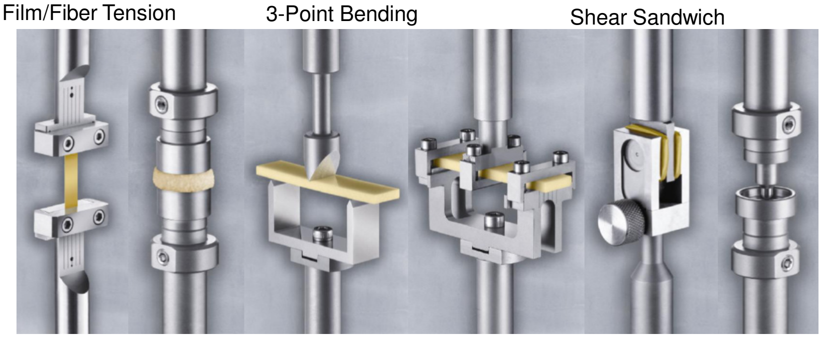
Clamps for RSA G2

Film/Fiber Tension 3-Point Bending Shear Sandwich



Compression S/D Cantilever Contact Lens

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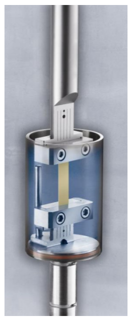
RSA G2 Immersion Clamps

- 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.

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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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RSA-G2 DETA

- 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

Keysight LCR Meter
Model 4980A

(LCR Meter)	Frequency	AC Test Signal (potential)
Keysight E4980A	20 Hz to 2 MHz	0.005 to 20 Volts
Keysight E4980AL/120	20 Hz to 1 MHz	0.001 to 2 Volts

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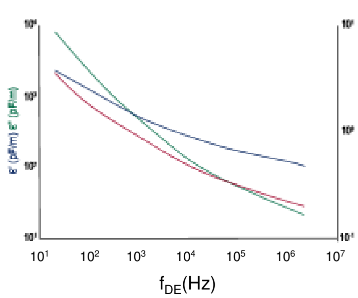
DETA Testing

Frequency Sweep

Figure 15 shows an example of a dielectric frequency sweep run on a rubber sample under ambient conditions. Shown are the storage and loss permittivity and loss tangent over a frequency range of 20 Hz to 2 MHz.

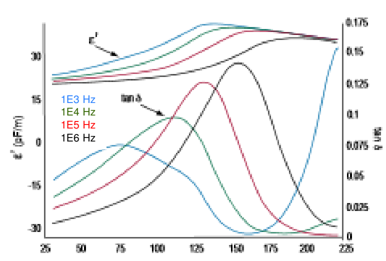
Figure 15: Dielectric Frequency Sweep on Rubber



Temperature Ramp

Figure 16 shows an example of a ramp on a PMMA Sample at four different Dielectric Frequencies ranging from 1kHz to 1MHz. It can be seen here that the magnitude of ε' decreases with increasing frequency through the transition region and the peak of the transition in tan δ moves to higher temperatures with increasing frequency.

Figure 16: DETA Temperature Ramp on PMMA



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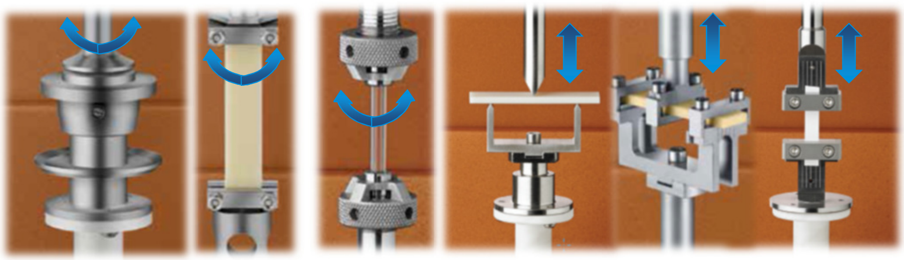
Testing Solids on a Rheometer

- Torsion (rotational) and DMA (axial) geometries allow solid samples to be characterized in a temperature controlled environment.

$$E = 2G(1 + \nu)$$

ν : Poisson's ratio

Shear Modulus: G', G'', G^* Young's Modulus: E', E'', E^*



Parallel plate | Rectangular and cylindrical torsion | 3-point bending | Cantilever | Tension

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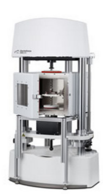
ESG DMA Instruments



ElectroForce DMA 3200 High Force DMA

ElectroForce 3100

ElectroForce 3200

ElectroForce 3300

ElectroForce 3500

The ESG division of TA Instruments also provides DMA measurements.
Many of these can impose very high forces.
See the spec sheet on the following page for the force capabilities.

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ESG Specs – much higher force capacity than DMA 850 and RSA-G2

	3100	3200	3300	3510
Linear Motor				
Standard				
Peak/Max Sine	± 22 N	± 225 N	± 1000 N	± 7500 N
Static or RMS (continuous)	± 22 N	± 160 N	± 700 N	± 5300 N
High Force Option				
Peak/Max Sine	—	± 450 N	± 3000 N	—
Static or RMS (continuous)	—	± 320 N	± 2100 N	—
Displacement	5 mm	13 mm	25 mm	50 mm
Extended Stroke Option	—	150 mm	150 mm	—
Linear Velocity	0.0025 µm/s – 1.0 m/s	0.0065 µm/s – 3.2 m/s	0.013 µm/s – 1.5 m/s [1] 0.013 µm/s – 2.0 m/s [2]	0.025 µm/s – 1.5 m/s
Frequency	0.00001 Hz – 100 Hz	0.00001 Hz – 300 Hz	0.00001 Hz – 100 Hz	0.00001 Hz – 100 Hz
Torsional Motor Option				
Standard				
Peak/Max	—	± 5.6 N·m	± 14 N·m[3] / ± 24 N·m[4]	± 49 N·m
Static or RMS (continuous)	—	± 5.6 N·m	± 14 N·m[3] / ± 24 N·m[4]	± 42 N·m
High Torque Option				
Peak/Max	—	—	± 49 N·m[5]	± 70 N·m
Static or RMS (continuous)	—	—	± 42 N·m[5]	± 50 N·m
Rotation	—	Multi-turn (± 20 revolutions Standard)	Multi-turn (± 20 revolutions Standard)	Multi-turn (± 20 revolutions Standard)
Thermal Chamber Option	—	-150 to 315°C	-150 to 350°C	-150 to 350°C
Fluid/Saline Bath Option	Ambient to 40°C	Ambient to 40°C	Ambient to 40°C	Ambient to 40°C

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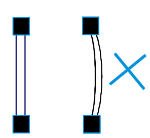
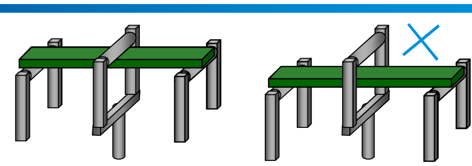
Some Clamps Require an Offset (Static) Force



Good Bad



Good Bad

Tension 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	Tension Film
Dual Cantilever	Tension: Fiber
Shear Sandwich	3-Point Bend
	Compression
	Penetration

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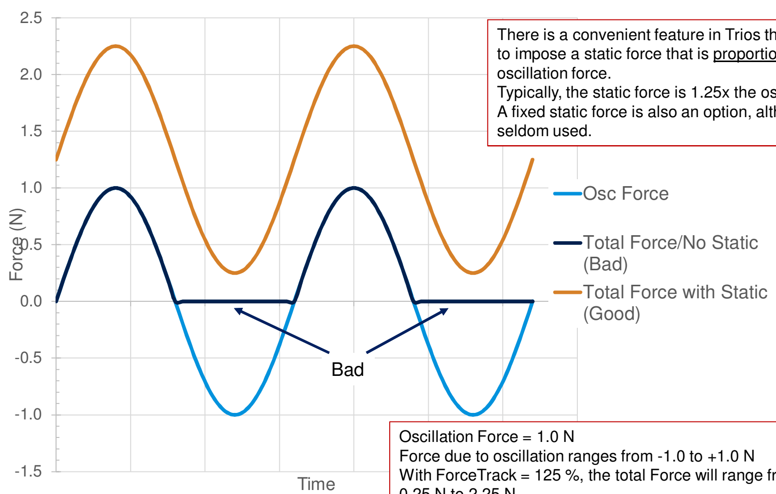
Waveforms with and without Static Force



There is a convenient feature in Trios that allows one to impose a static force that is proportional to the oscillation 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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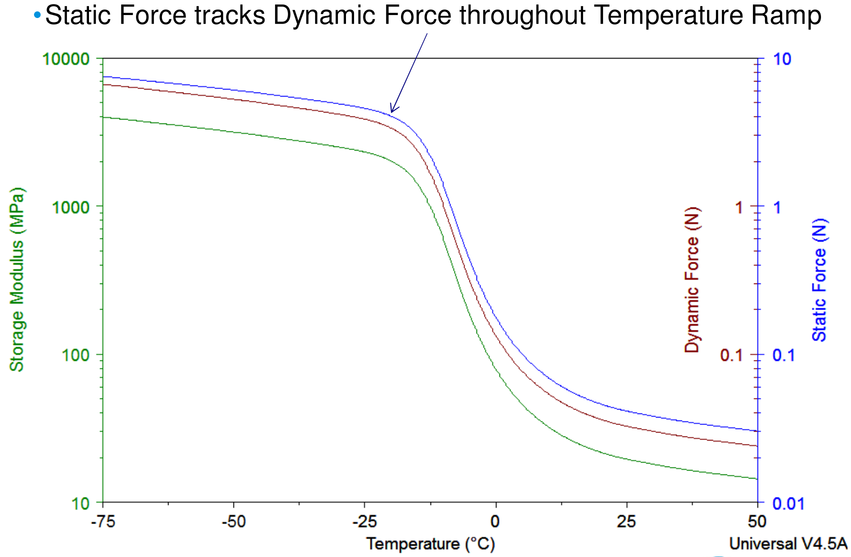
Temperature Ramp with Force Track

- Static Force tracks Dynamic Force throughout Temperature Ramp



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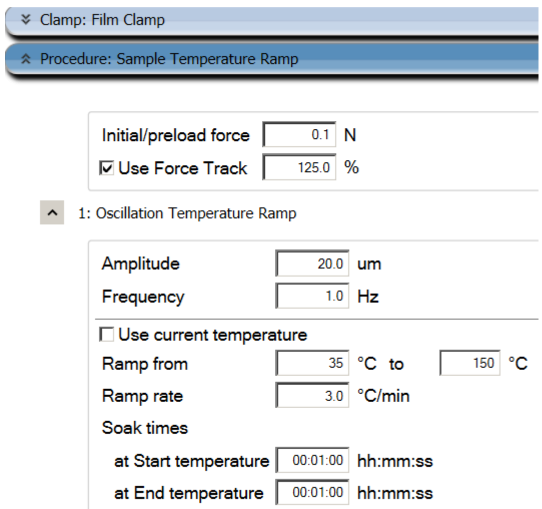
Force Track in Trios with the DMA 850



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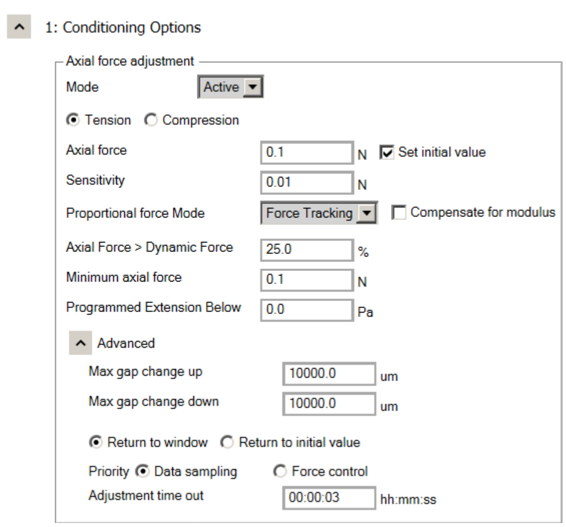
Force Track in Trios with the RSA-G2



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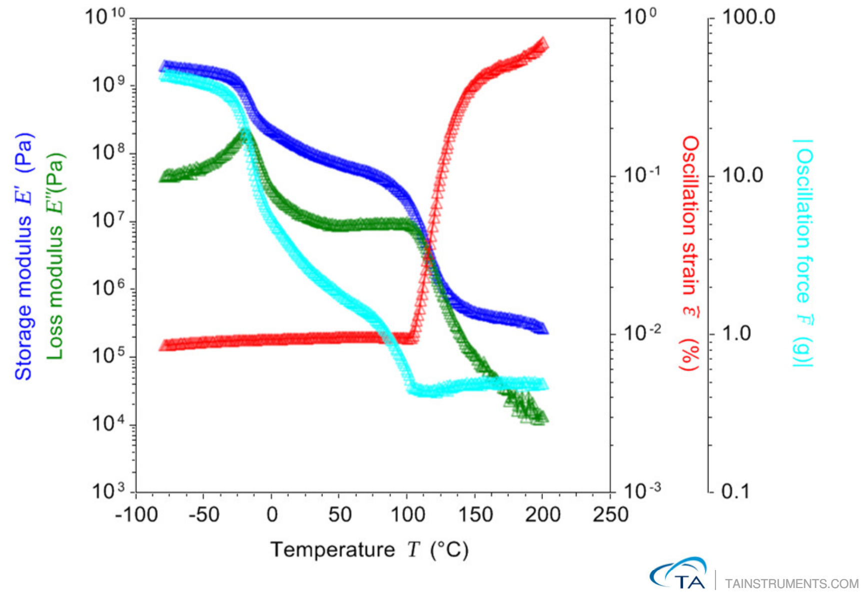
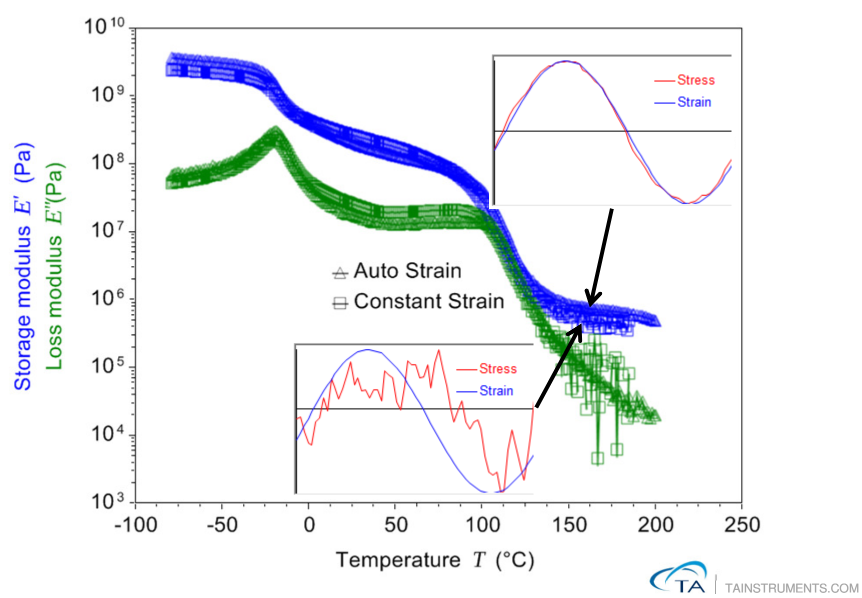
Auto Strain- Temperature Ramp

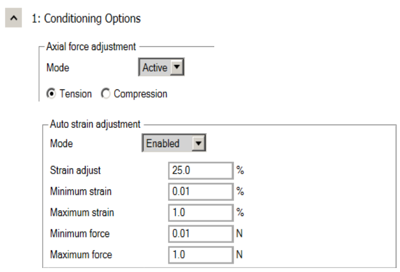


Temperature Ramp with and without Auto Strain

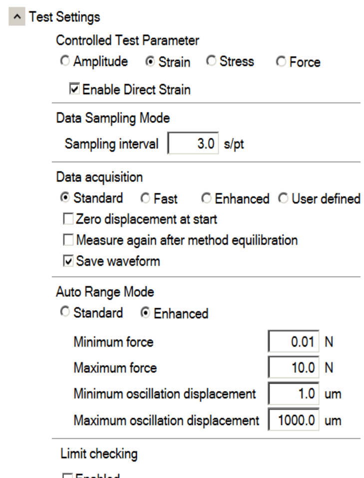


Strain Adjustment during the Temperature Ramp

RSA-G2: Auto-Strain



DMA 850: Auto-Ranging



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Trios Software

- Non-restricted, available for free on our website
- Versatile
- User Friendly

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Test Modes for the DMA 850 in Trios

- Conditioning
- Oscillation
- Strain Control
- Stress Control
- Rate Control

- Temperature
- Data
- Other
- Repeat
- Stress
- Strain

- Conditioning
- Oscillation
- Strain Control
- Stress Control
- Rate Control

- Creep
- Creep Recovery
- Creep TTS
- IsoStress

- Conditioning
- Oscillation
- Strain Control
- Stress Control
- Rate Control

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

- Conditioning
- Oscillation
- Strain Control
- Stress Control
- Rate Control

- Strain Ramp
- Stress Ramp

- Conditioning
- Oscillation
- Strain Control
- Stress Control
- Rate Control

- Stress Relaxation
- Stress Relaxation TTS
- IsoStrain

We discussed the features of Trios in the Rheology presentation.
Most of those features are also available with the DMA's.
You can devise any kind of test that you want, including mixing test modes.

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Test Modes for the RSA-G2 in Trios

- Oscillation
- Step (Transient)
- Other
- Conditioning
- Script

- Frequency
- Temperature Ramp
- Temperature Sweep
- Amplitude
- Time
- Multiwave
- Fast Sampling
- Cycle Sweep

- Oscillation
- Step (Transient)
- Other
- Conditioning
- Script

- Transducer
- Sample
- Stress Control
- Dielectric
- UV Curing
- ElectroRheology
- Sample Loading
- End Of Test
- Advanced Options
- Options

- Oscillation
- Step (Transient)
- Other
- Conditioning
- Script

- Creep
- Stress Relaxation
- Sine Strain

- Oscillation
- Step (Transient)
- Other
- Conditioning
- Script

- Source

- Oscillation
- Step (Transient)
- Other
- Conditioning
- Script

- Axial
- Arbitrary Wave
- Temperature Ramp IsoForce
- Temperature Ramp IsoStrain

There are some minor differences between the choices for the RSA-G2 and the DMA 850.

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Common Dynamic (Oscillatory) Testing

- Available oscillatory test modes
  - Strain (stress) Sweep
  - Time Sweep
  - Frequency Sweep
  - Temperature ramp
  - Temperature Step (Sweep) (TTS)

Typical Sequence:
Strain Sweep → Temperature Ramp

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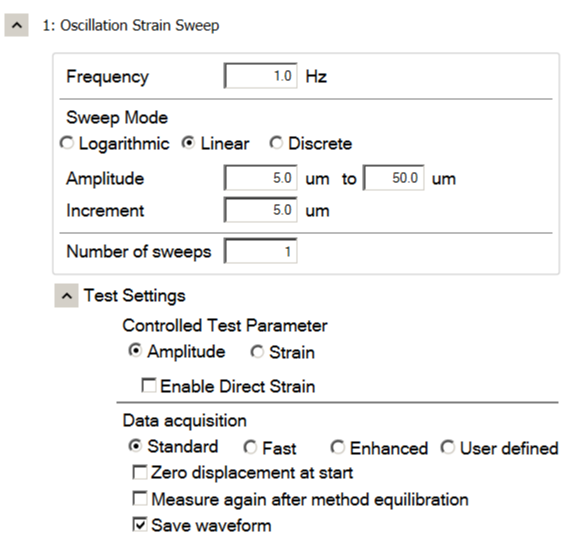
Trios Oscillation Strain Sweep for the DMA 850



There are some differences for the RSA-G2, but the DMA principles are the same as those for the DMA 850.

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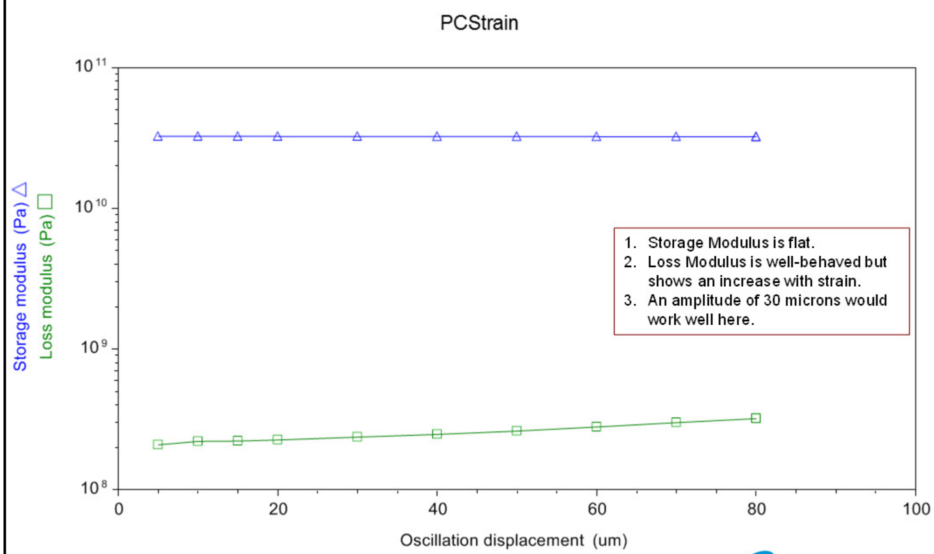
Dynamic Strain Sweep – Trios Plot



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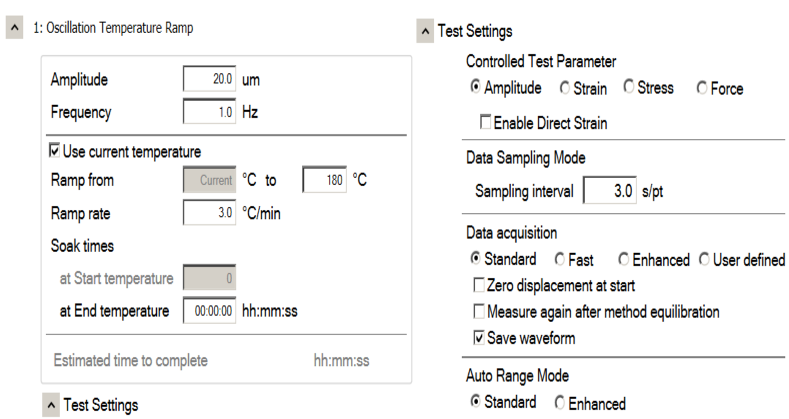
Trios Oscillation Temperature Ramp for the DMA 850



Again, the method for the RSA-G2 would be essentially the same.

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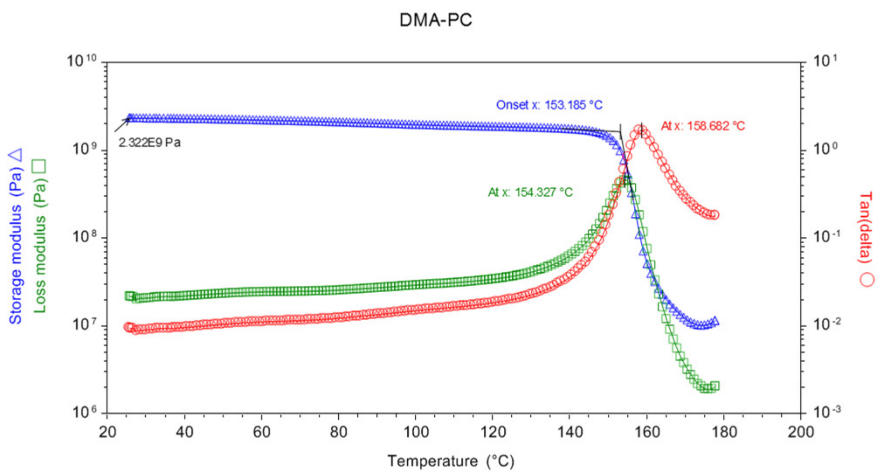
Polycarbonate Testing on the DMA 850



This is the same graph that we saw at the beginning of the dynamic oscillation section.
This is a very common test.

More Examples

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 & 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 (eg. plasticizer.)

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

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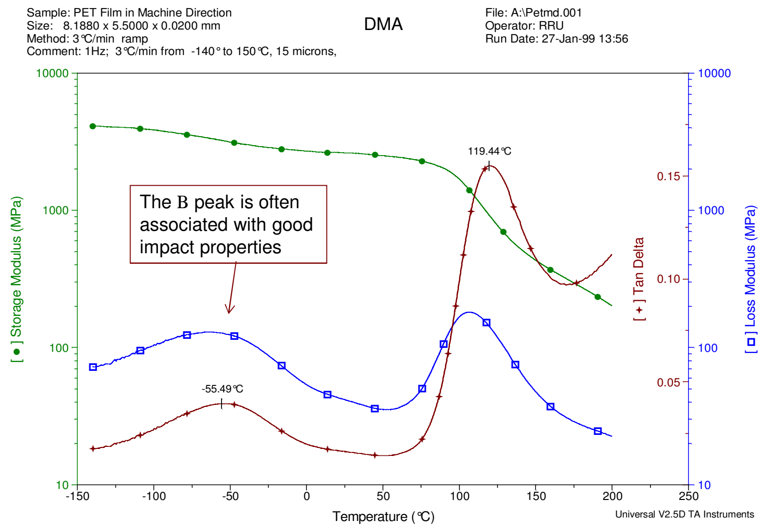
Primary and Secondary Transition in PET Film



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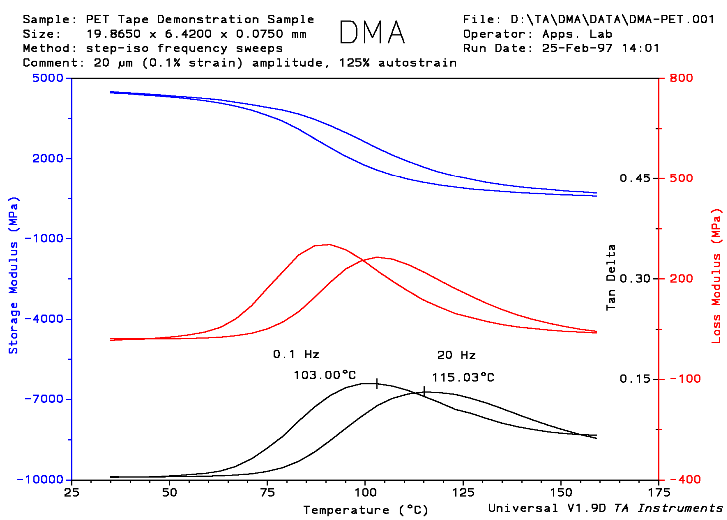
PET Film: Effect of Frequency



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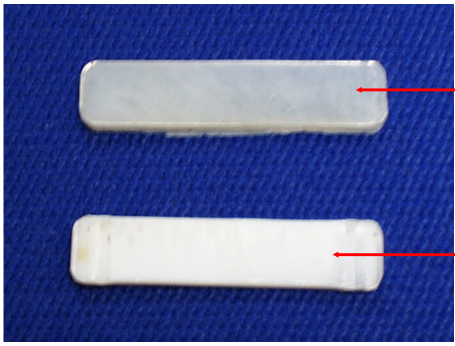
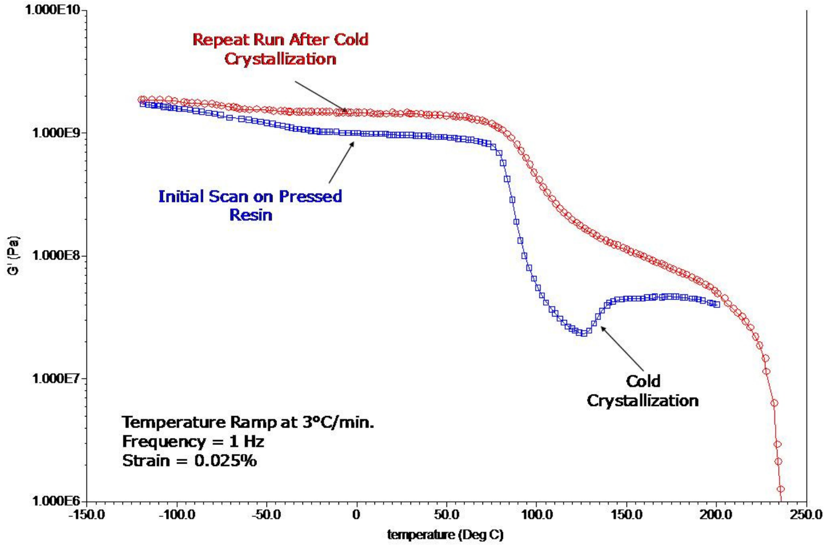
PET Bottle Resin - Polyethylene terepthalate



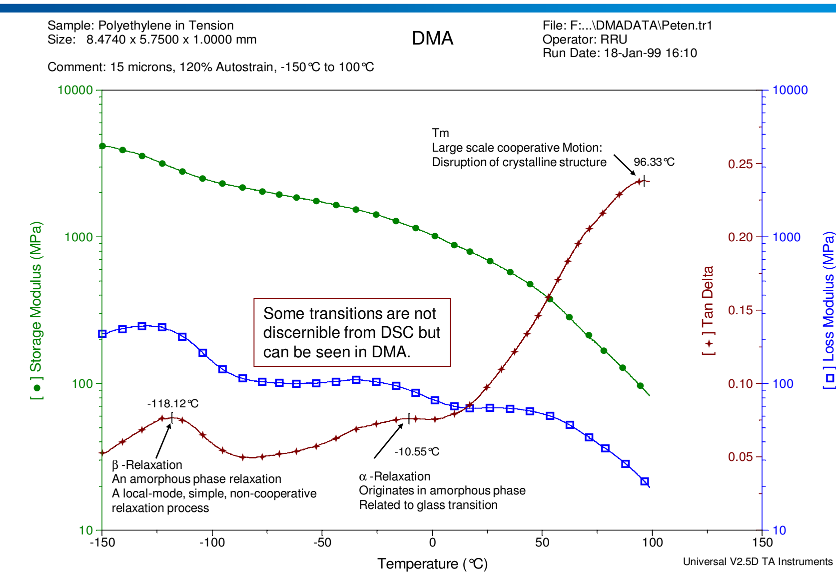
Pressed PET Bottle Resin

PET After Temperature Ramp Scan (Cold Crystallization)

PET Bottle Resin – Before & After Cold Crystallization



LDPE: Primary and Secondary Transitions



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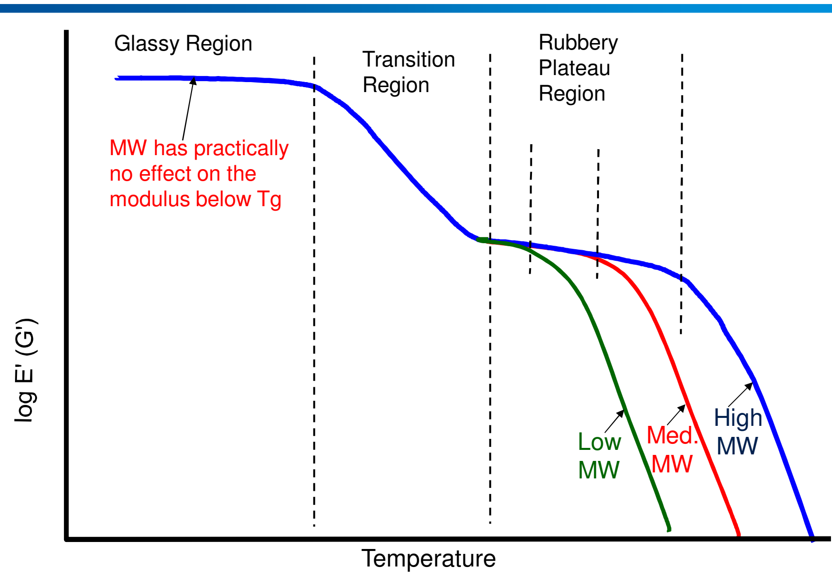
Molecular Structure - Effect of Molecular Weight



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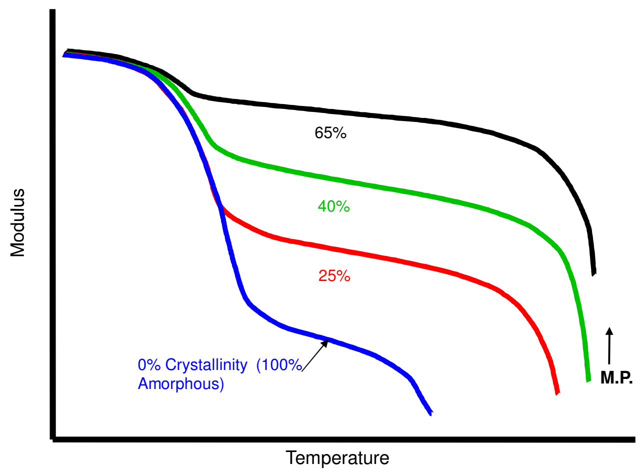
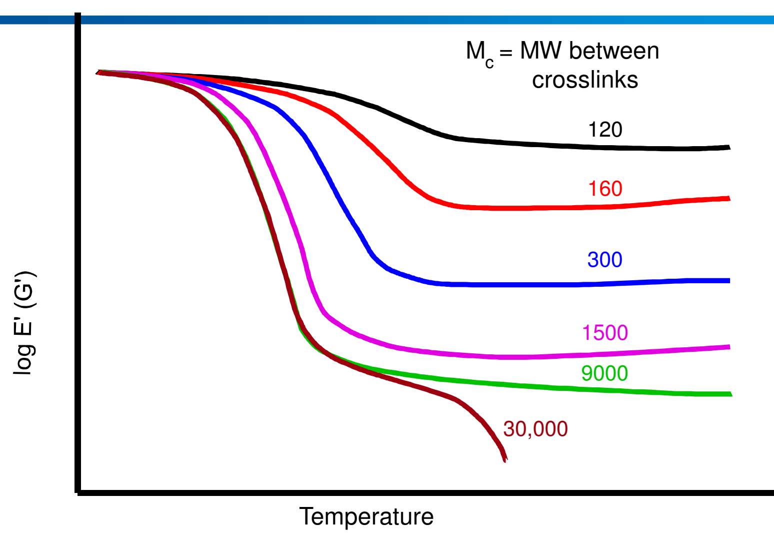
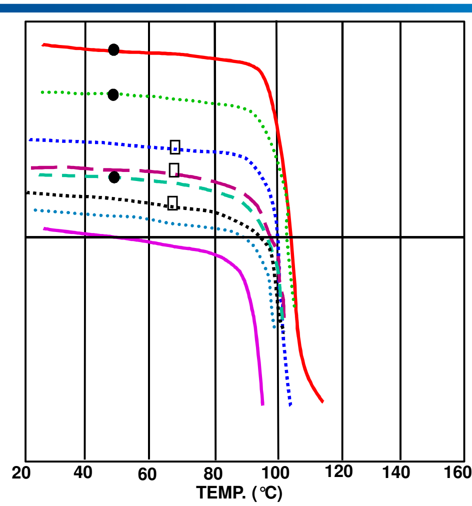
Effect of Crystallinity



Effect of Crosslinking



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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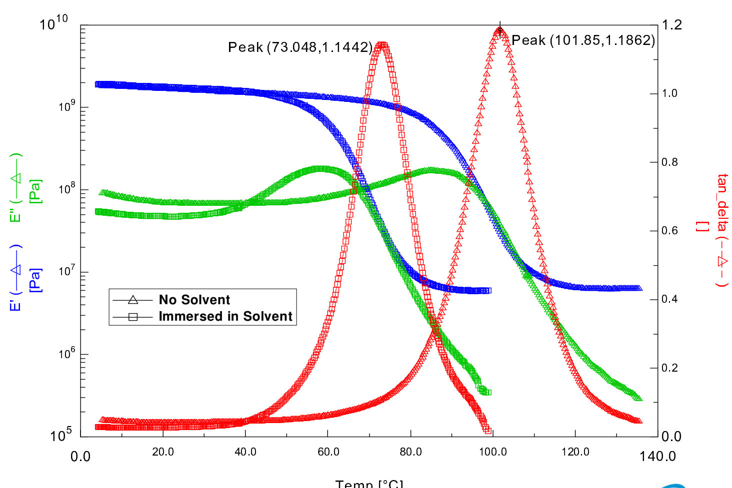
Effect of Moisture

- Automotive coating measured under dry vs. wet conditions



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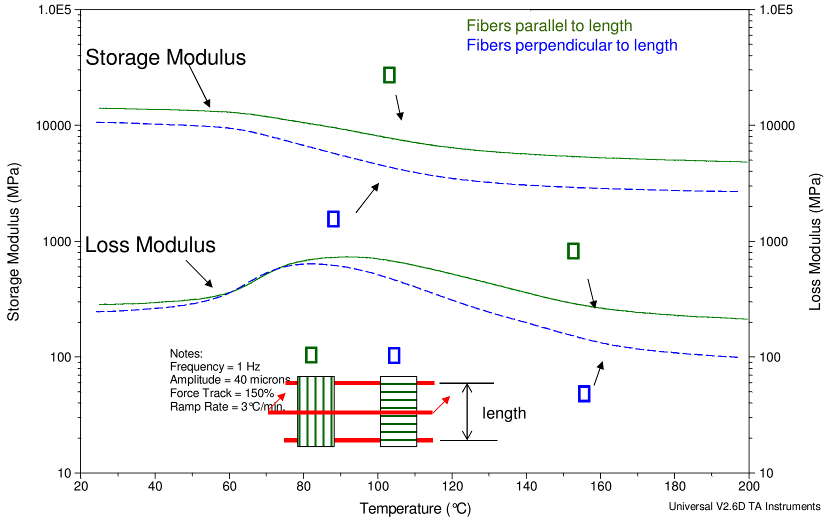
Anisotropic Material Thermoset Polyester/ Glass Fiber Composite



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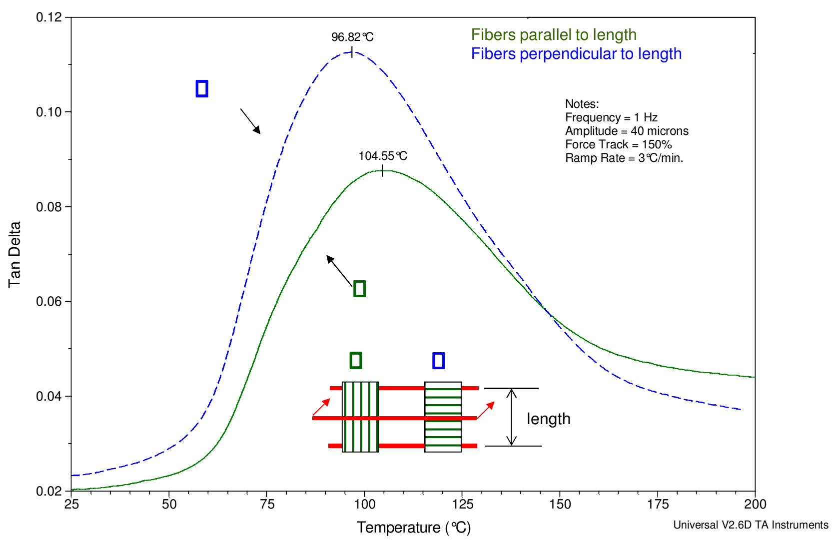
Anisotropic Material Thermoset Polyester/ Glass Fiber Composite



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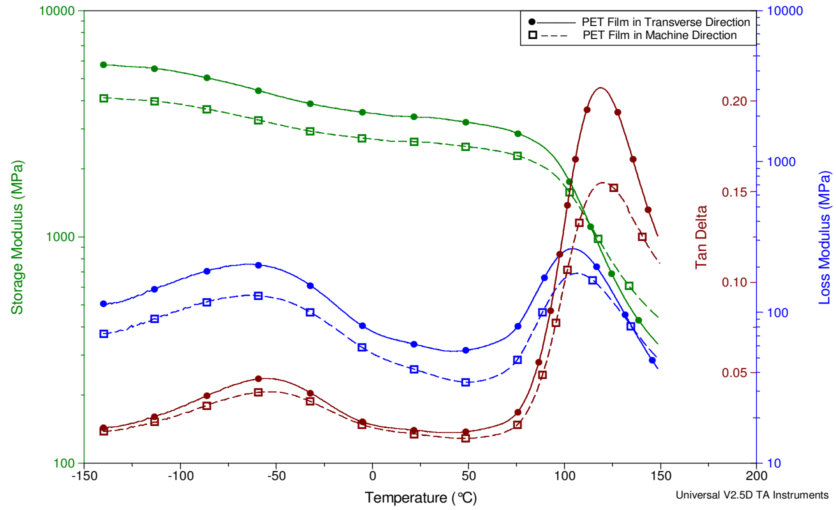
PET Film in Machine and Transverse Direction



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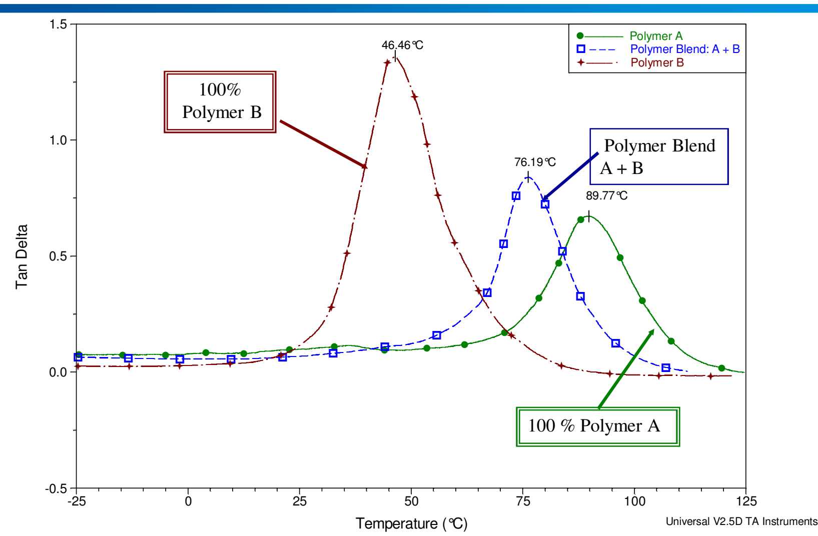
Polymer Blend - Aerospace Coating



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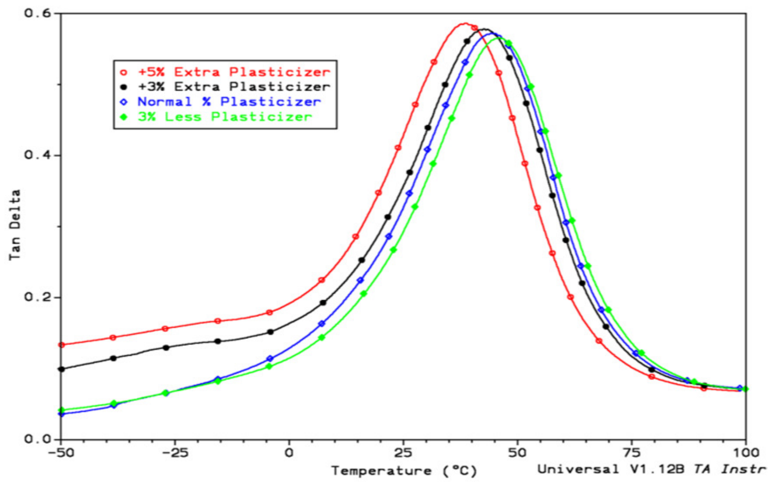
Effect of Plasticizer on Vinyl Flooring



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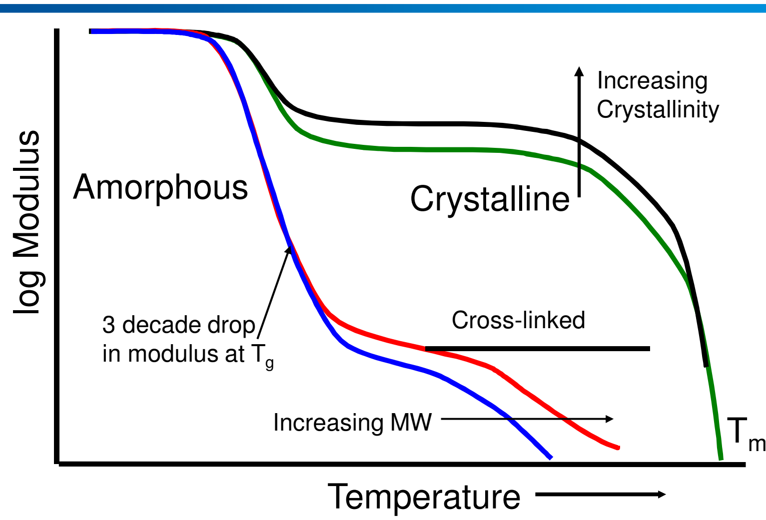
Summary of Effects of Crystallinity, Molecular Weight, and Crosslinking



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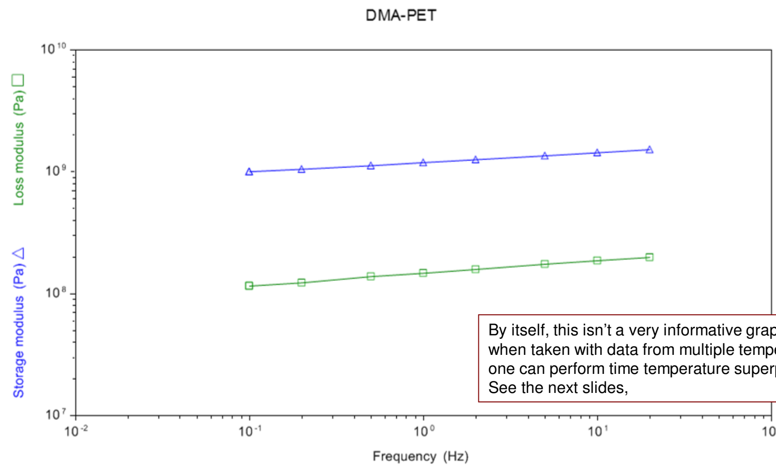
Dynamic Frequency Sweep



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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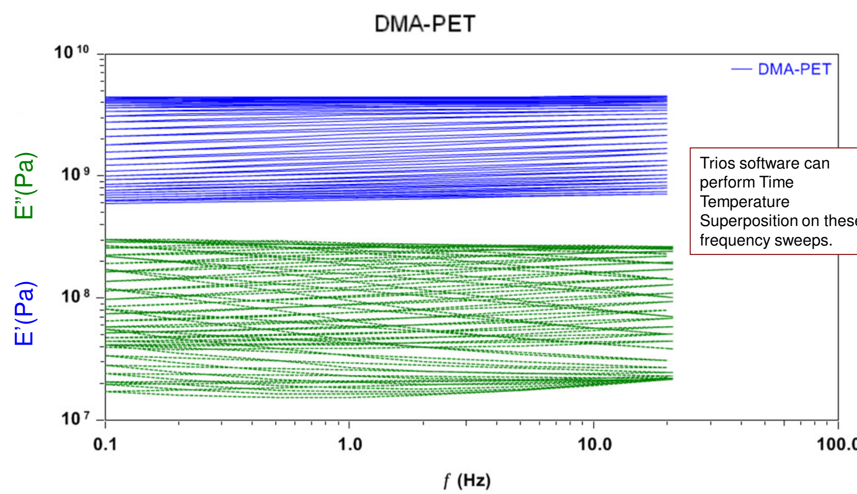
Temperature/Frequency Sweep



Trios software can perform Time Temperature Superposition on these frequency sweeps.

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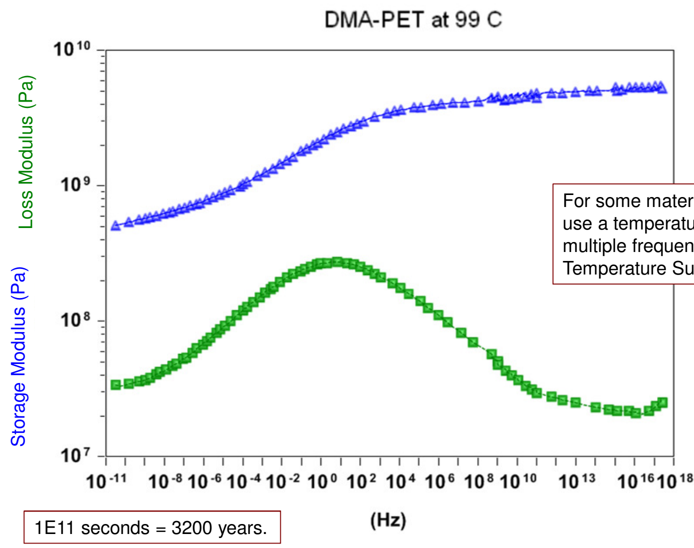
Frequency/Temperature Sweep – Time Temperature Superposition



For some materials, one can use a temperature step test at multiple frequencies to do Time Temperature Superposition.

1E11 seconds = 3200 years.

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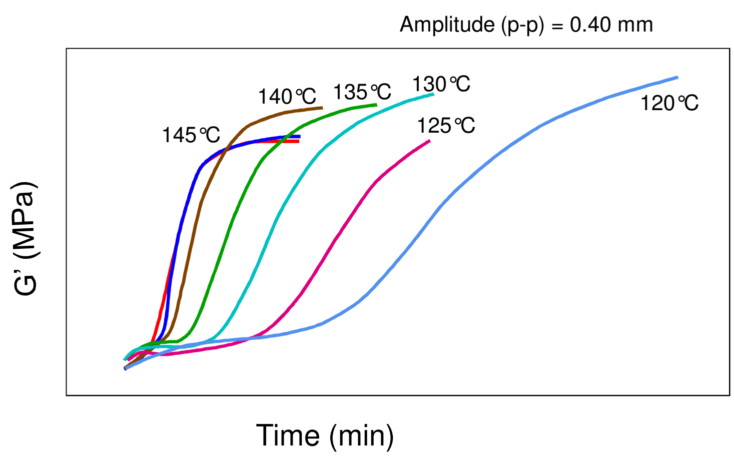
Isothermal Cure of Tire Compound: Effect of Curing Temperature



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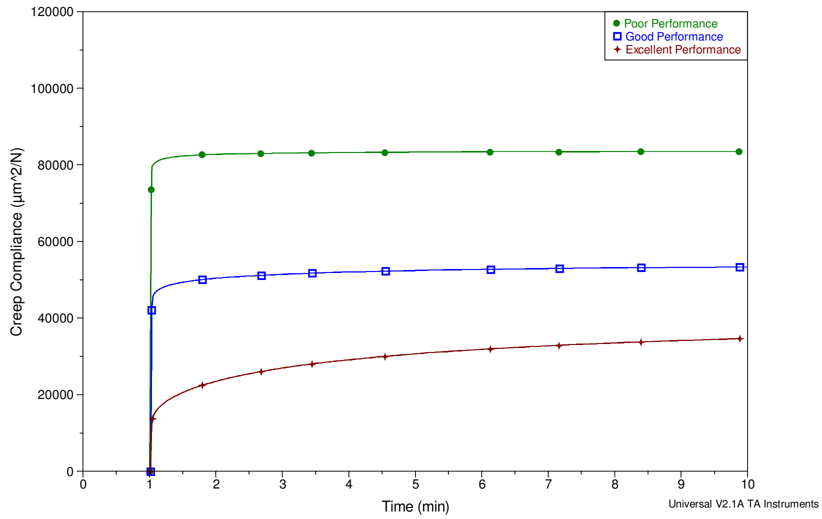
Creep on Packaging Films used in Thermoforming



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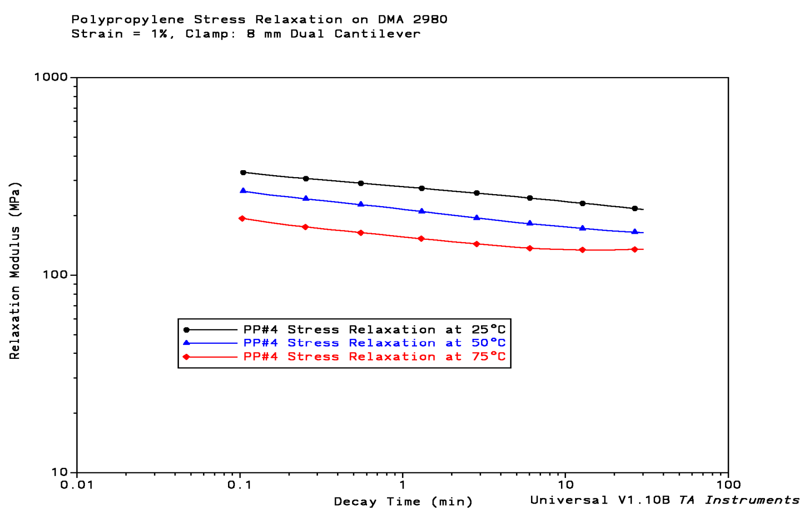
DMA: Stress Relaxation on Polypropylene



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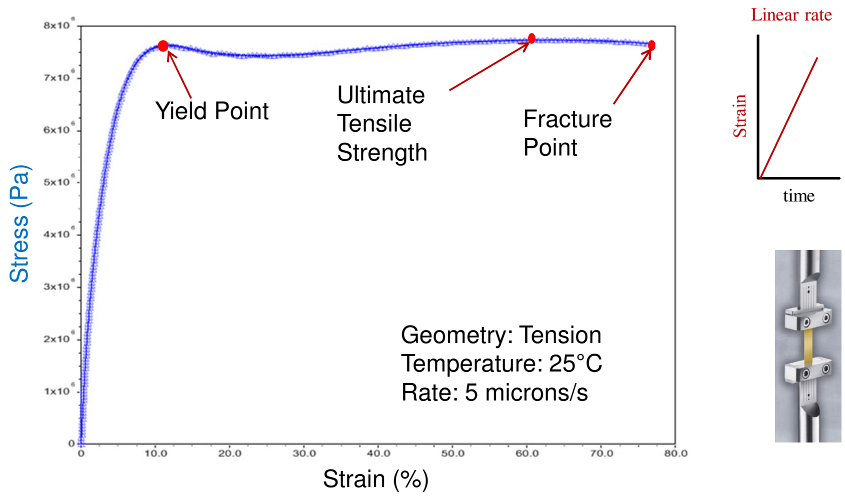
Polyethylene Bag Linear Strain Ramp



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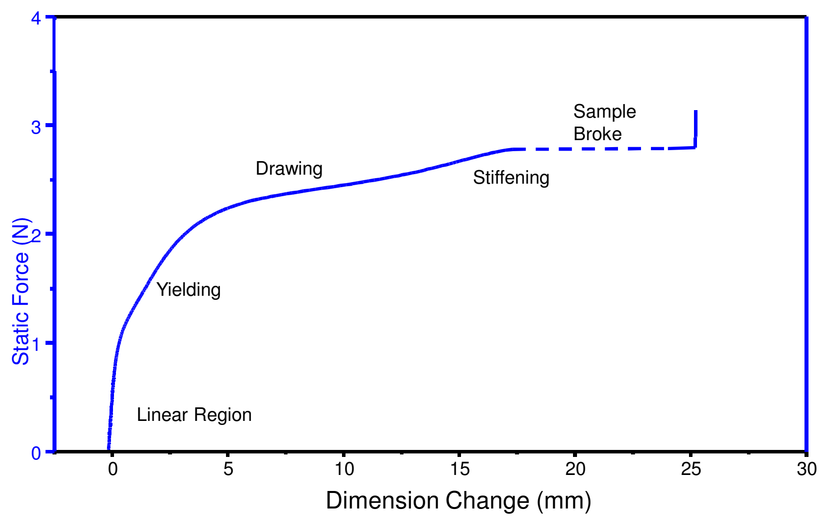
Stress-Strain Experiment (Ramped Force) Polyethylene Film 4 mm



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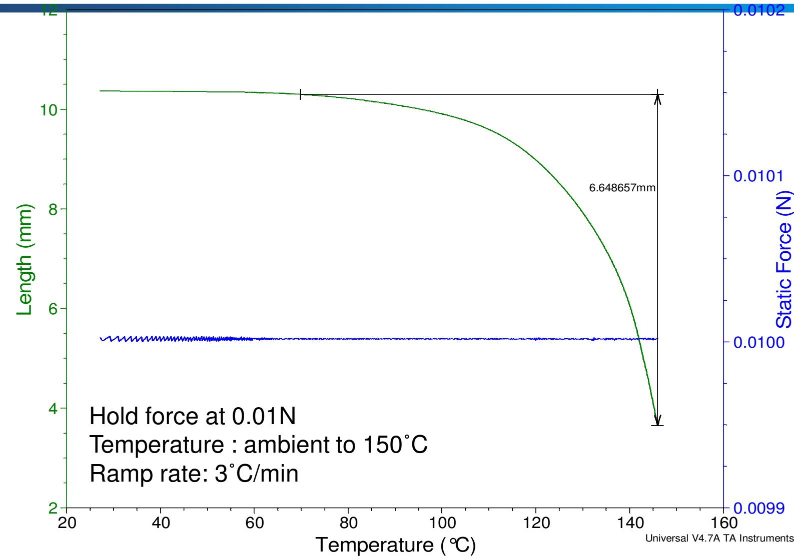
Iso-force Temperature Ramp: measure sample shrinkage



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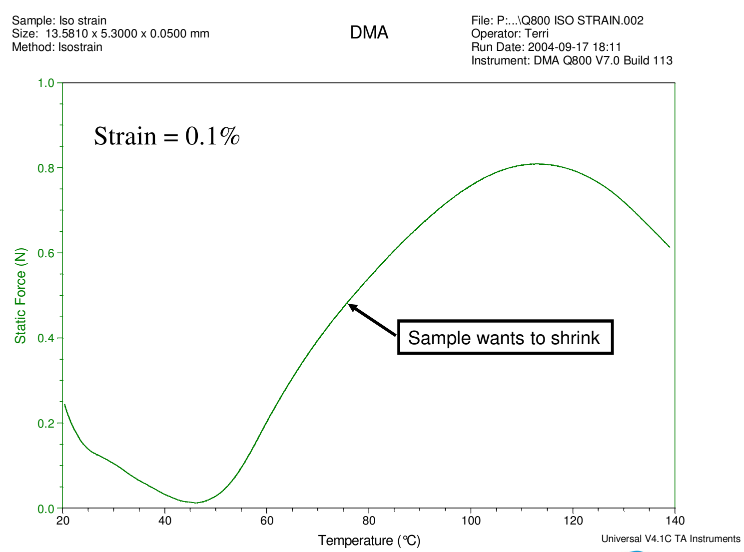
PVC Based Film - IsoStrain



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DMA-Humidity

- Dynamic Mechanical Analysis performed under controlled conditions of both temperature and relative humidity
- Potential Applications
  - Fuel Cell Components
  - Packaging Films
  - Pharmaceutical Components
  - Food Materials
  - Electronics

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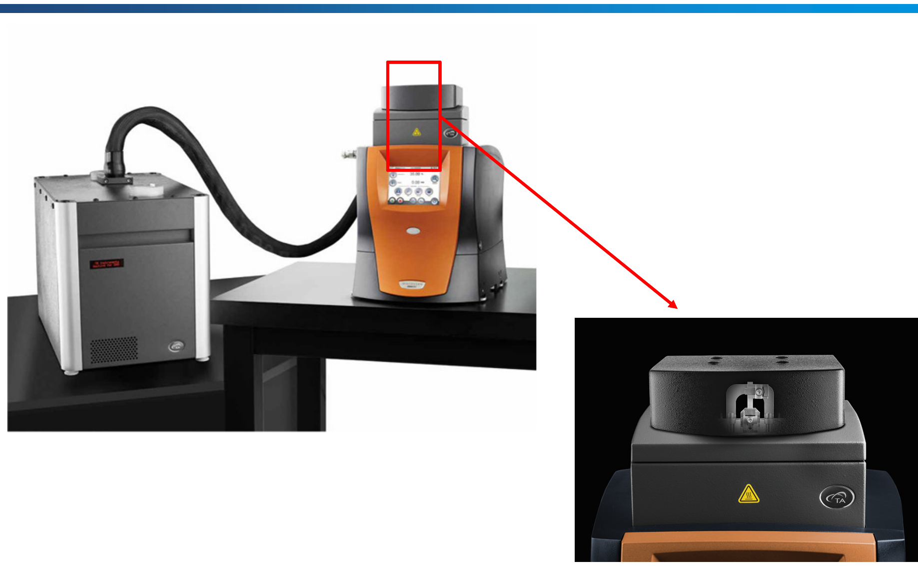
DMA850 and Q800: Humidity Option



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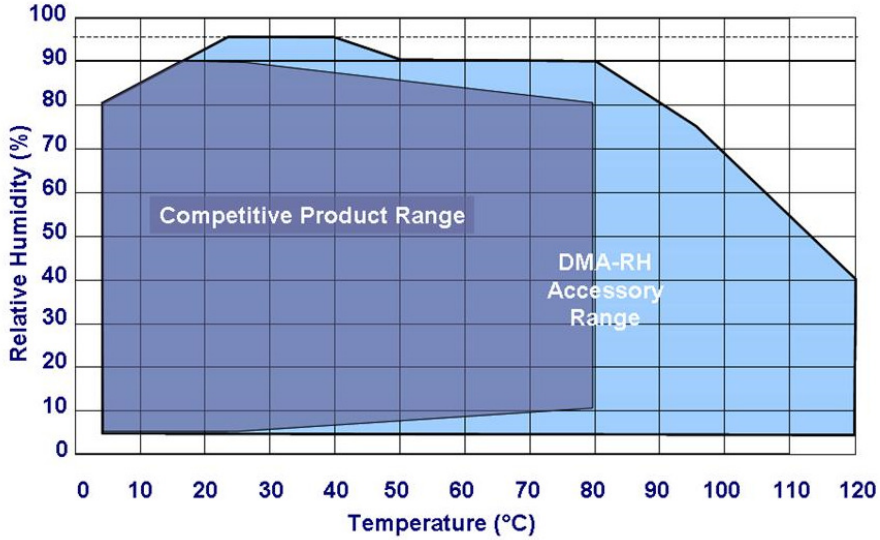
Q800: DMA-RH Operating Range



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DMA-RH Performance Specifications

Temperature Range	5°C–120°C
Temperature Accuracy	±0.5°C
Heating/Cooling Rate	Maximum ±1°C/min over entire temperature range
Humidity Range	See humidity range chart
Humidity Accuracy	5-90%RH: ±3% RH >90%RH: ±5% RH
Humidity Ramp Rate	±2% RH/min (fixed*) both increasing and decreasing

*Alternative pseudo-linear RH ramp rates can be achieved through Step-Iso control

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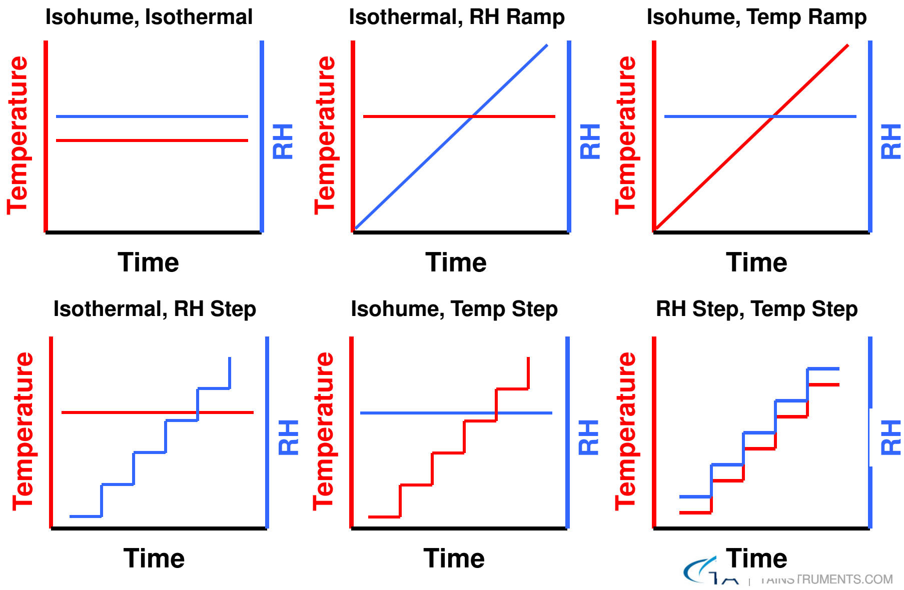
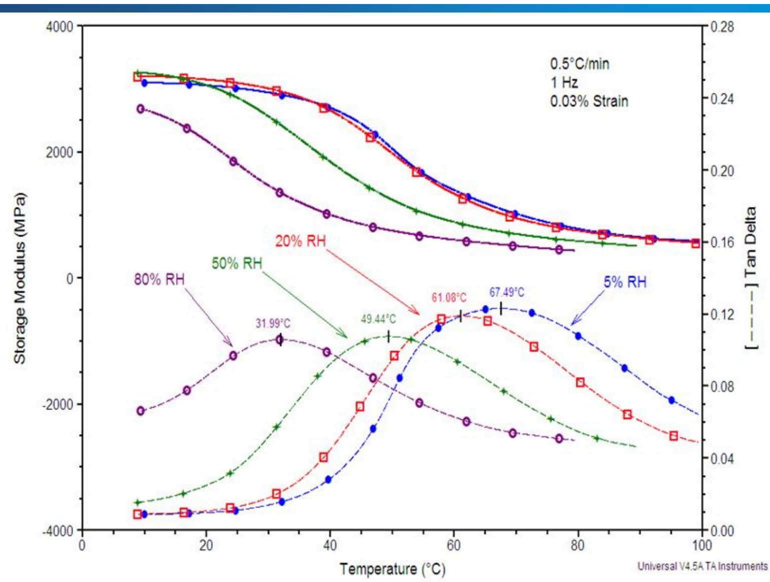
DMA-RH Experimental Options



Analysis of Nylon 6: Isohume-Temperature Scans



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Need Some Assistance?

- Instrument Manuals
- Help Feature in Trios
- TA Instruments website
- TA Instruments Rheology Helpline
  - rsupport@tainstruments.com

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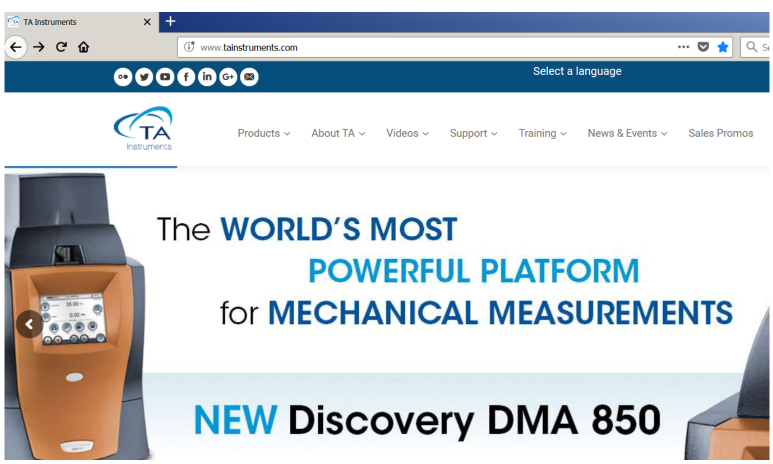
Website: www.tainstruments.com



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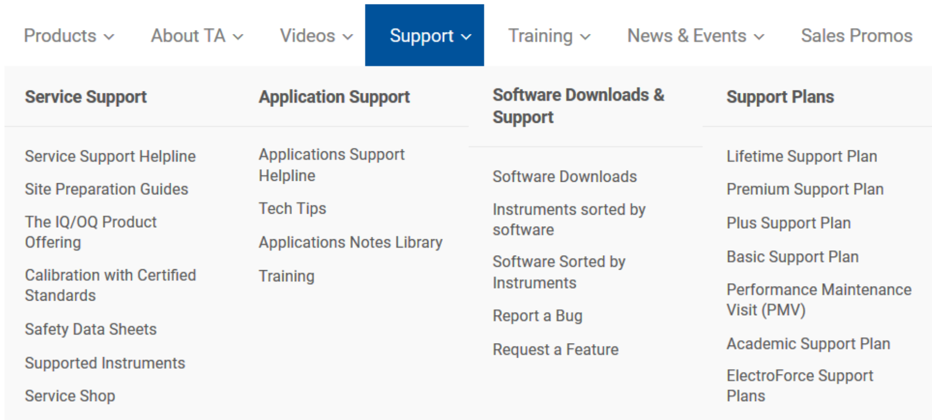
Website: www.tainstruments.com



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Don't forget http://www.tainstruments.com/

If you have questions or need help
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http://www.tainstruments.com/support/applications/applications-hotline/

We made it!

Remember – Rheology is FUN.

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