Rheology: Basic Theory and Applications Training

Section #2

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Agenda

Section 1 (2 hours)

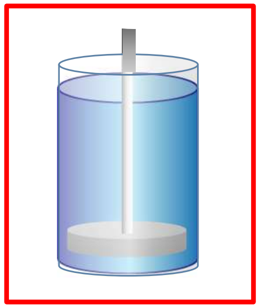
- Basics in rheology and instrumentation
  - Rheology theory
  - How rheometers work and geometry selections
- Introduction to all rheological methods
  - Flow experiments
  - Oscillatory experiments
  - Transient experiments

Section 2 (2 hours)

- Rheology Applications- how to select correct geometries and test methods
  - Structured fluids
    - Low viscosity liquids
    - Creams/slurries/pastes
    - Gels and soft solids
  - Polymers
    - Polymer melts
    - Reactive polymers
    - Solid polymers

What Rheology Measures

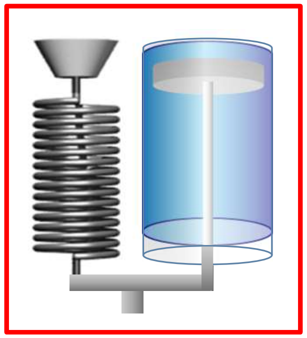
- **Viscosity (Liquids)**



- **Elasticity (Solids)**



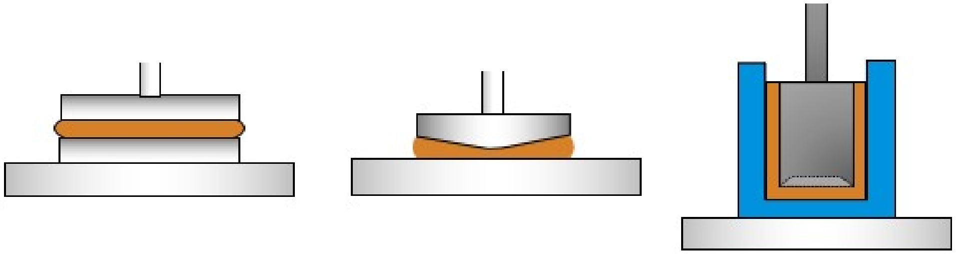
- **Viscoelasticity (Liquids to Solids)**



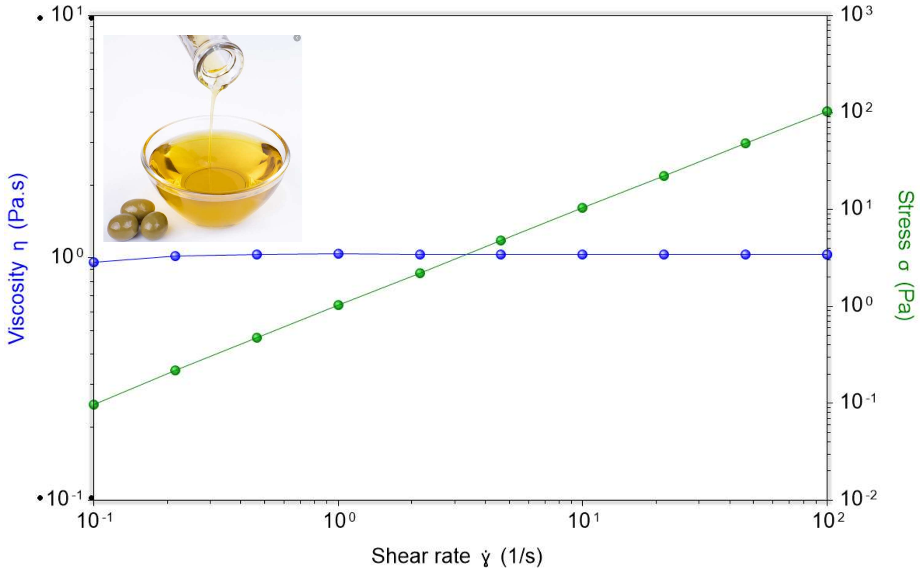

Rheology Applications
1. Structured Fluids and Soft Solids

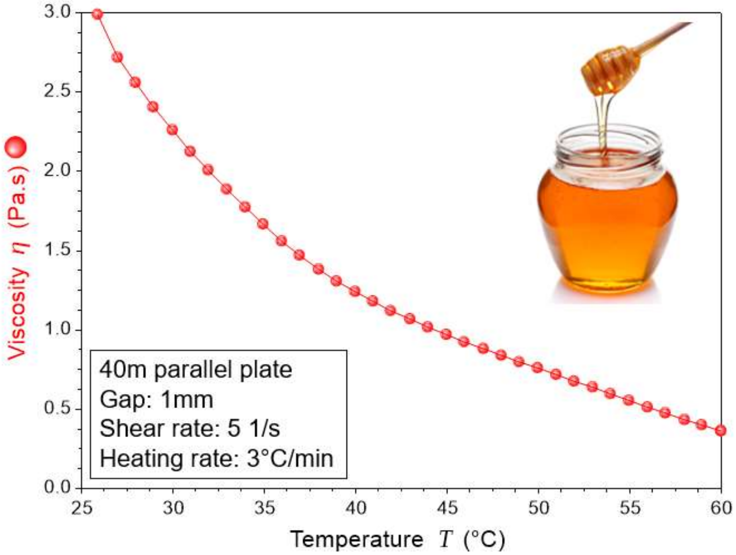
Low Viscosity Liquids – 1. Newtonian

- What geometry to use?
  - Large diameter cone-plate or parallel plate(e.g. 60mm, 40mm, concentric cylinder cup/rotor).



- What methods?
  - Isothermal viscosity
  - Viscosity versus temperature



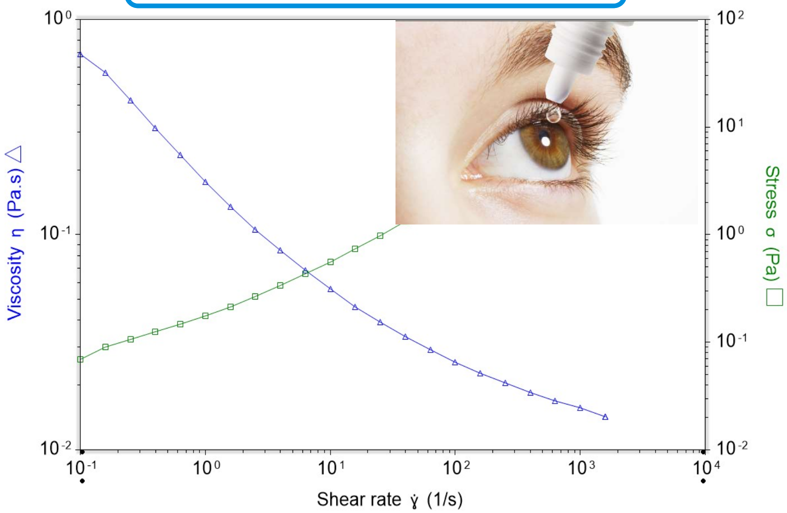


Low Viscosity Liquids – 2. Non-Newtonian

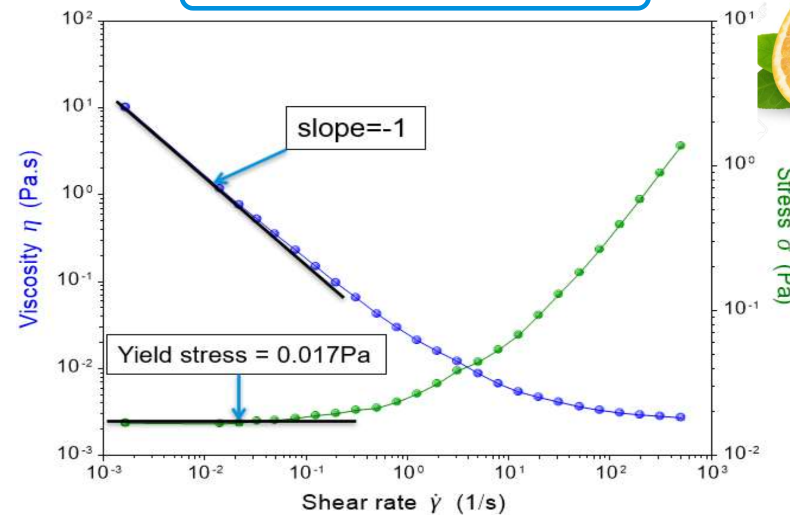
- What geometry to use?
  - Large diameter cone-plate or parallel plate(e.g. 60mm, 40mm, concentric cylinder cup/rotor.

- What methods?
  - Isothermal viscosity versus shear rate/stress
  - Yield stress – why orange juice has no phase separation?

Eye drop: Shear thinning

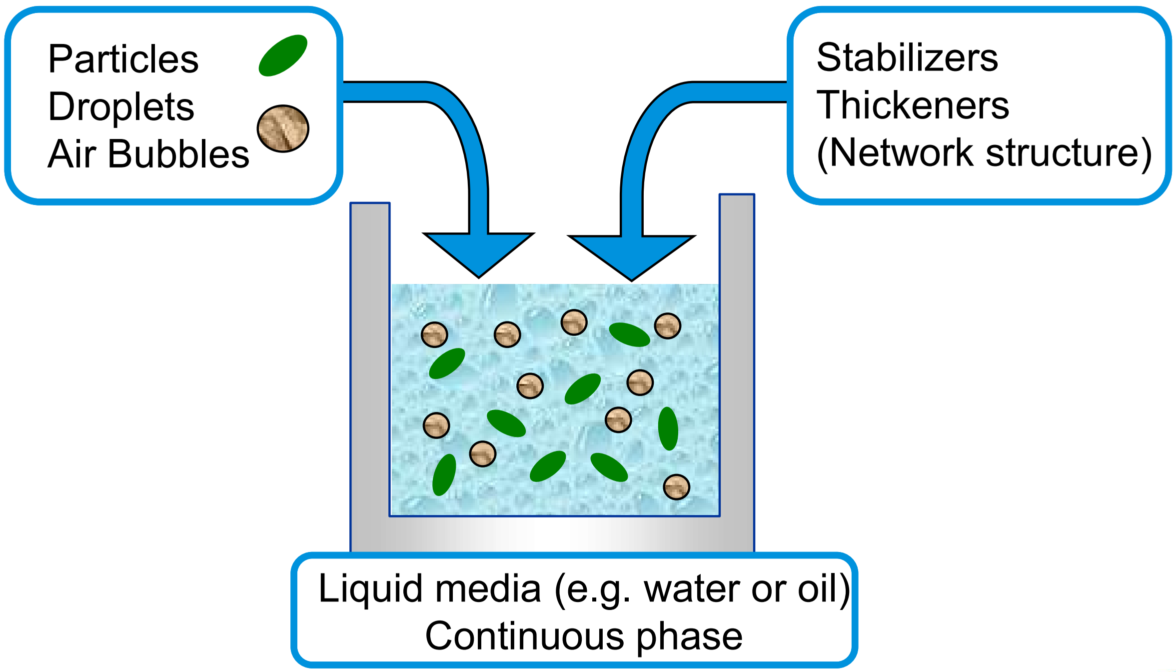


Orange Juice: Yield



Structured Fluids

- A multiphase complex system consists of a continuous phase (e.g. water or oil) and a dispersed phase (solid, fluid, gas)
- Stabilizers or thickeners are added to form a weak three-dimensional network structure



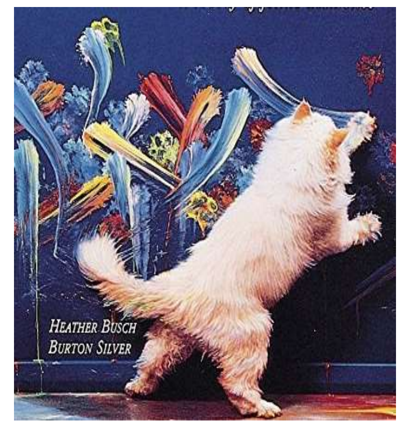
Types of Structured Fluids

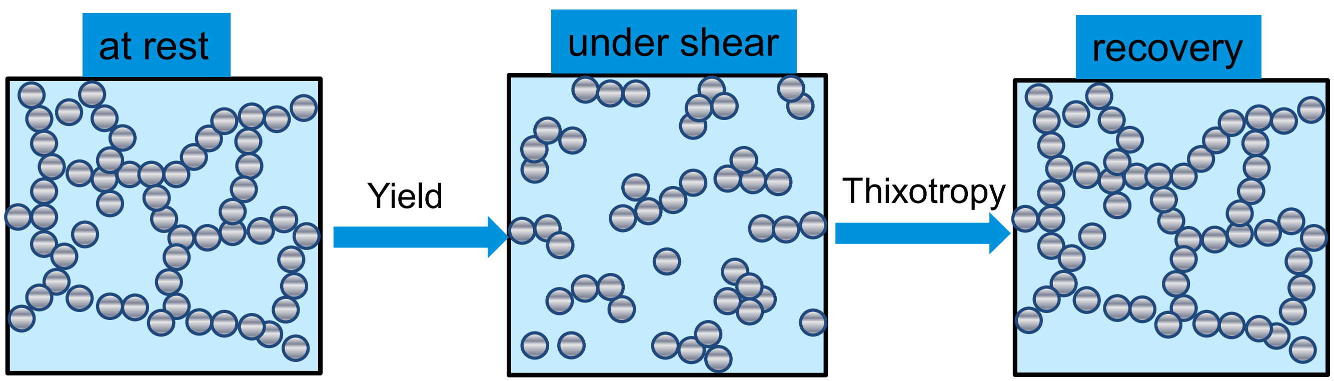
- Three categories
  - Suspension — Solid particles in a Newtonian fluid
  - Emulsion — Fluid in a fluid
  - Foam — Gas in a fluid (or solid)

- Examples are:
  - Paints
  - Coatings
  - Inks
  - Adhesives
  - Personal Care Products
  - Cosmetics
  - Foods

Properties of Structured Fluids

- Structured fluid properties
  - **Non-Newtonian**
  - **Yield stress**
  - **Thixotropic**
  - **Viscoelasticity**





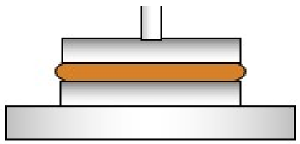
High viscosity
Elasticity

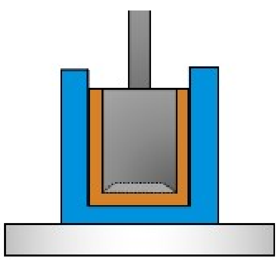
Structure destroyed
Shear thinning

Viscosity & elasticity
recover over time

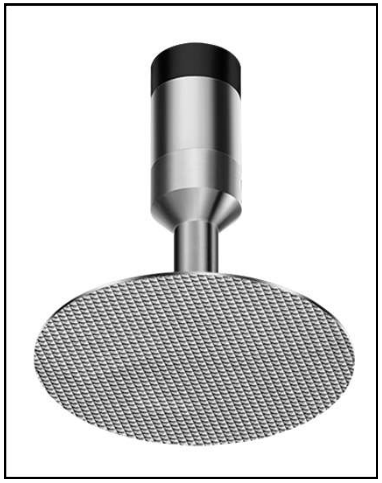
What Geometry to Use?

- Parallel plate (e.g. 40mm, 25mm, 20mm)
- Roughen surface parallel plate (e.g. crosshatched, sandblasted)
- Concentric cylinder cup with vane or helical rotor



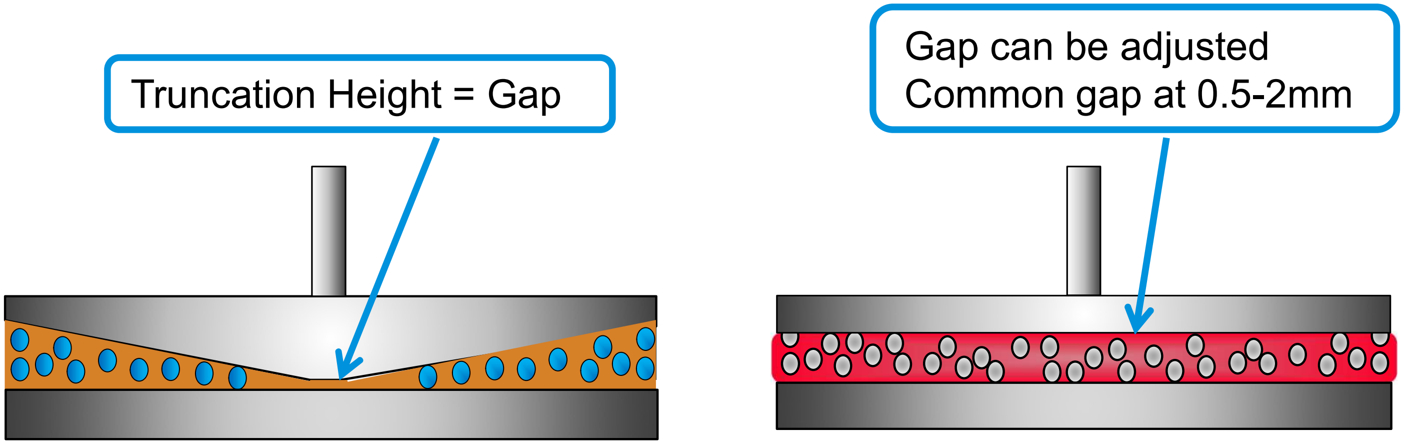


Avoid slippage

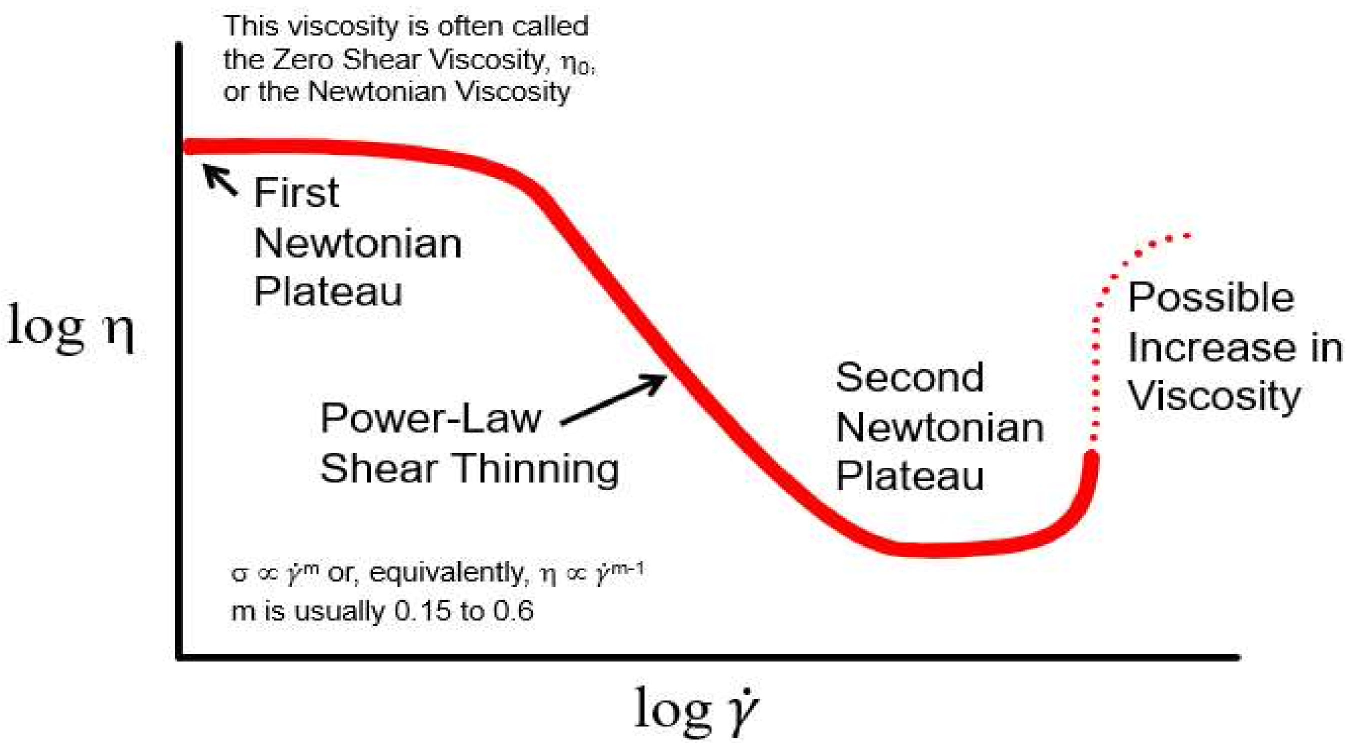


Be Careful When Using a Cone and Plate

- Most structured fluids contain particles with size in the micrometer range
- Depending on the cone angle, the truncation gap of a cone geometry will be between 10 and 120 μm
- Parallel plate geometry is recommended

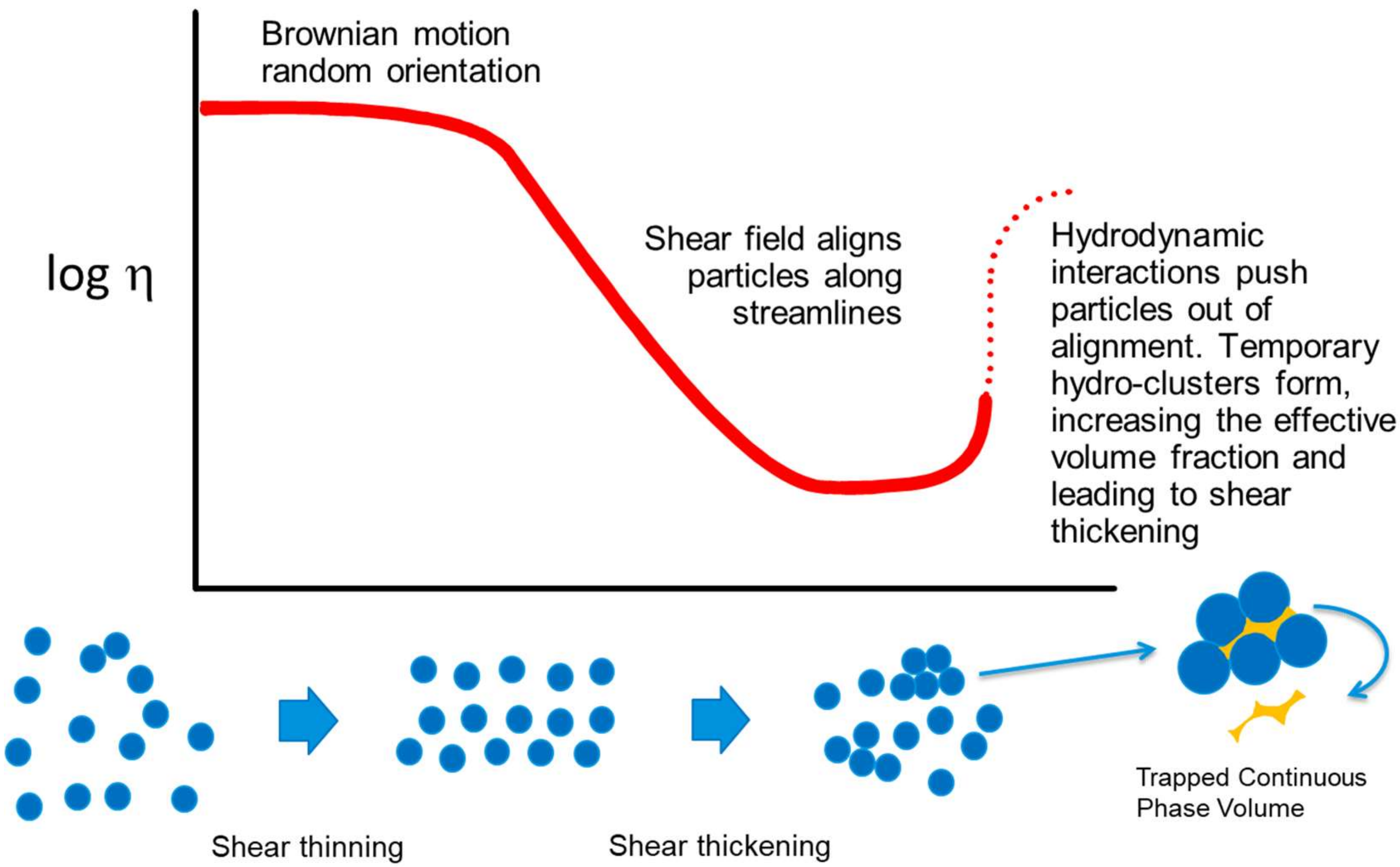


General Viscosity Curve for Suspensions



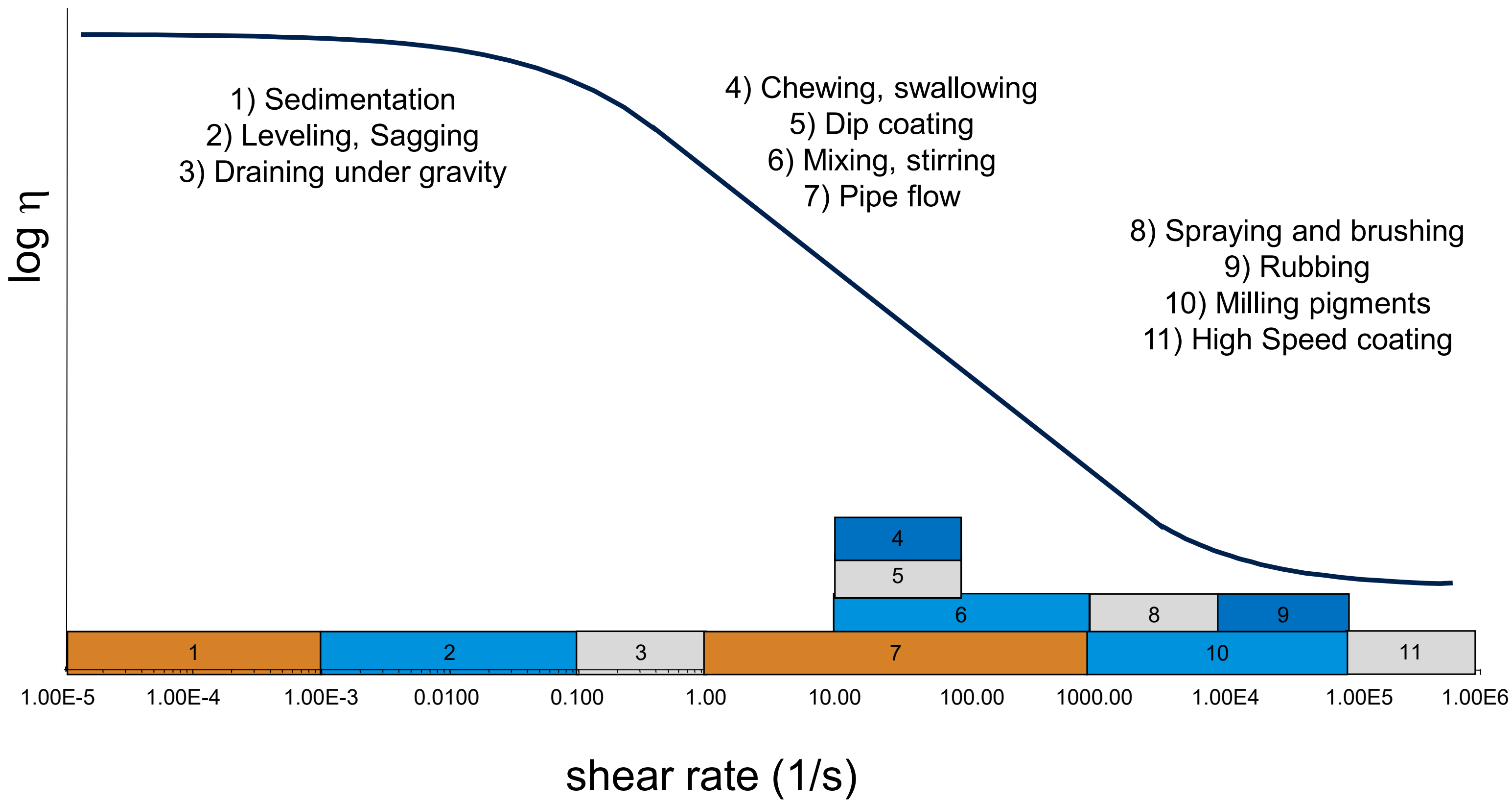
Reference:Barnes, H.A., Hutton, J.F., and Walters, K., An Introduction to Rheology, Elsevier Science B.V., 1989. ISBN 0-444-87469-0

Reason for Shape of General Flow Curve

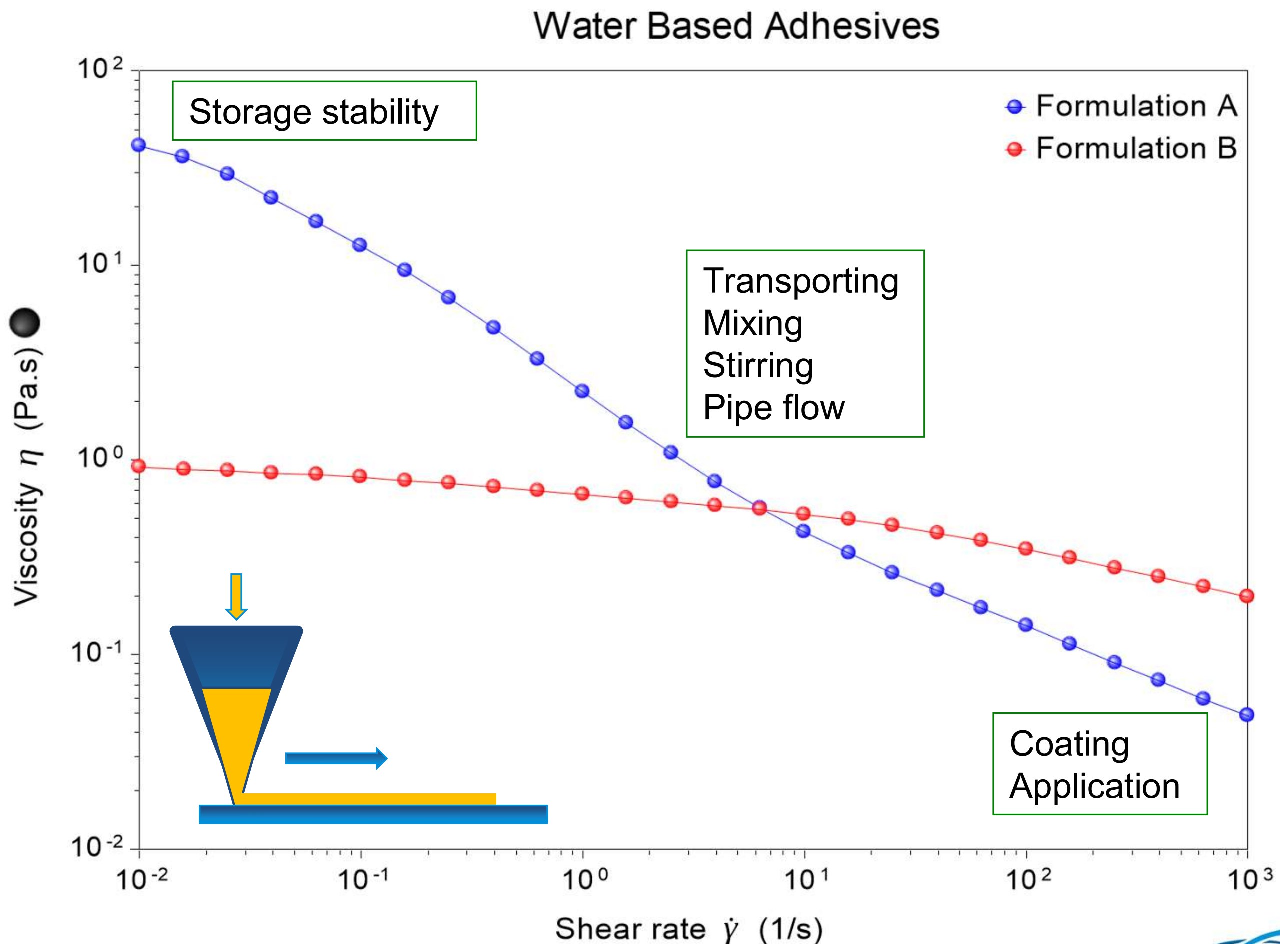


Viscosity vs. Shear Rate and Properties

- What shear rate?



Adhesive Coating Process: Viscosity Scan



What is Yield?

- Yield stress is a time dependent characteristic that is associated with many structured fluids such as Mayonnaise, Ketchup, hand lotion, hair gels, paints etc.
- A material that has yield does not flow unless the applied stress exceeds a certain value – yield point
- Yield stress is created in formulation by adding additional thickeners
- Yield helps stabilize complex fluids
  - Avoid sedimentation and increase shelf life
  - Reduce flow under gravity
  - Stabilize a fluid against vibration




How to Measure Yield

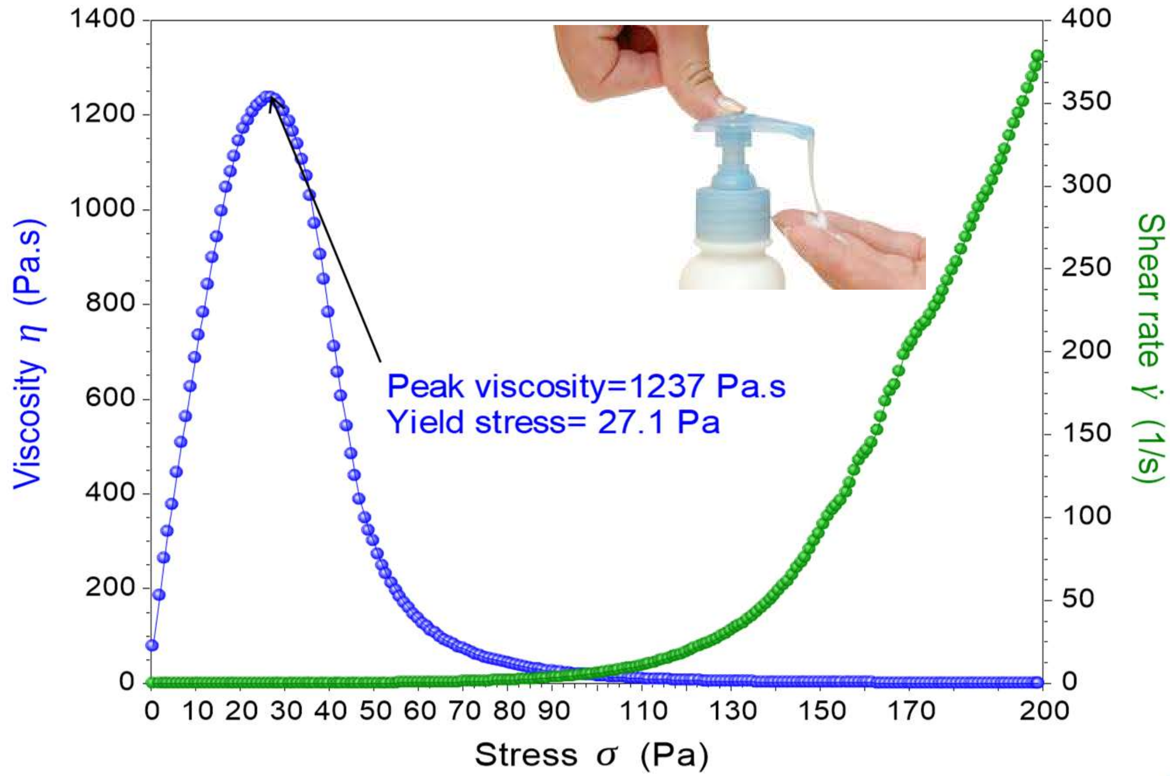
- Yield can be quantitatively measured on a rotational rheometer

- Common methods
  - Stress ramp
  - Stress sweep
  - Shear rate ramp
  - Dynamic stress/strain sweep

Note:
Yield behavior is a time dependent characteristic. Measured yield stress values will vary depending on experimental parameters

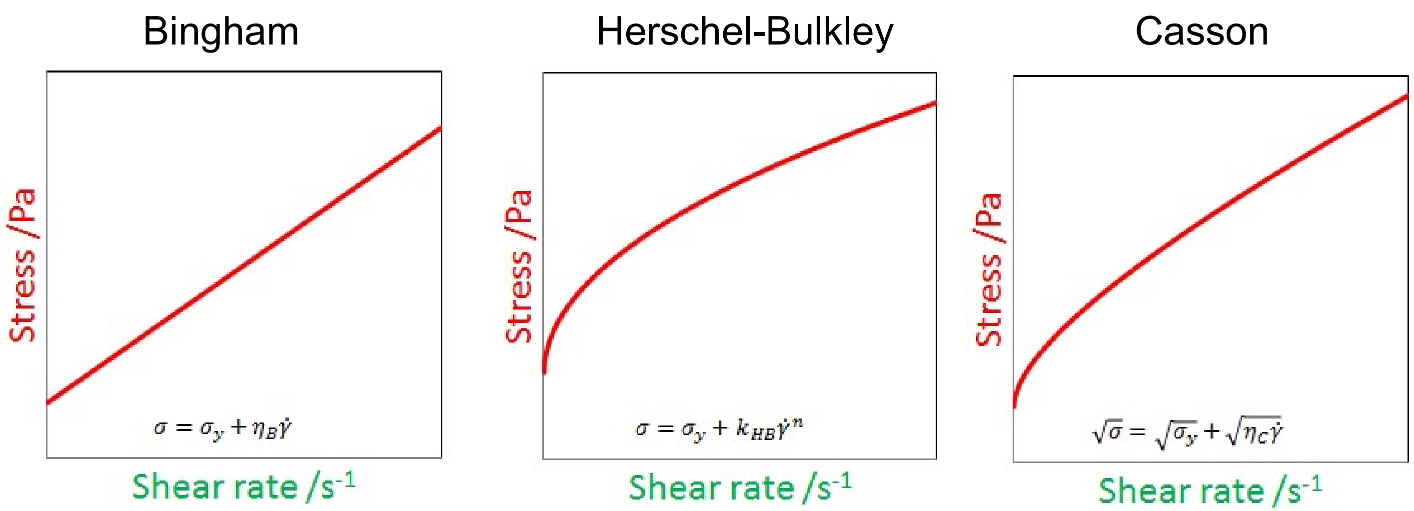
Yield Stress of a Body Lotion

- Stress ramp from 0 to 200 Pa in 60 seconds
- Yield is determined at the point where viscosity shows a peak



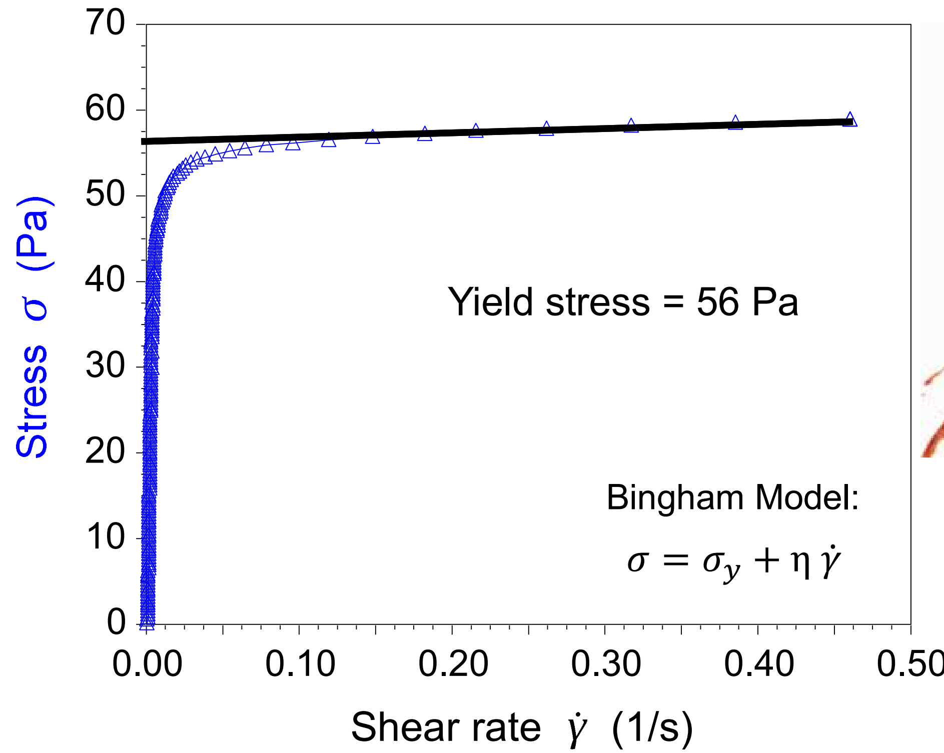
Fit Results with a Flow Models

- Fit the stress ramp curves with a mathematical flow model
- Three flow models to describe the yield behavior



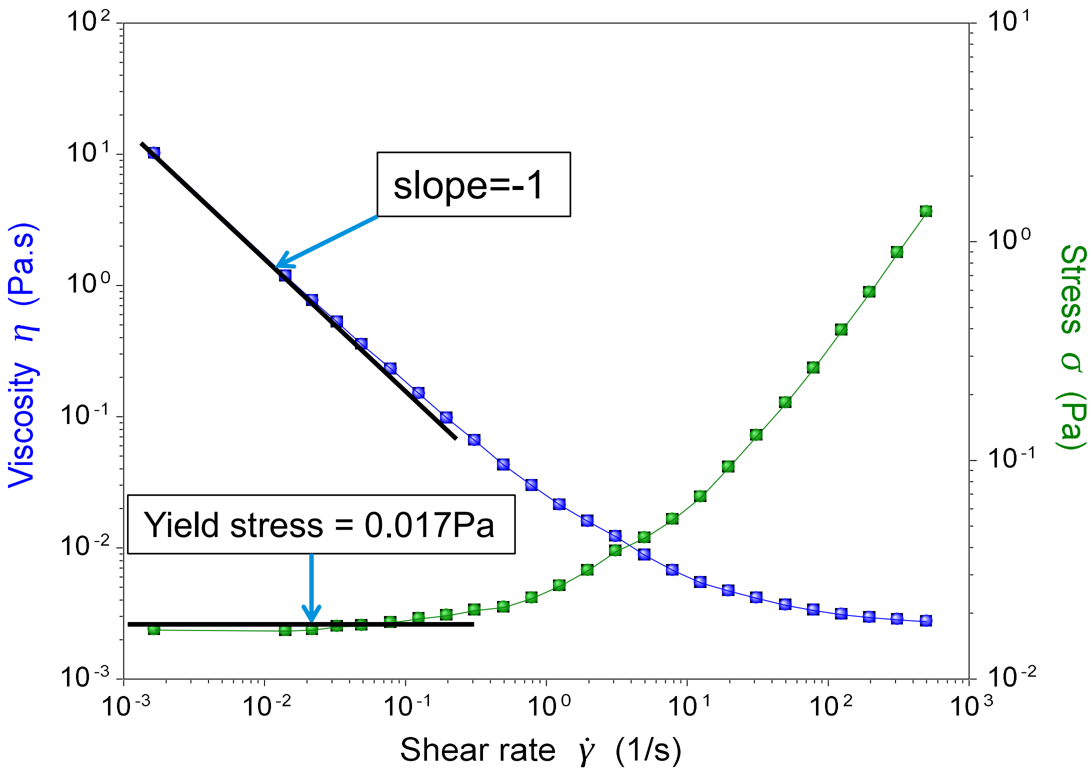
Yield Stress of Ketchup

- Stress ramp test on Katchup
- Yield is computed by fitting the flow curve with a mathematical model

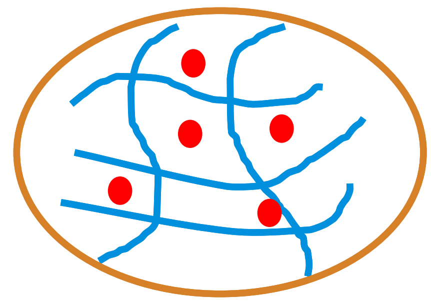


Yield Stress of Orange Juice

- Shear rate ramp down from 500 to 0.001 1/s
- Yield is identified by the stress plateau

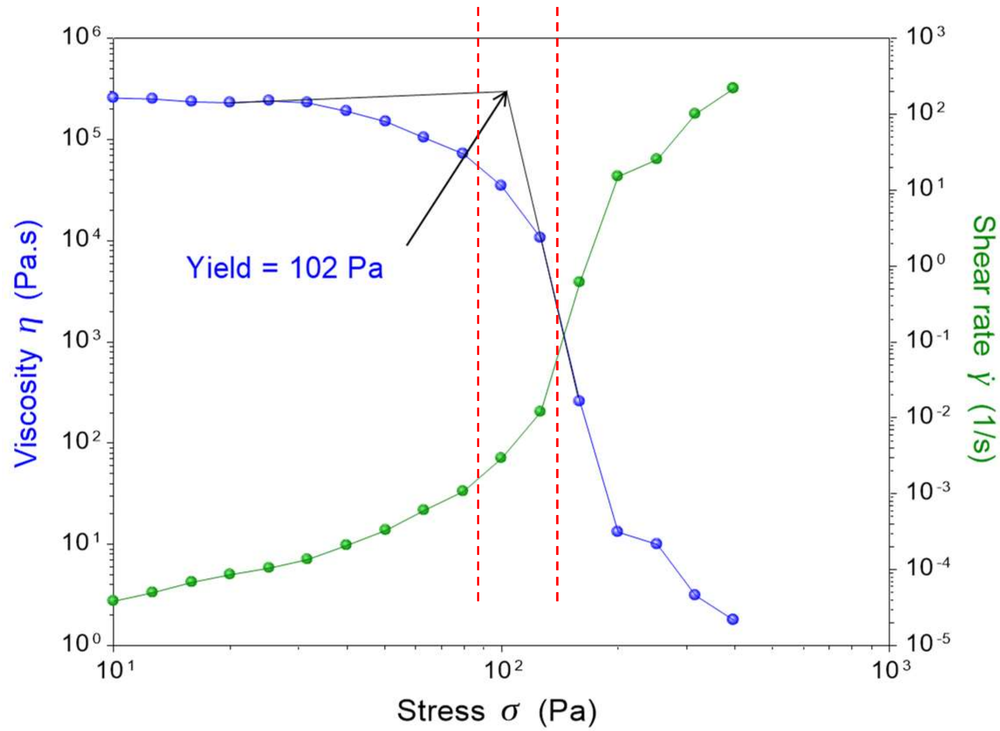


No settling?!



Yield Stress of a Toothpaste

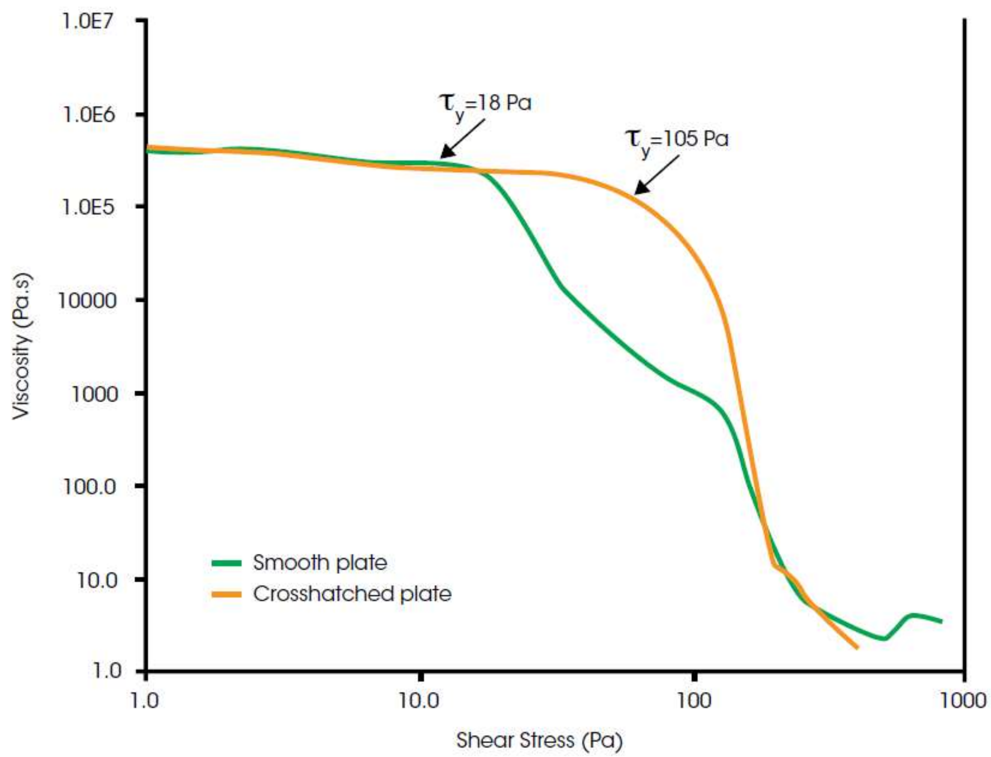
- Steady state stress sweep from 10 Pa to 500 Pa
- Yield stress is determined by a sharp decrease in viscosity over a narrow range of applied shear stress
- Take the onset of viscosity vs. stress curve

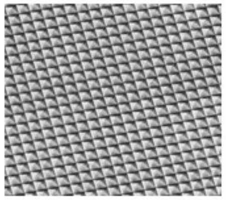


Wall Slip – Artifact Yield

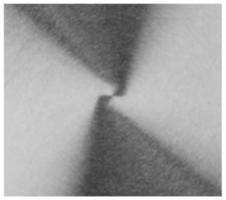
- Incidence of wall slip is often observed when testing structured fluids
- Wall slip shows artifact yield

Yield Stress Measurements on Toothpaste





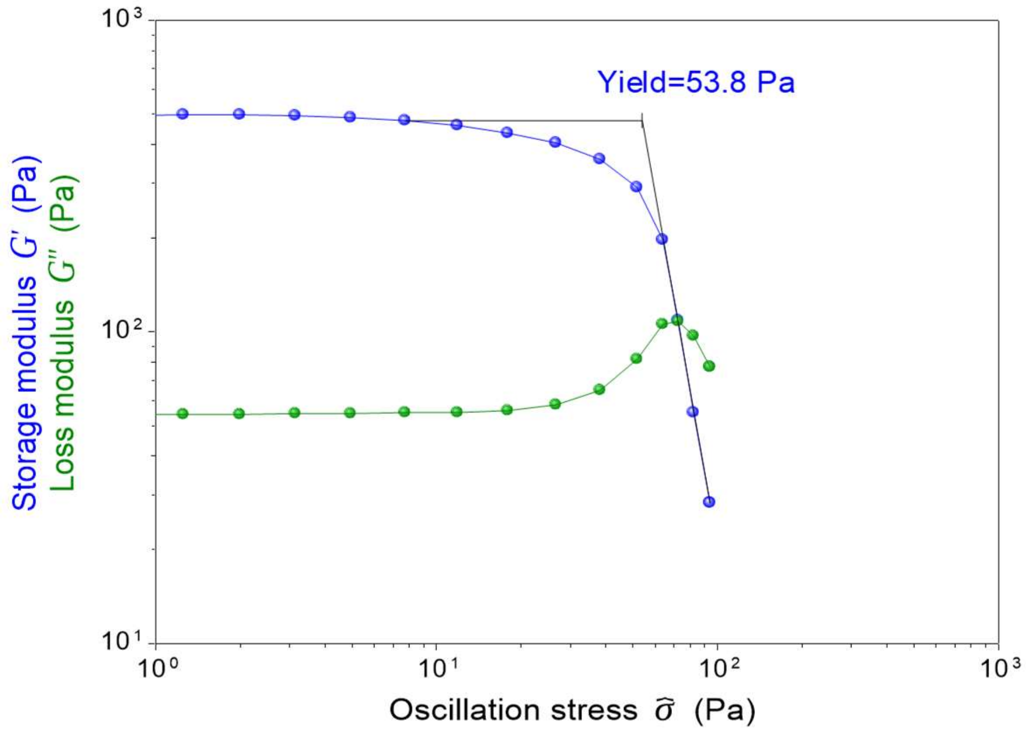
crosshatched plate



smooth plate

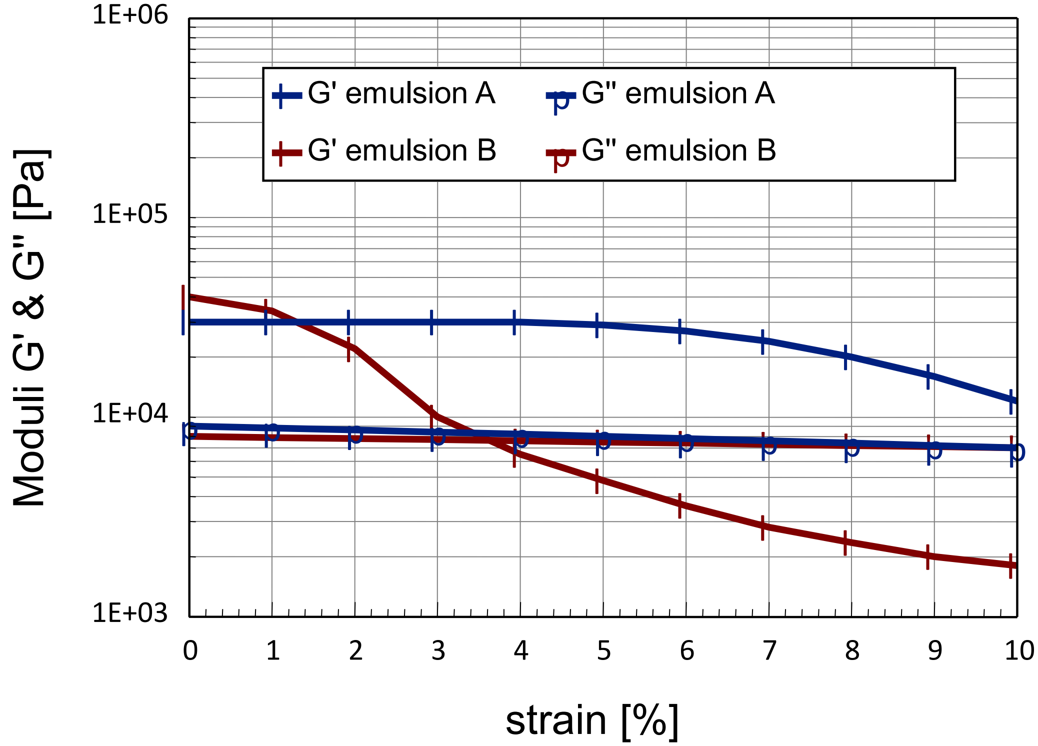
Yield Stress of Mayonnaise

- Dynamic stress/strain sweep test on Mayonnaise
- Yield stress is signified at the onset of G’ vs. stress curve
- Yield determined by this method indicates the critical stress at which irreversible plastic deformation occurs



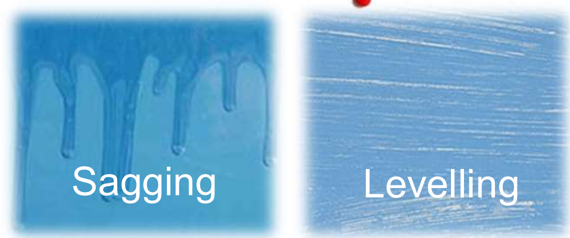
Creams/Lotions: Predict Stability

Stability, phase separation of a cosmetic cream



What is Thixotropy?

- Thixotropy is a time-dependent shear thinning property, which is used to characterize structure change reversibility
- A thixotropic fluid takes a finite time to attain equilibrium viscosity when introduced to a step change in shear rate
- Thixotropy is a desired property for many applications such as:
  - Control sagging and levelling of paints
  - Start up of pipleline flow after rest



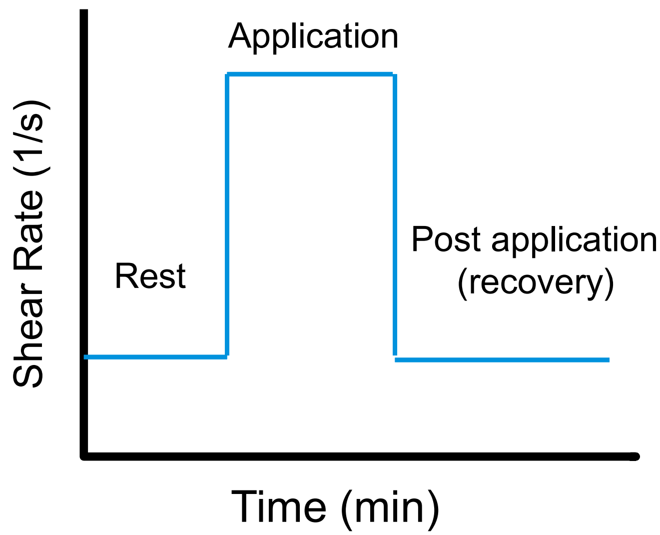
How to Measure Thixotropy

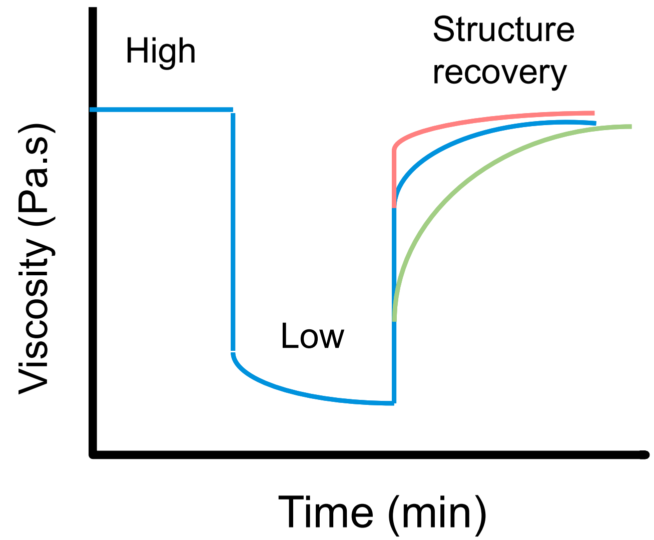
- Thixotropy can be quantitatively measured on a rotational rheometer

- Common methods
  - Stepped flow method
  - Stepped dynamic method
  - Stress ramp up and down method (Thixotropic loop)
  - Dynamic time sweep after pre-shear method

Note:
Thixotropic behavior is a time dependent characteristic. Measured thixotropy will vary depending on experimental parameters.

Stepped Flow Method





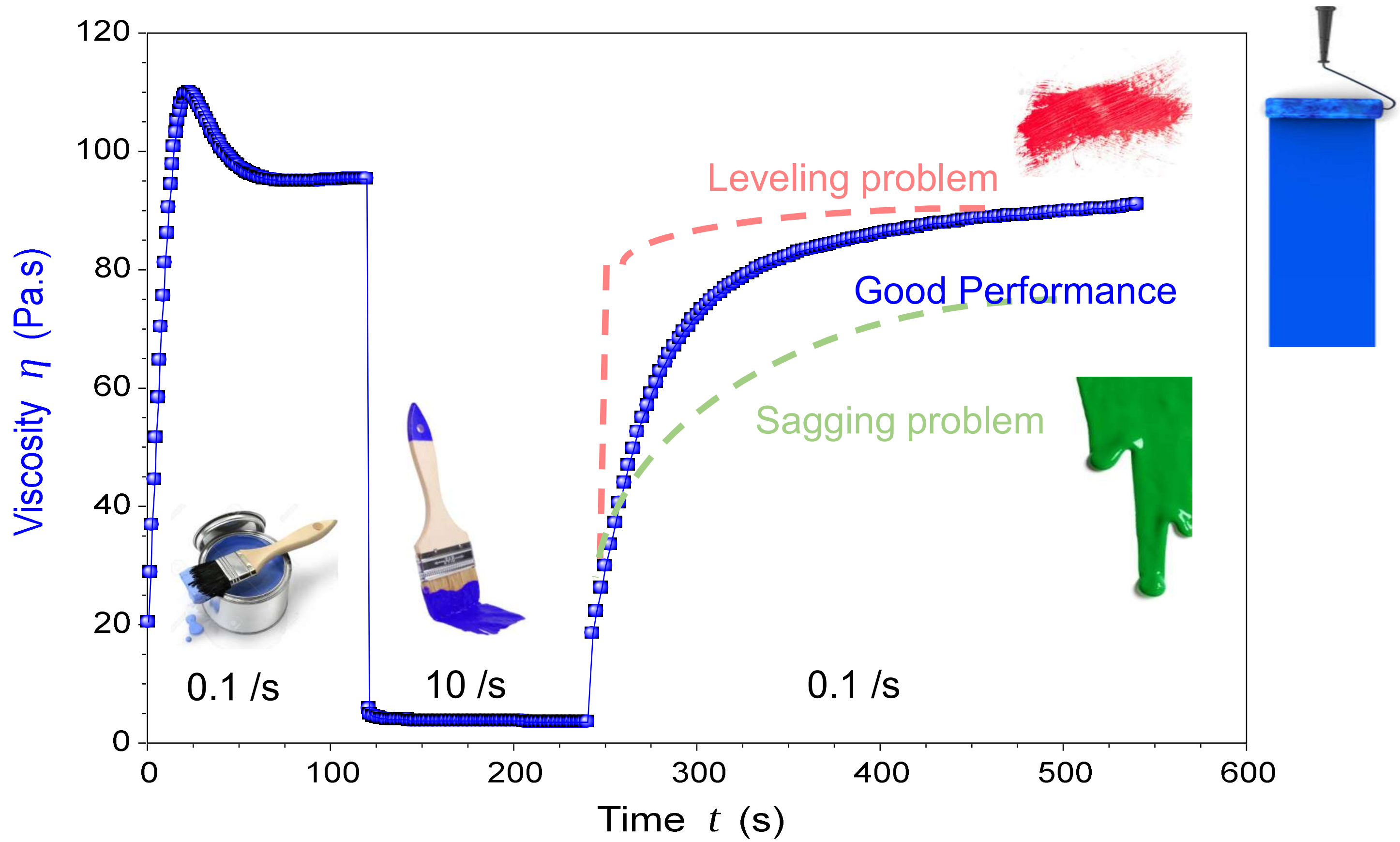
Experimental:

Step 1: Low Shear (e.g. 0.1 1/s), state of rest

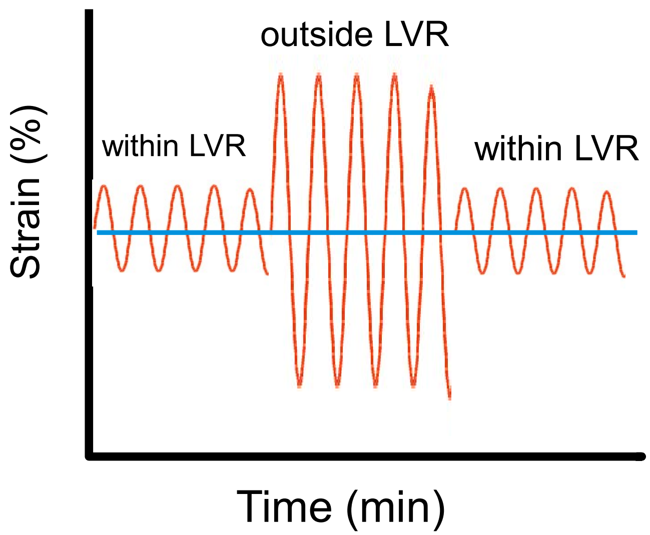
Step 2: High Shear (e.g. 10 1/s), structural destruction

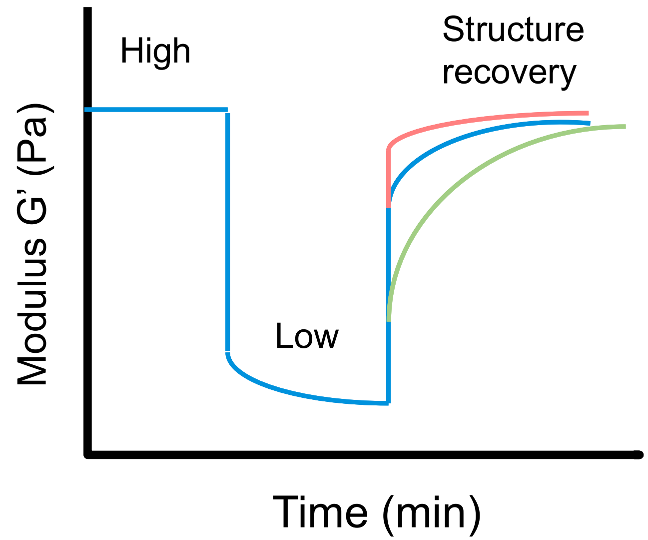
Step 3: Low Shear (e.g. 0.1 1/s), structural regeneration

Thixotropic Analysis of a Blue Paint



Stepped Dynamic Method





Experimental:

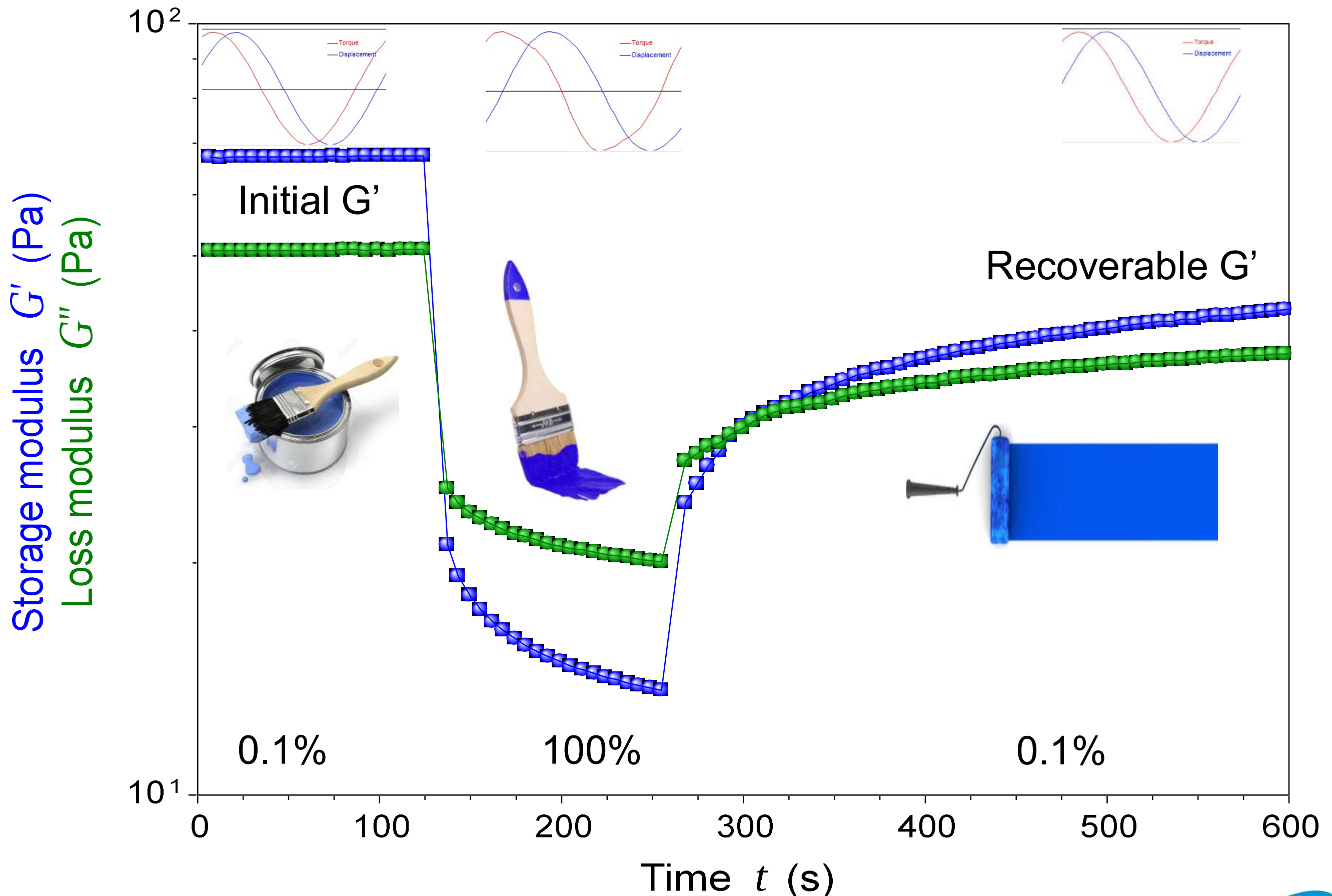
Step 1: Dynamic time sweep within LVR, structure at rest

Step 2: Dynamic time sweep outside LVR, structural destruction

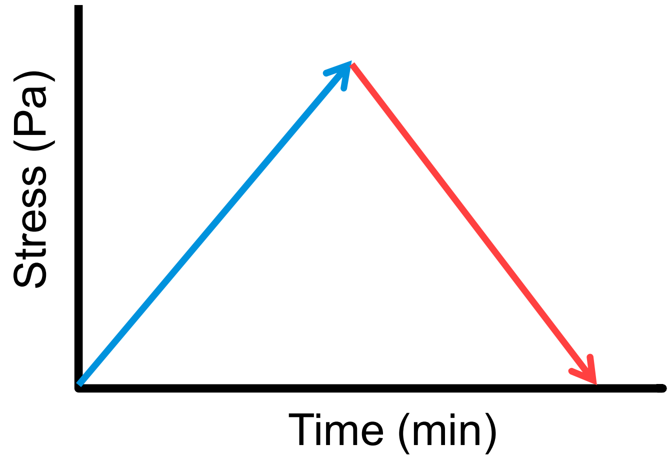
Step 3: Dynamic time sweep within LVR, structural regeneration

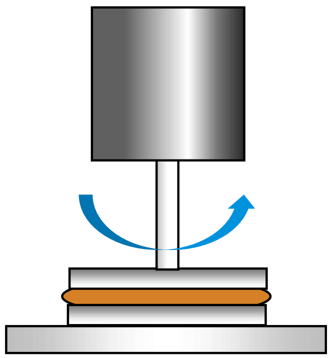
Good for measuring high viscosity samples

Blue Paint: Stepped Time Sweep



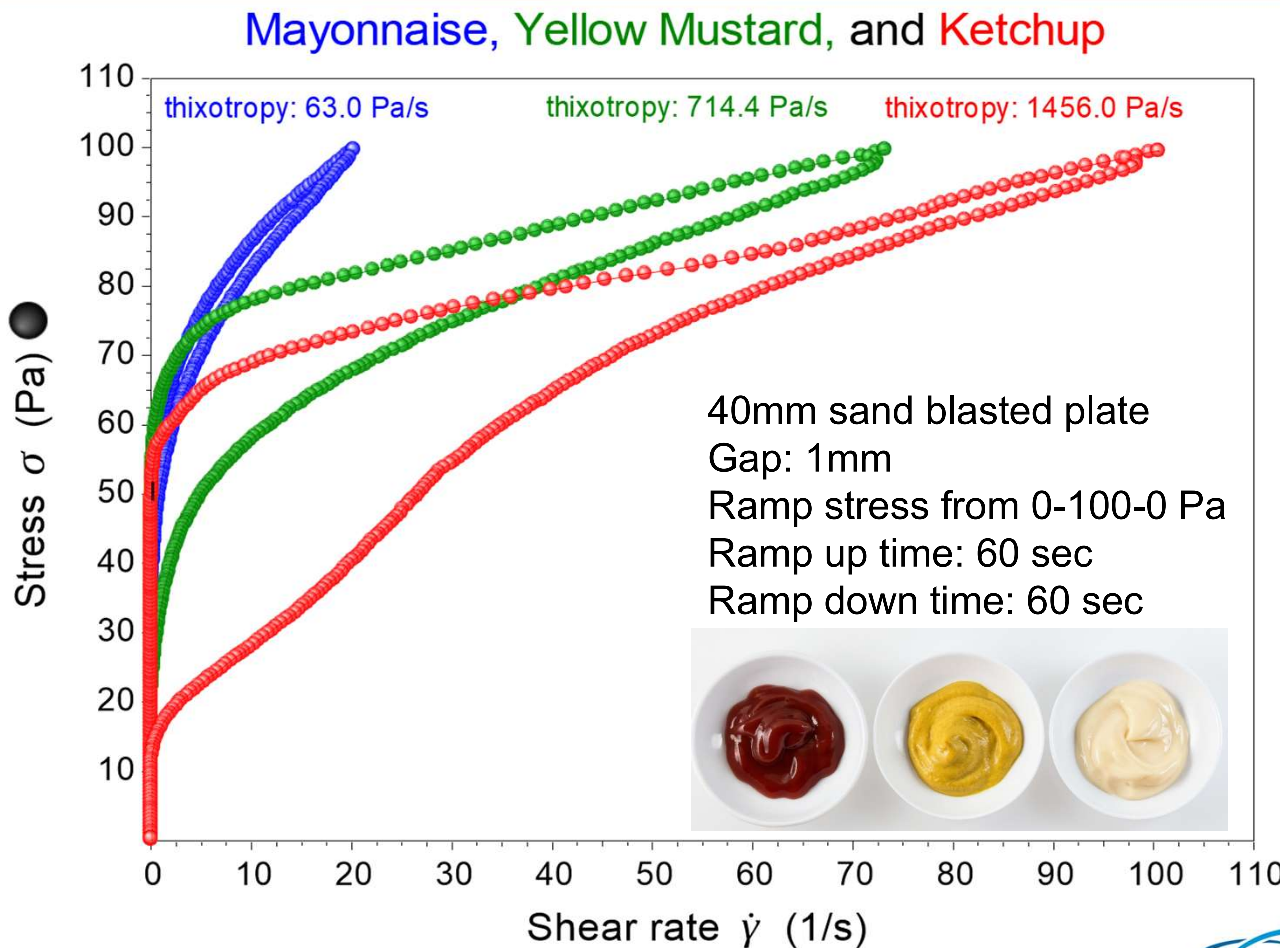
Stress/Rate Ramp Up and Down Method



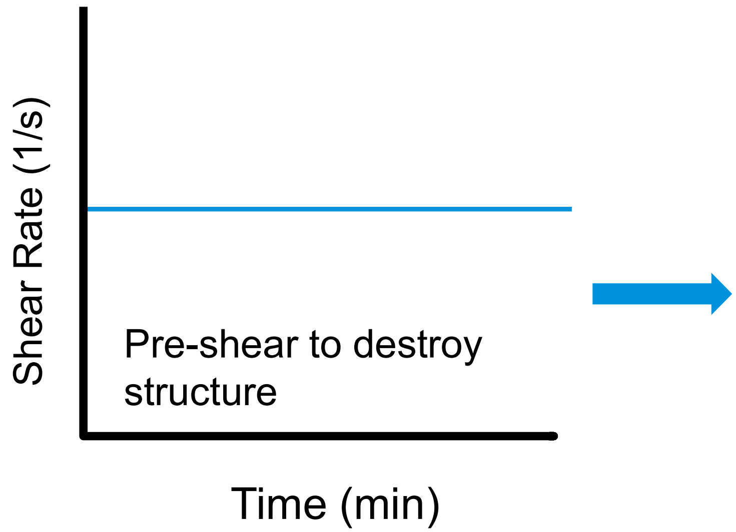


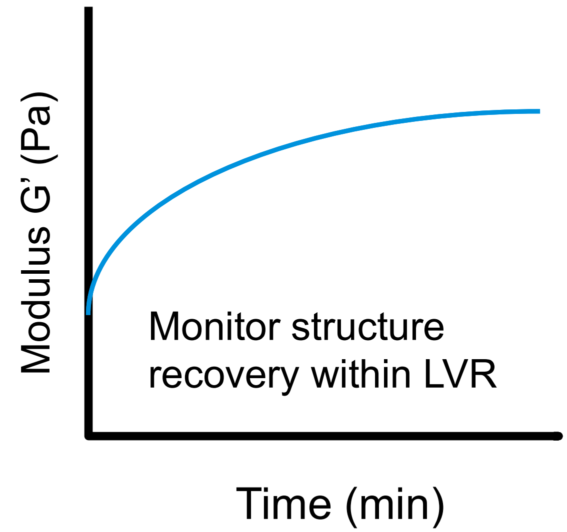
- Ramp shear stress linearly from zero up until sample flows, then ramp stress back down to zero
- Thixotropic index is measured by taking the area between the up and down stress curves
- TA Tech Tip: https://www.youtube.com/watch?v=8lZangOp1SY

Thixotropic Loop Testing on Foods



Time Sweep After Pre-shear Method

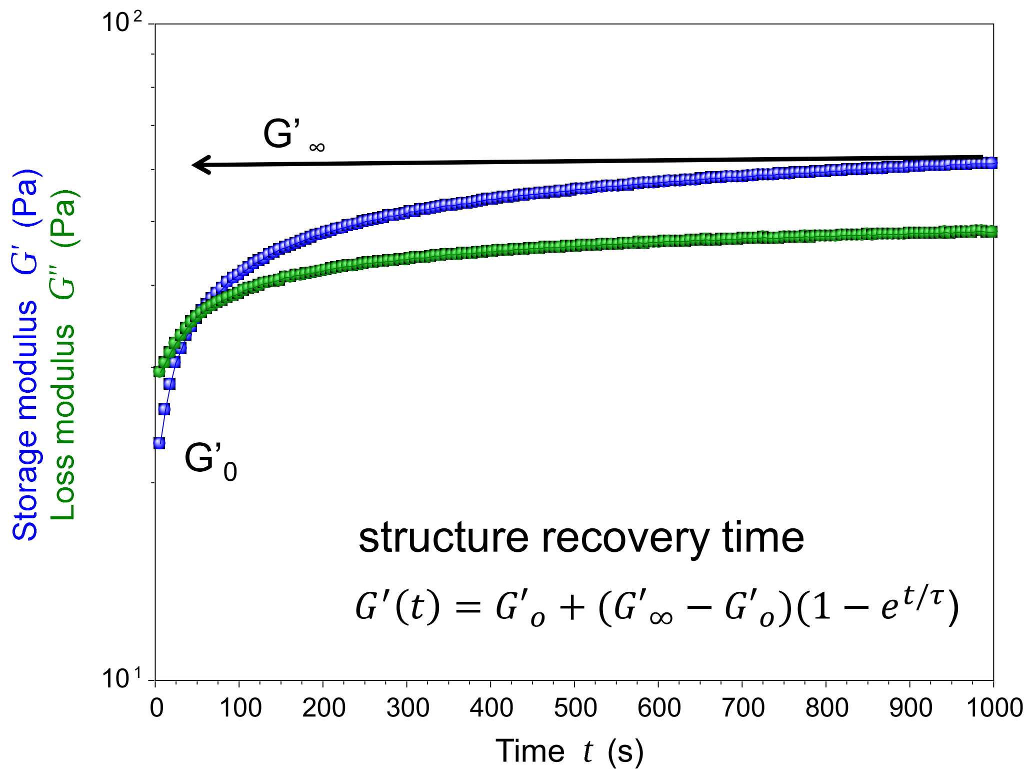




- Apply a constant shear (e.g. 10 or 100 1/s) for a certain time (e.g. 1 min.) to break down structure
- Immediately start a time sweep within the linear region of the material to monitor structure recovery

Blue Paint: Time Sweep After Pre-shear

- Monitor the increase of the G‘ as a function of time.
- Thixotropic recovery is described by meausring the recovery time (τ)



TA Practical Series Training Course

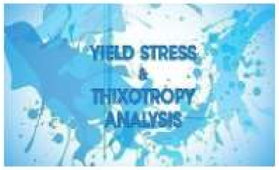
https://www.tainstruments.com/a-practical-approach-to-rheology/

- How to measure Yield stress
- How to measure Thixotropy
- How to avoid wall slip and edge fracture
- How to fit flow curves with models

Viscosity Measurements on Liquids

The second chapter this four part series on rheology will cover viscous behaviors of liquids.

View Archive



Yield and Thixotropy Measurements

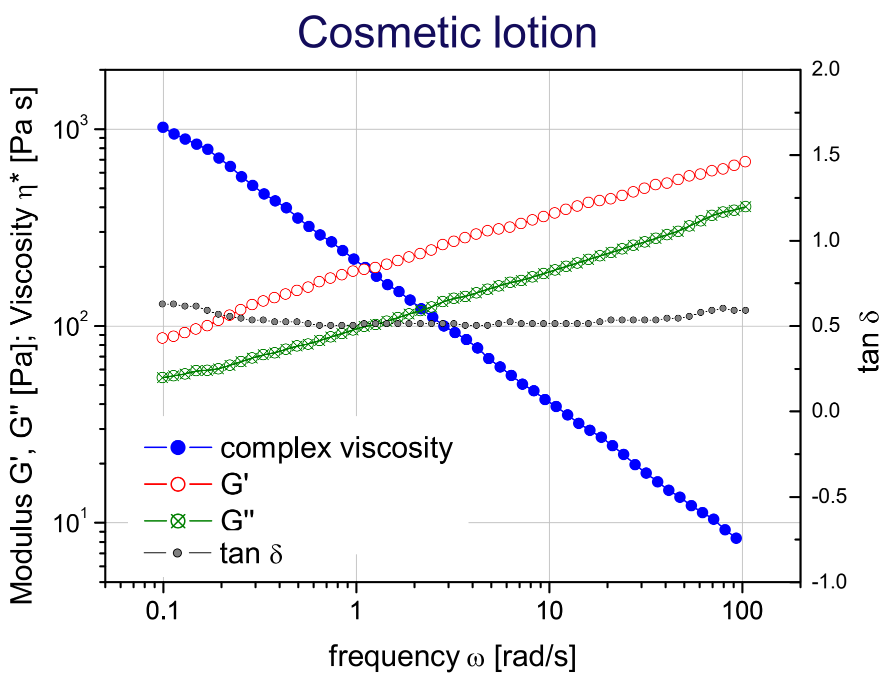
Beyond viscous behavior, complex fluids can exhibit other important flow characteristics, most notably yield stresses and thixotropy. In this third part, we will explore effective ways to quantify these behaviors.

Elasticity Measurement

The elasticity characterizes the mechanical energy stored (recoverable) during deformation and is a measure of the structure in a material

- Three test methods are commonly used to determine the elastic contribution:
  - Oscillation test – frequency sweep (most common)
  - Creep Recovery test
  - Normal stress measurement

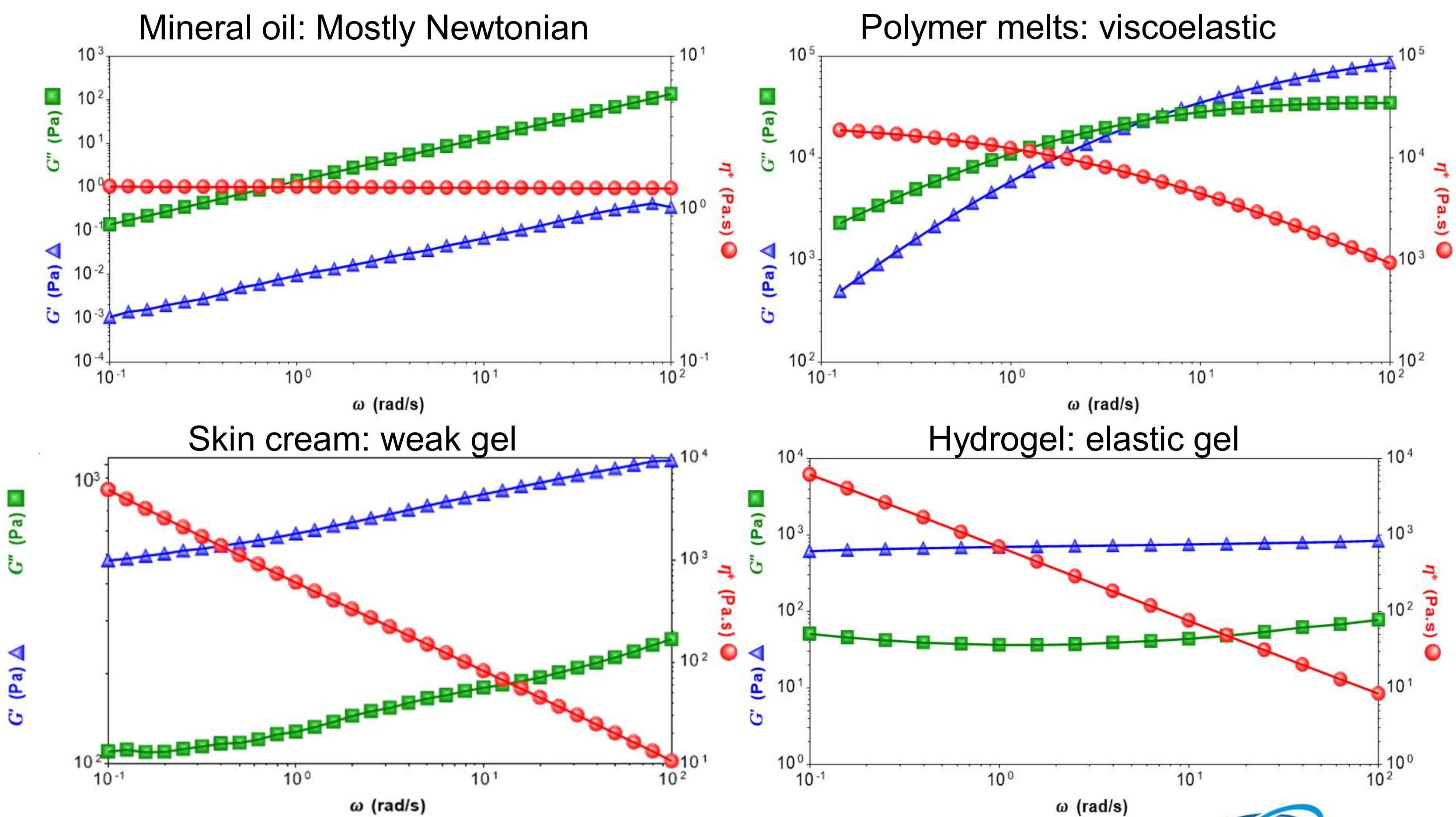
Elasticity: Oscillation Frequency Sweep



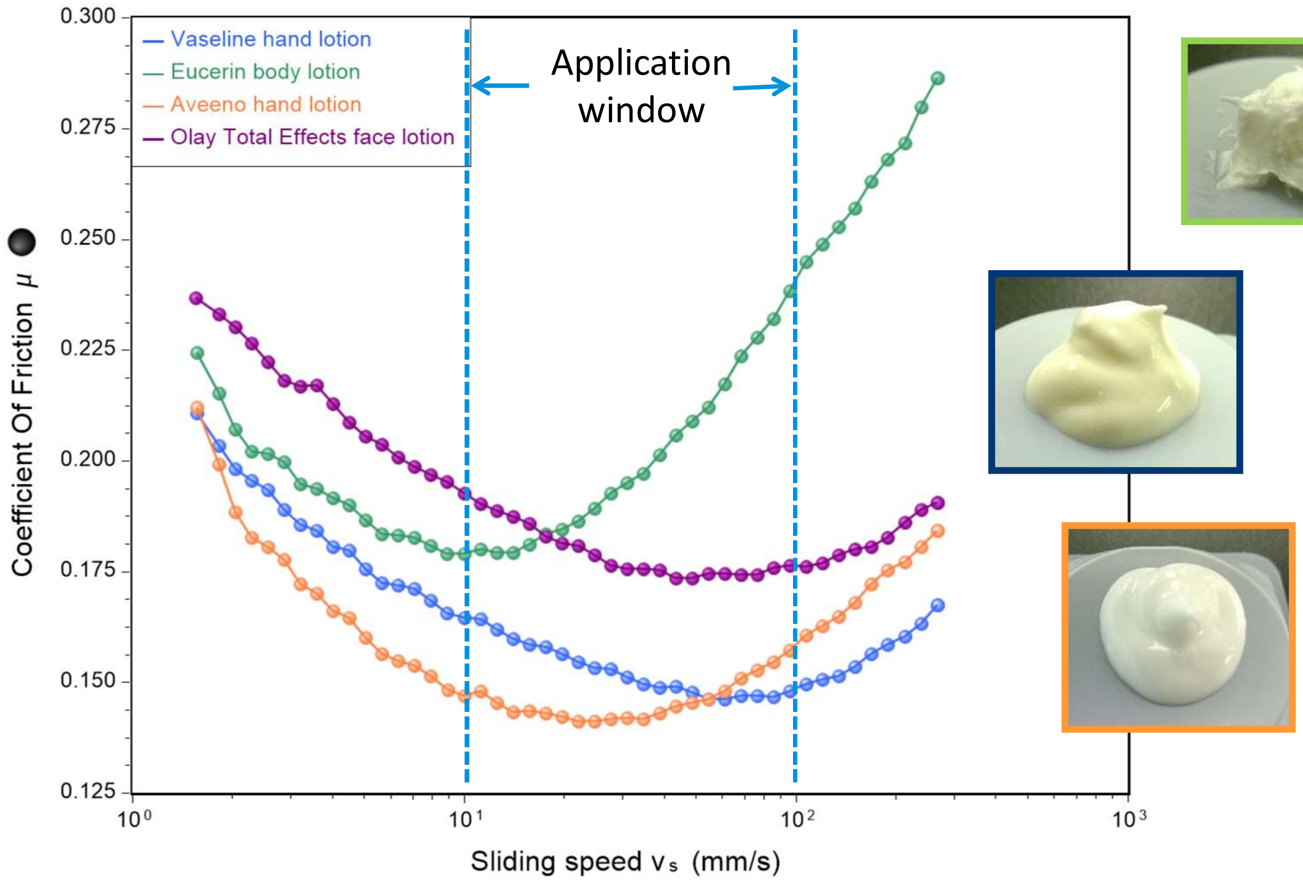
- Many dispersion exhibit solid like behavior at rest
- The frequency dependence and the absolute value of tan δ correlate with long time stability

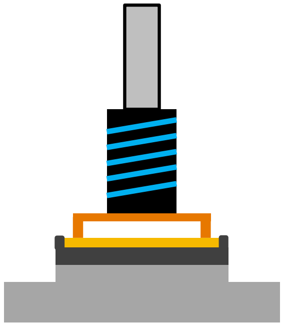
- Note: strain amplitude has to be in the linear region

Differences in elasticity using frequency sweep



Lotions: Coefficient of Friction



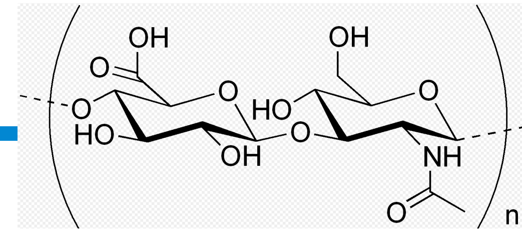


37°C, 3 N load
TransPore ™

Hydrogels

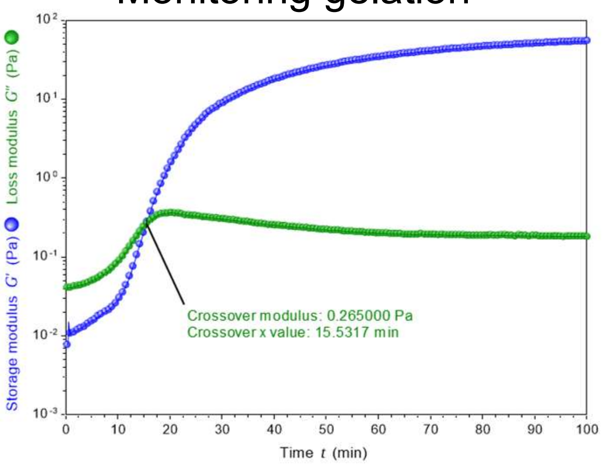
- Hydrogels and creams are used in a wide variety of applications including tissue engineering, wound patch, drug delivery, contact lenses and superabsorbent materials
- Rheology can provide key information on gel formation and gel strength on different formulations
- Related applications Notes: AAN033; EF014; EF015; EF016; TA384; TA410

Natural Polymer: Hyaluronic Acid

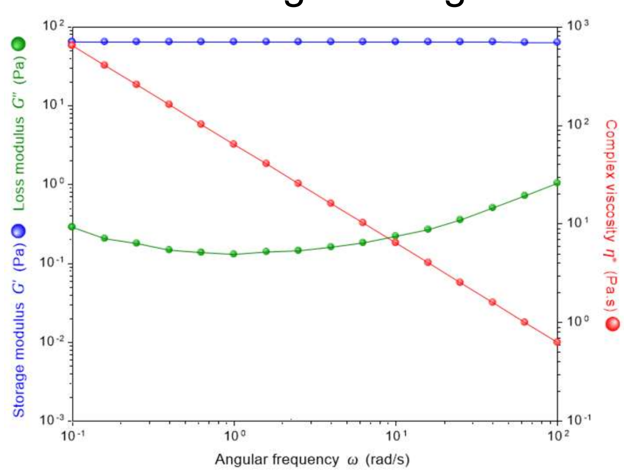


- Hyaluronic acid is a natural polysaccharide, which is commonly used in pharmaceutical, biomedical and personal care
- Rheology can evaluate the visco-elastic properties as function of concentration, ionic strength, Mw, degree of crosslinking, formulations etc.

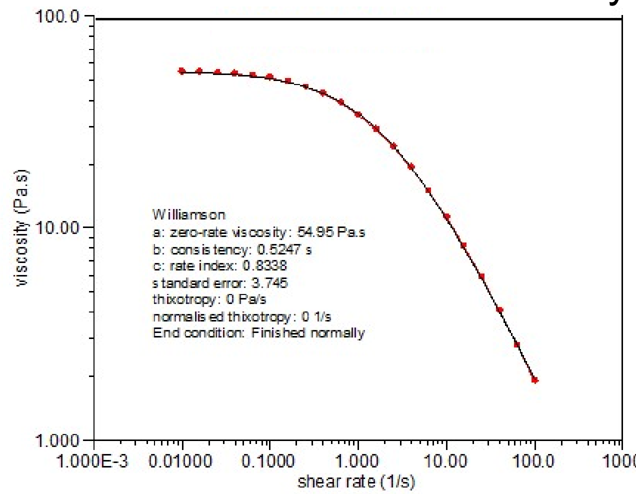
Monitoring gelation



Measure gel strength

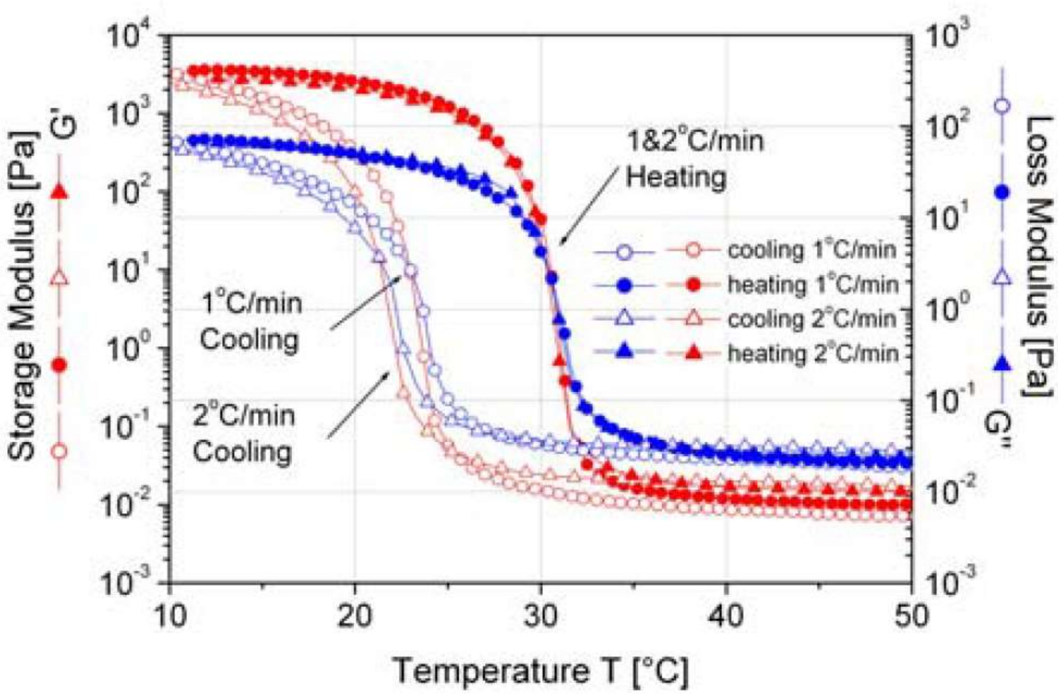


Measure zero shear viscosity



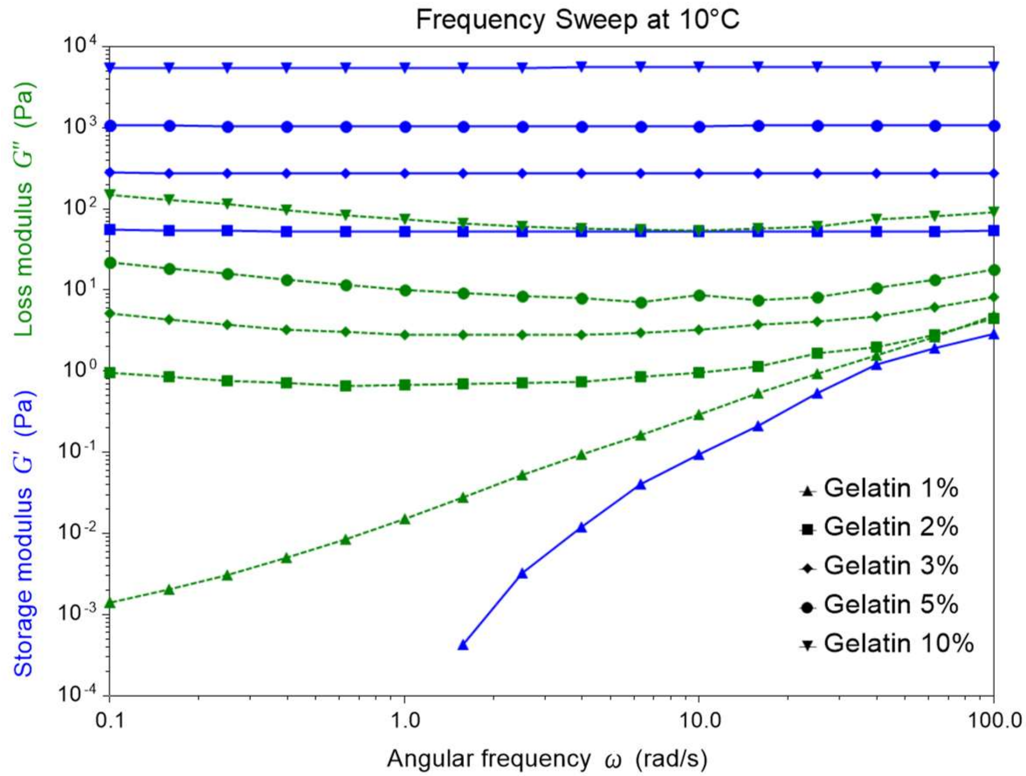
Gelatin: Gelation vs. Temperature

- Thermal reversible gelatin gels:
  - Measure gelation and gel melt



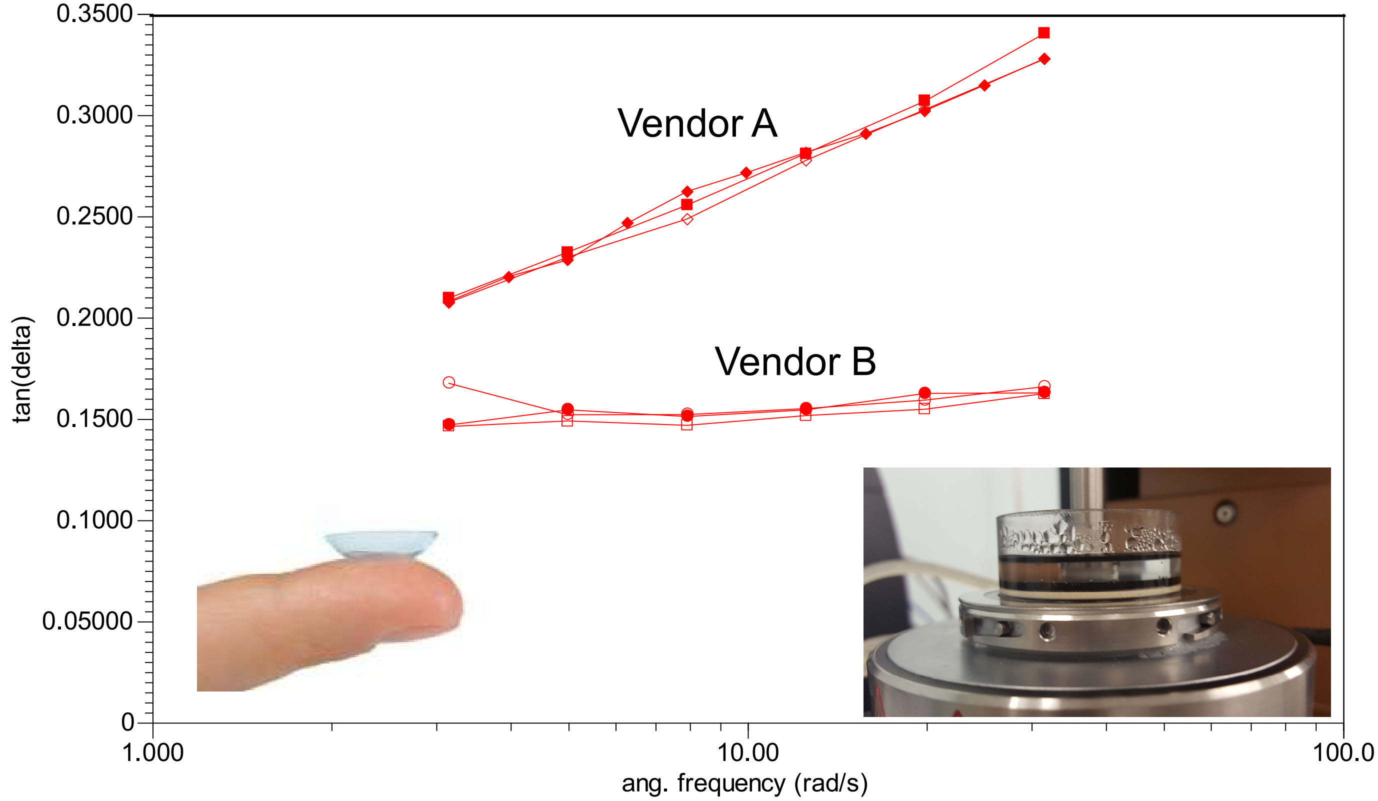
Gelatin Gel Strength at Different Concentration

- A dynamic frequency sweep test can be used to compare gel strength at applications temperature



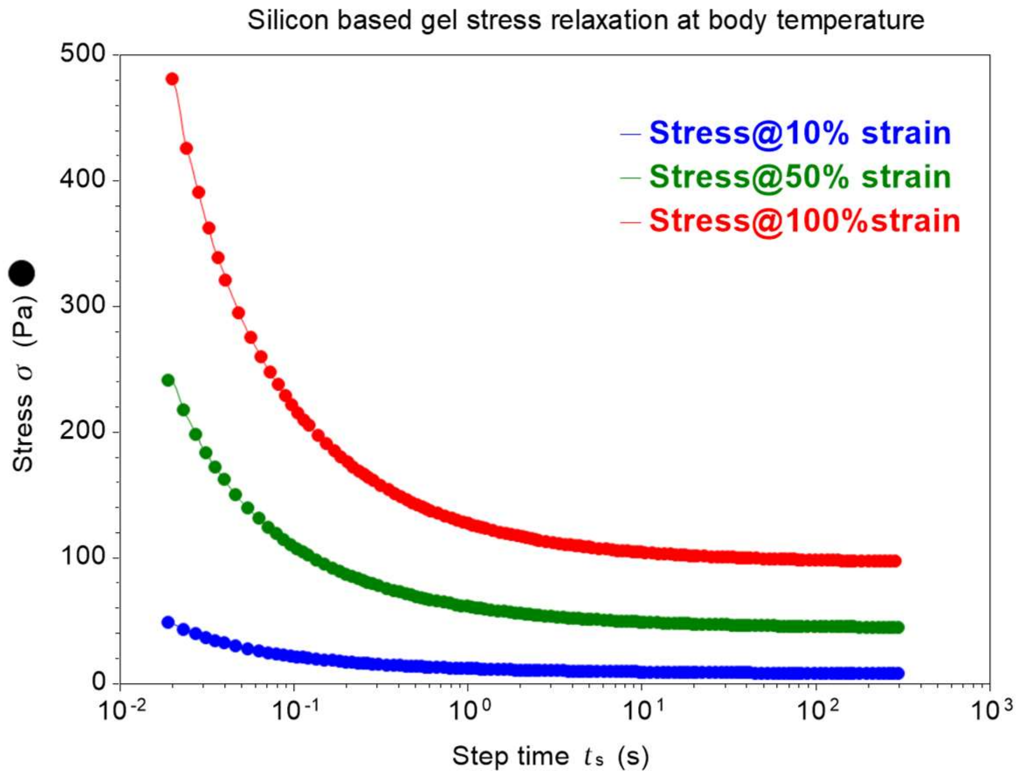
Contact Lens Visco-elasticity

- Compare frequency dependency of contact lens' elasticity



Eye Patch Gel: Stress Relaxation

- A stress relaxation test can measure how much stress a gel can hold at a given deformation



Rheology Applications
2. Polymers

Available Polymer Applications Notes on TA Website

Products ⌄ Videos ⌄ Support ⌄ Training ⌄ News & Events ⌄ Sales Promos Careers ⌄ About TA ⌄ Contact ⌄

Applications Notes Library

Applications Notes Library

Our instruments are used in a variety of products, in multiple industries. The application notes below provide more detail on specific potential applications. You can search for specific app notes with the search field.

polymer

Title	Product Category	Ref#	Link
Application of Rheology of Polymers	Rheology	AAN009	Download Note
Understanding Rheology of Thermoplastic Polymers	Rheology	AAN013	Download Note
Creep Recovery Measurements of Polymers	Rheology	AAN022	Download Note
Introduction to Polymer Blends and Alloys	Rheology	AAN023	Download Note
The ARES-EVF: Option for Extensional Viscosity of Polymer Melts	Rheology	APN002	Download Note
Automotive Fatigue Life and Dynamic Mechanical Analysis of a Matrix Polymer	ElectroForce Mechanical Testing	EF026	Download Note
Use of Reology to Determine Molecular Weight Distribution of Polymers	Rheology	L2092	Download Note
Efficiency of Stabilisers in Polymers Measured by Microcalorimetry	Microcalorimetry	M139	Download Note
Oxidation of Polymers Studied by Microcalorimetry	Microcalorimetry	M22033	Download Note
Multisample Stability Testing of Polymers	Microcalorimetry	M22037	Download Note
Mixing Rules for Complex Polymer Systems	Rheology	RH095	Download Note

RS25 Polymer Mw....pdf

Purpose of a Rheological Measurement

Three main reasons for rheological testing:

- Characterization

  MW, MWD, formulation, state of flocculation, etc.

- Process performance

  Extrusion, blow molding, pumping, leveling, etc.

- Product performance

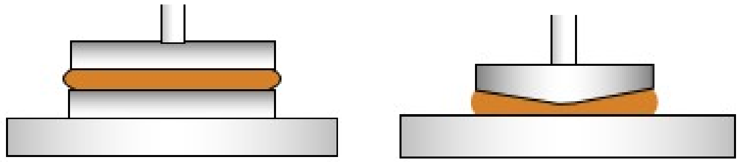
  Strength, use temperature, dimensional stability, settling stability, etc.

Most Common Experiments on Polymers

- **Oscillation/Dynamic**
  - Time Sweep
    - Degradation studies, stability for subsequent testing
  - Strain Sweep – Find LVR
  - Frequency Sweep – G', G", η^*
    - Sensitive to MW/MWD differences melt flow can not see
  - Temperature Ramp/Temperature Step
    - Transitions, end product performance
  - TTS Studies
- **Flow/Steady Shear**
  - Viscosity vs. Shear Rate, mimic processing
  - Find Zero Shear Viscosity
  - Low shear information is sensitive to MW/MWD differences melt flow can not see
- **Creep and Recovery**
  - Creep Compliance/Recoverable Compliance are sensitive to long chain entanglement, elasticity

Most Common Geometries

- Polymer melts:
  - 25mm and 8mm parallel plates, and disposable plates (cure)
  - Cone-plate (normal force measurement)
  - Cone partitioned plate (avoid edge fracture, LAOS)
- Polymer solids:
  - Torsion rectangular and cylindric geometry
  - DMA clamps (tension, bending, cantilever, compression)



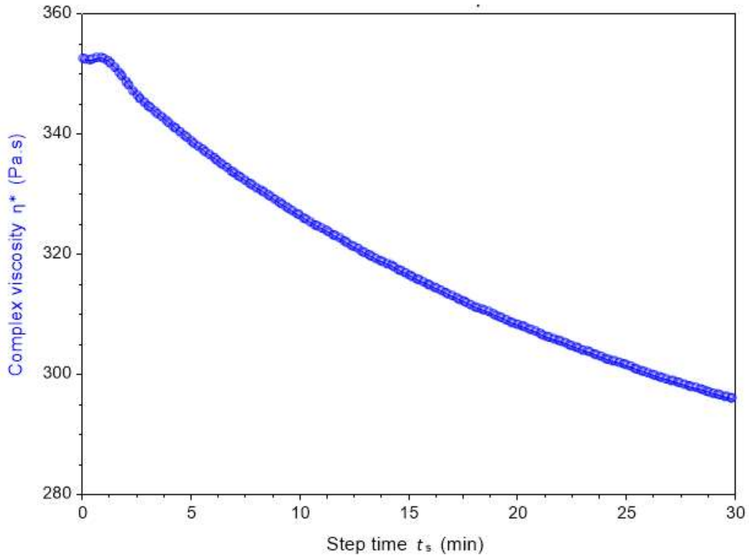
Torsion rectangular and cylindrical clamps

DMA cantilever, 3-point bending and tension clamps

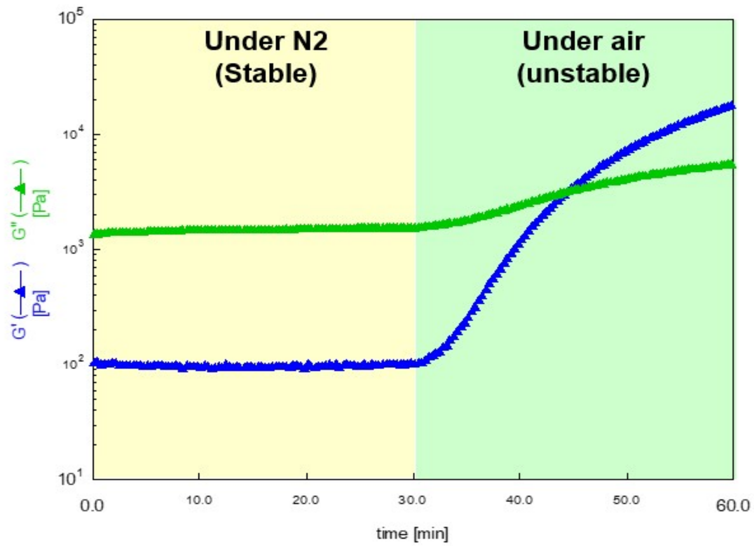
Polymer Melt Thermal Stability

- Determines if properties are changing over the time of testing
  - Degradation
  - Molecular weight building, crosslinking

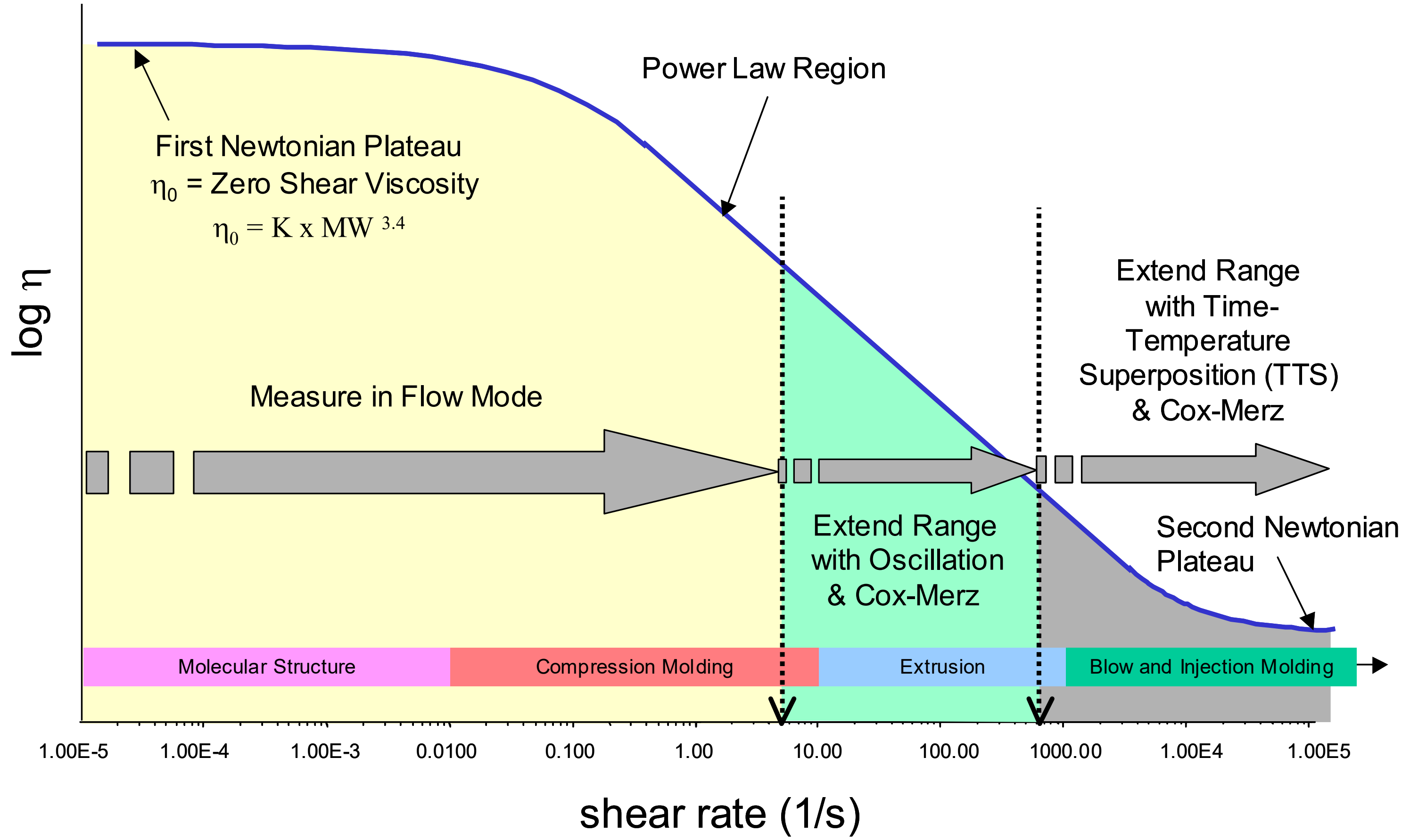
PP at 230°C (degradation)



PEEK at 400°C (crosslinking)



Idealized Flow Curve – Polymer Melts



Melt Flow Testing Considerations

- Edge Fracture:

  Sample leaves gap because of normal forces

- Cox-Merz Rule

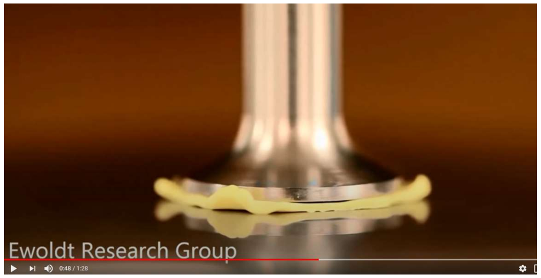
  An empirical relationship between a dynamic complex viscosity and steady shear viscosity. It has been observed working with many polymer melt systems

$$\eta = \sigma/\dot{\gamma}$$

$$\eta^* = G^*/\omega$$

$$\eta(\dot{\gamma}) \equiv \eta^*(\omega)$$

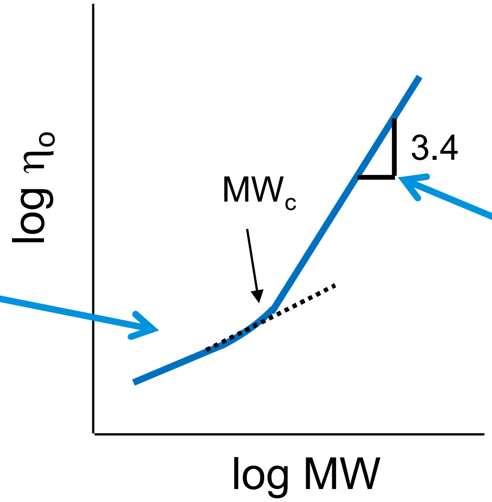
https://www.youtube.com/watch?v=urGKnj5Qmhc



Melt Rheology: MW Effect on Zero Shear Viscosity

- Sensitive to Molecular Weight, Mw
- For Low MW (no Entanglements) η_0 is proportional to Mw
- For MW > Critical Mw_c, η_0 is proportional to $Mw^{3.4}$

$\eta_0 = K \cdot Mw$

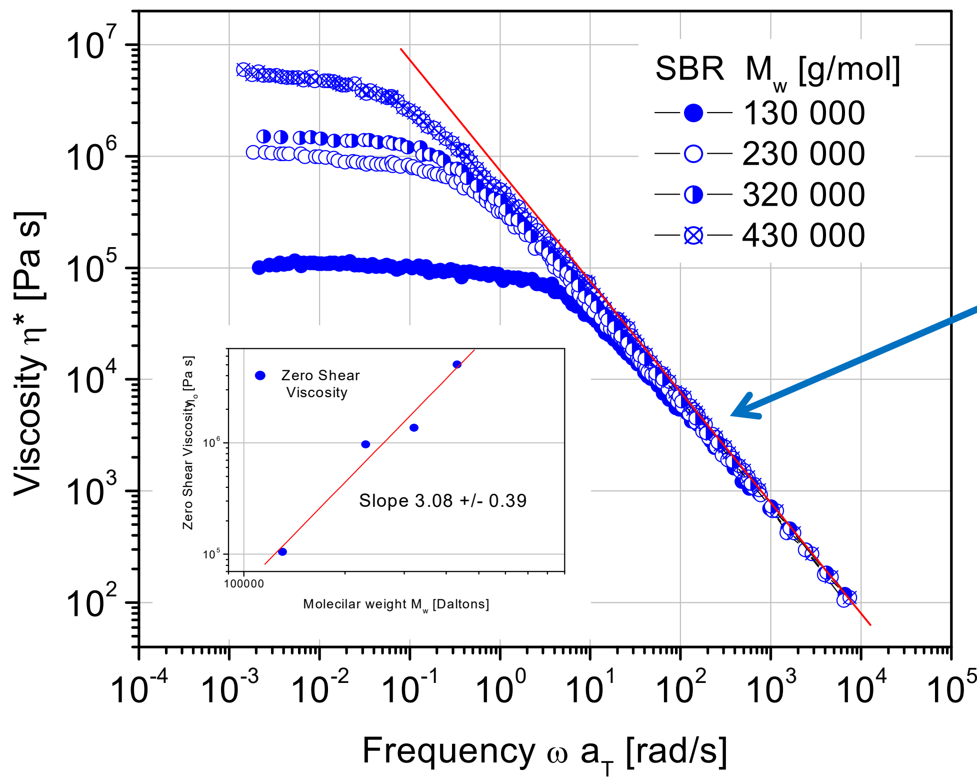


$\eta_0 = K \cdot Mw^{3.4}$

Ref. Graessley, Physical Properties of Polymers, ACS, c 1984.

Influence of MW on Viscosity

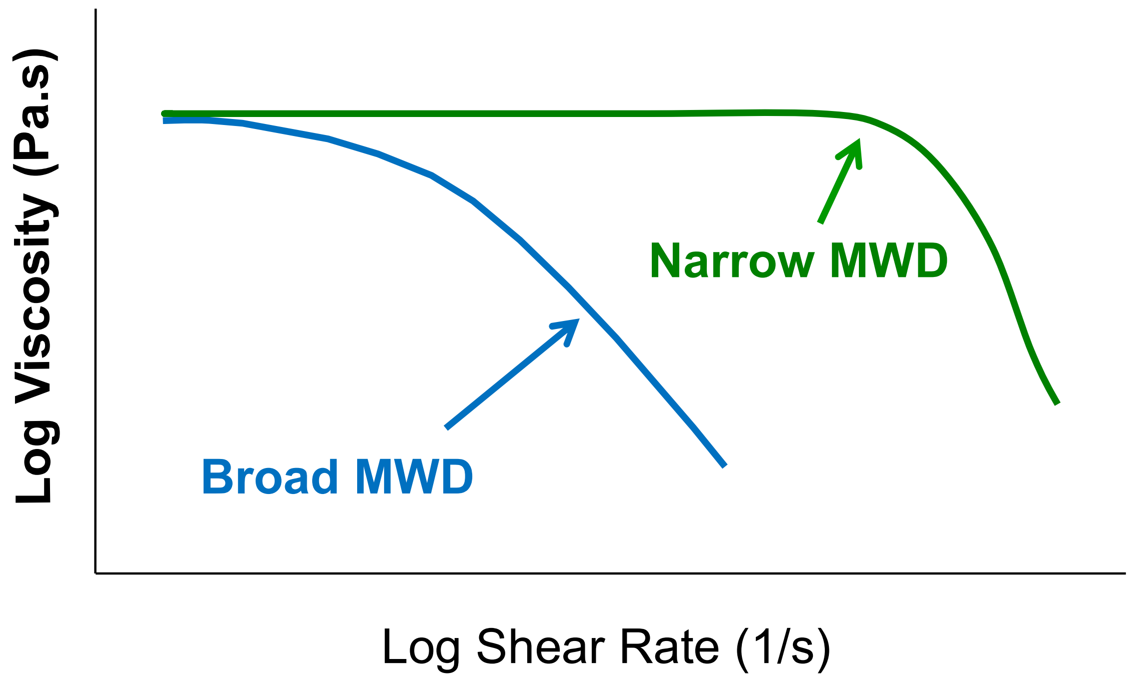
- The zero shear viscosity increases with increasing molecular weight. TTS is applied to obtain the extended frequency range.



The high frequency behavior (slope -1) is independent of the molecular weight

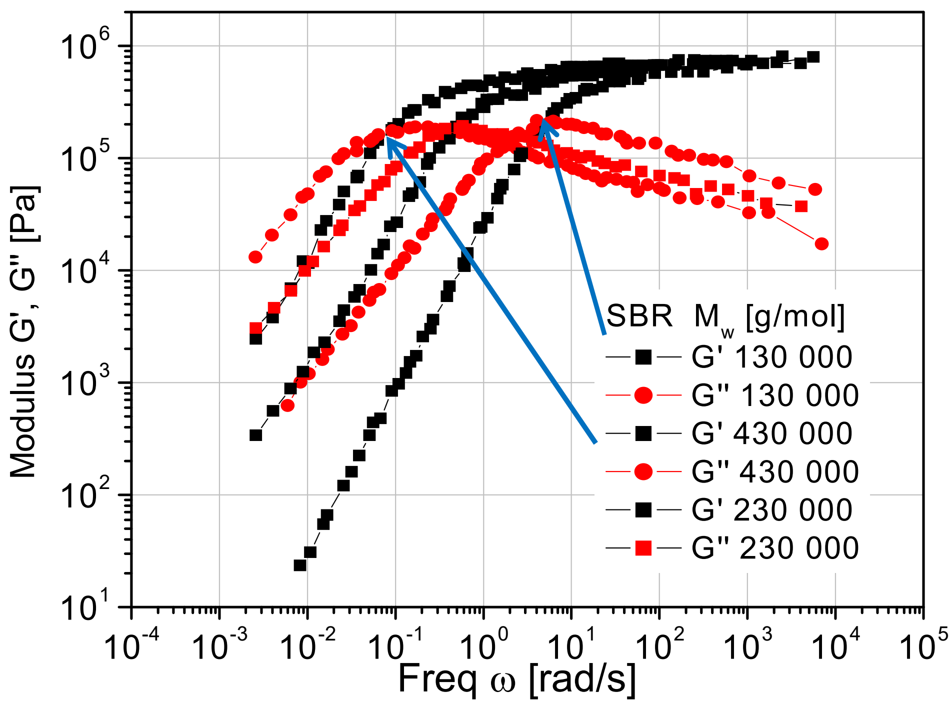
Influence of MWD on Viscosity

- A Polymer with a broad MWD exhibits non-Newtonian flow at a lower rate of shear than a polymer with the same η_0, but has a narrow MWD.



Influence of MW on G' and G"

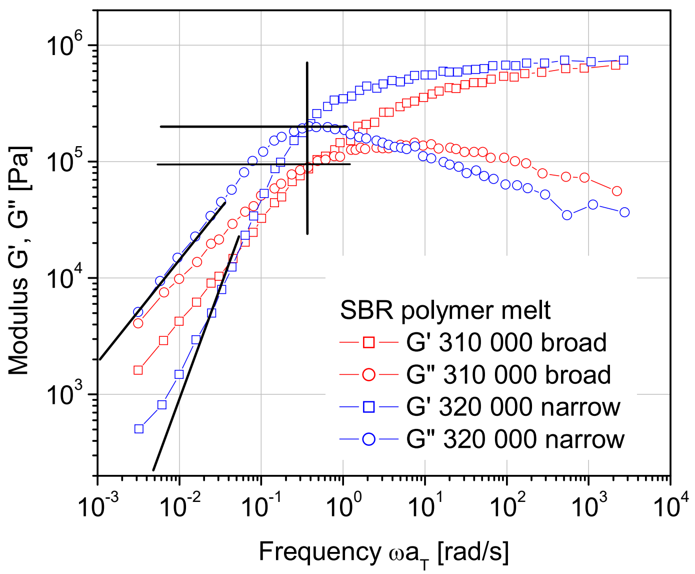
- The G' and G" curves are shifted to lower frequency with increasing molecular weight.



TA Instruments Webinar

Professor Chris Macosko – Analyzing Molecular Weight Distribution w/ Rheology

Influence of MWD on G‘ and G“

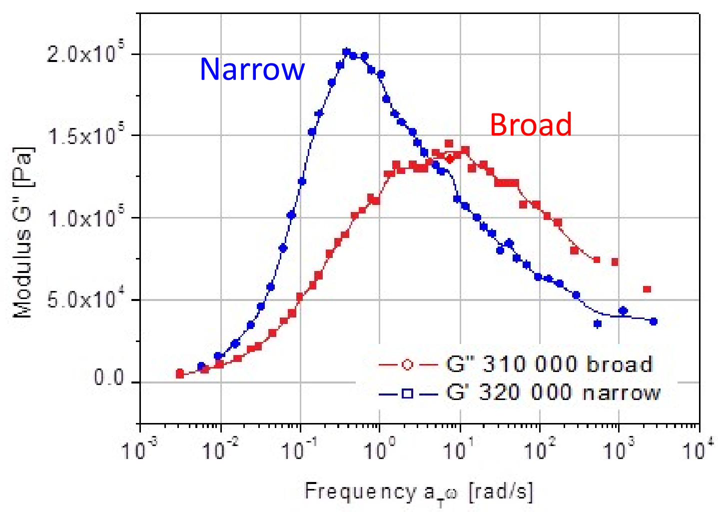


Higher crossover frequency : lower M_w

Higher crossover Modulus: narrower MWD

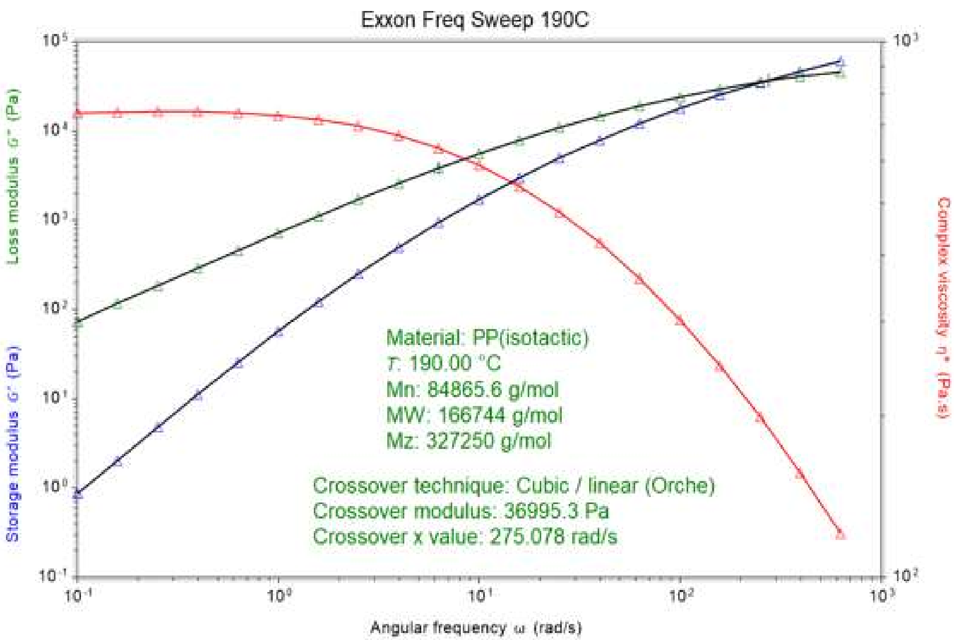
(note also the slope of G” at low frequencies – narrow MWD steeper slope)

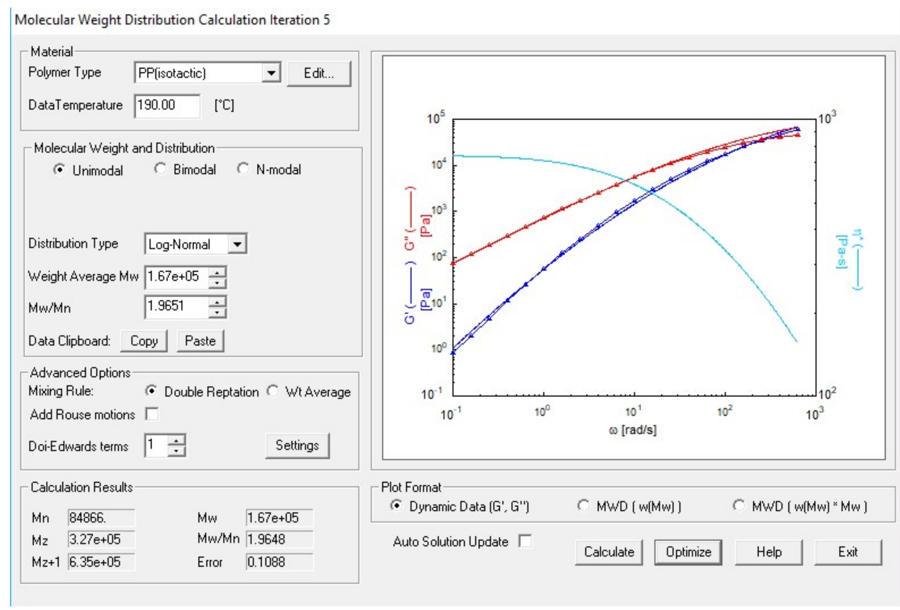
- The maximum in G“ is a good indicator of the broadness of the distribution



Frequency Sweep – Mw and MWD

- Using rheological measurements to quantify molecular weight and molecular weight distribution

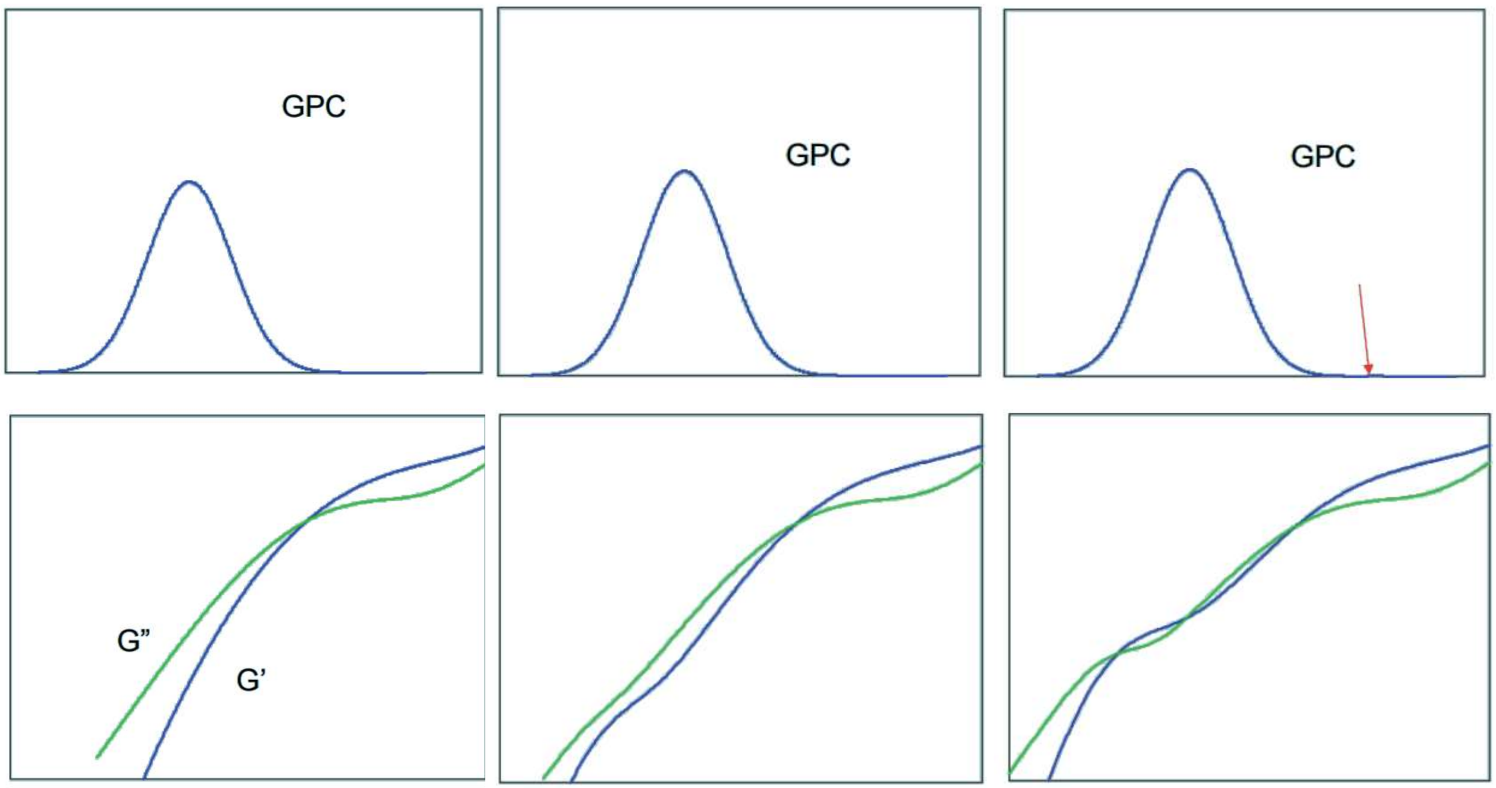




João Maia: The Role of Interfacial Elasticity on the Rheological Behavior of Polymer Blends
Chris Macosko: Analyzing Molecular Weight Distribution w/ Rheology

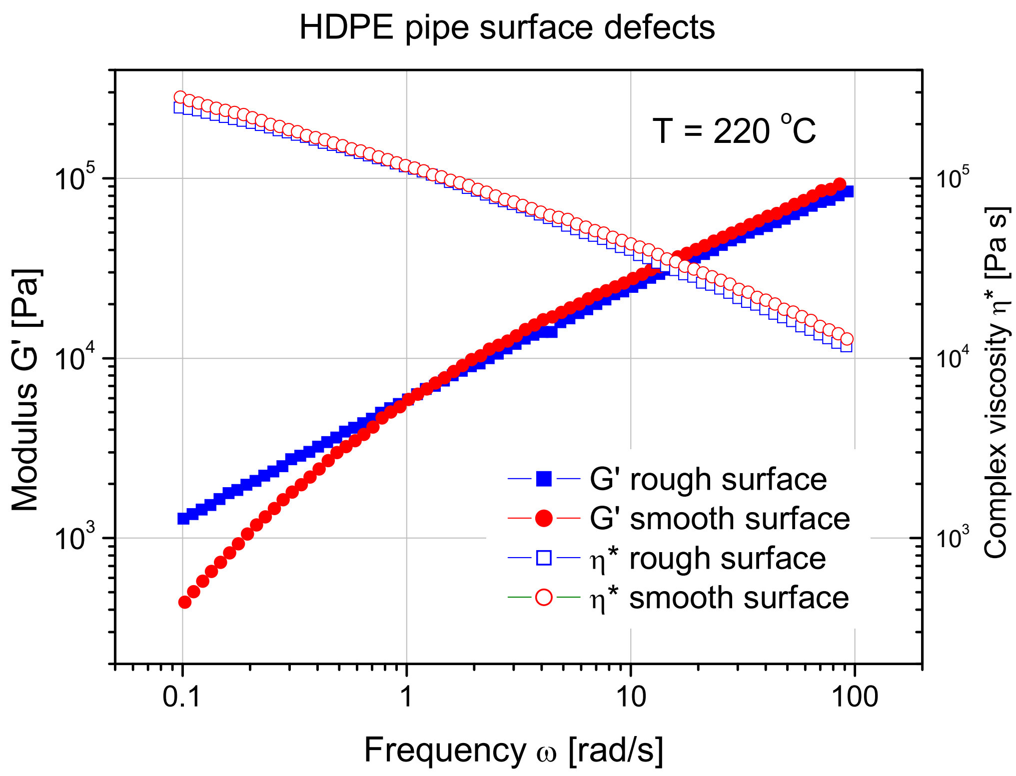
High MW Contributions

400,000 g/mol PS	400,000 g/mol PS + 1% 12,000,000 g/mol	400,000 g/mol PS + 4% 12,000,000 g/mol



Macosko, TA Instruments Users' Meeting, 2015

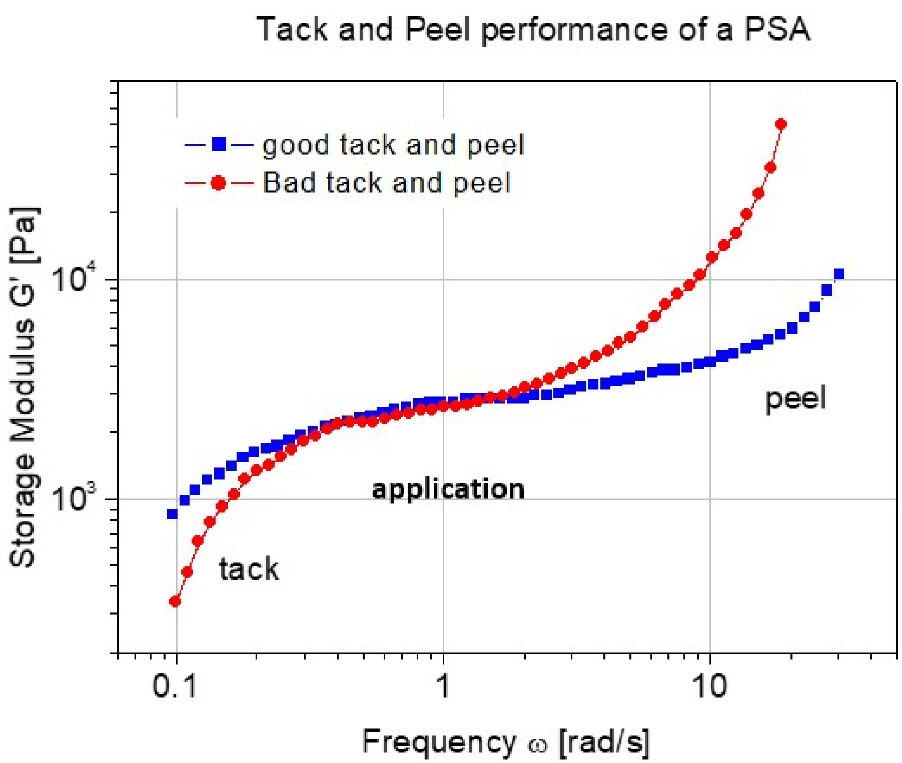
Surface Defects during Pipe Extrusion

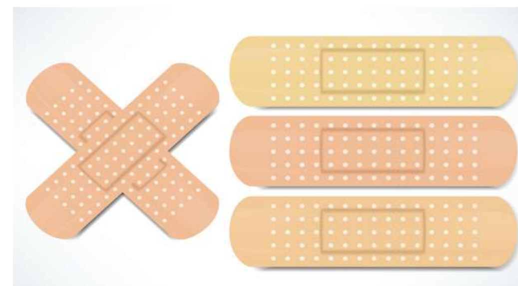


- Surface roughness correlates with G‘ or elasticity → broader MWD or tiny amounts of a high MW component
- Blue-labled sample shows a rough surface after extrusion

Frequency Sweep – Tack and Peel of Adhesives

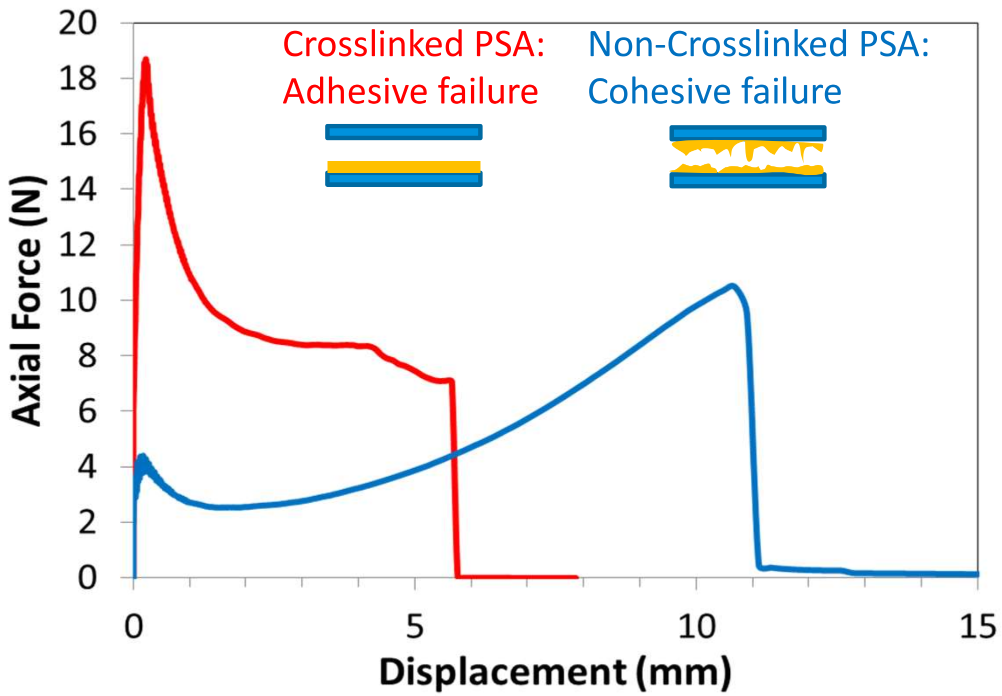
- A dynamic frequency sweep test results can correlate to tack and peel performance
- One single frequency sweep test cannot cover the entire frequency range of interest. Use Time-Temperature Superposition (TTS).

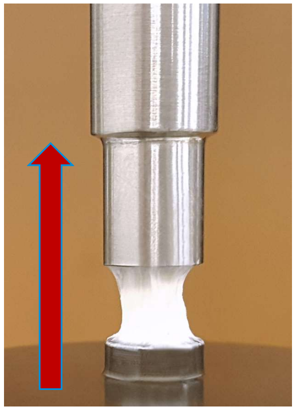




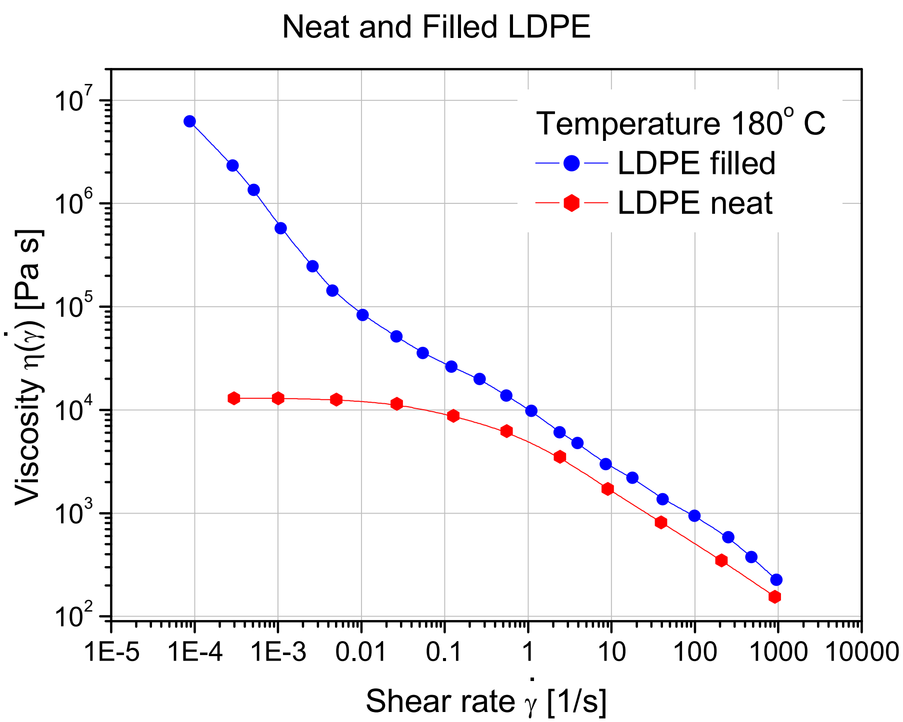
Adhesive Tack Testing

- Tack testing method: ASTM D2979
- Use 8mm parallel plate, axial tensile at 0.1mm/sec
- The maximum force required to pull the plate away is defined as the sample's tackiness.





Effect of Filler on Melt Viscosity

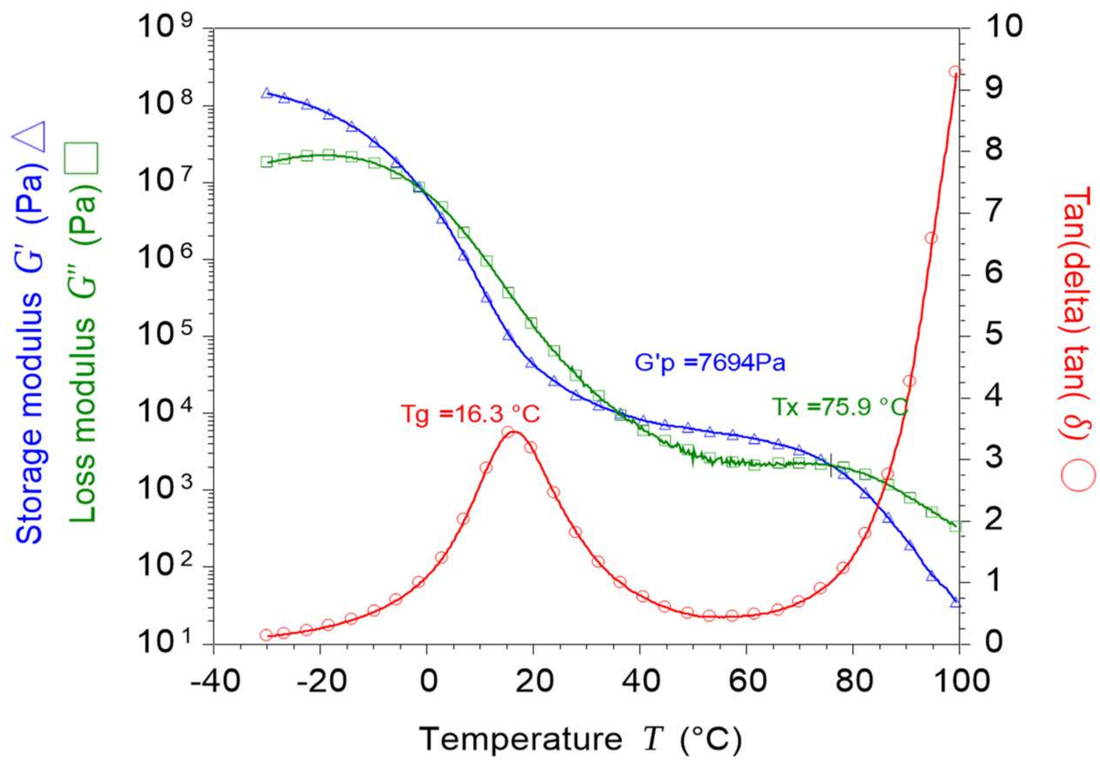


- Fillers increase the melt viscosity
- Due to inter-particle interactions, the non-Newtonian range is extended to low shear rates and the zero shear viscosity increases dramatically

The material has a yield, when rate and viscosity are inverse proportional at low rate.

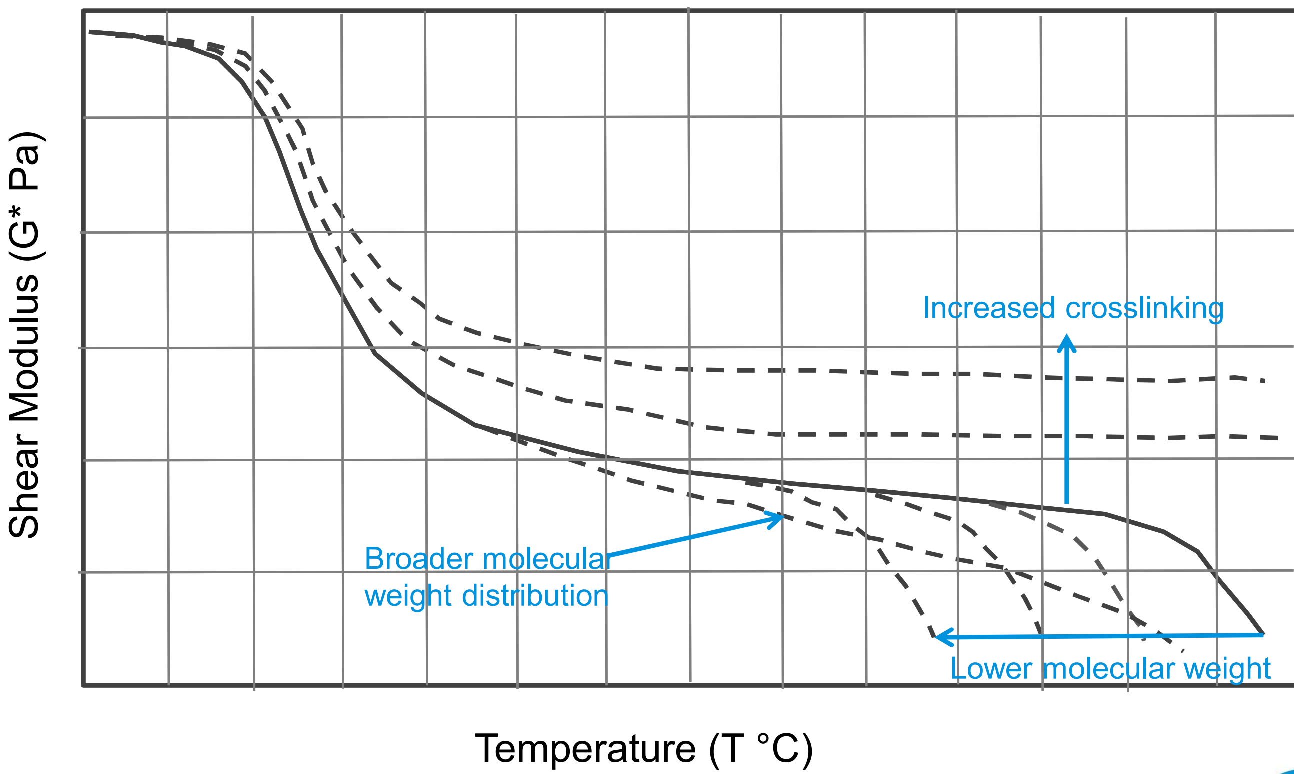
Dynamic Temp Ramp Test on Adhesives

- Most popular test for PSA evaluations
- Results correlate to the PSA performance with temperature



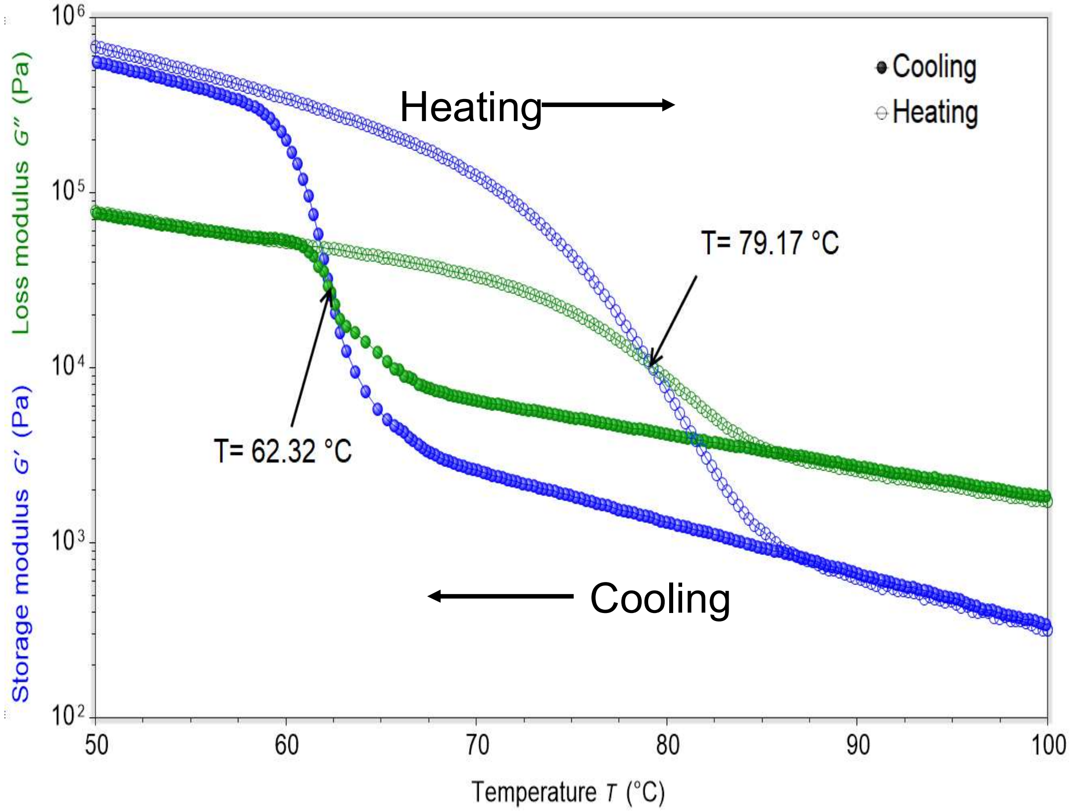
What do We Learn from a Temp Ramp Test?

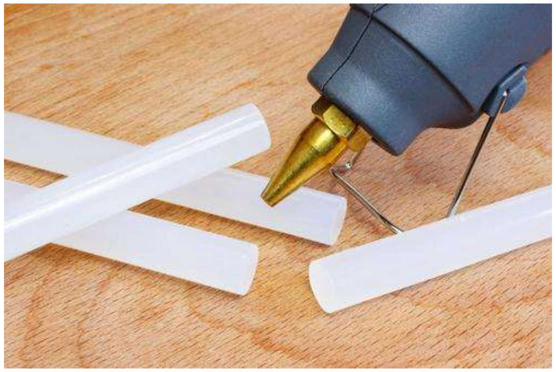
- Correlates with polymer molecular structure:
  Mw, MWD, and crosslinking



Hot Melt Adhesive – Operation Temperature Window

- Operation temperature window: 62°C to 79°C
- Oscillation temperature ramp at 3°C/min

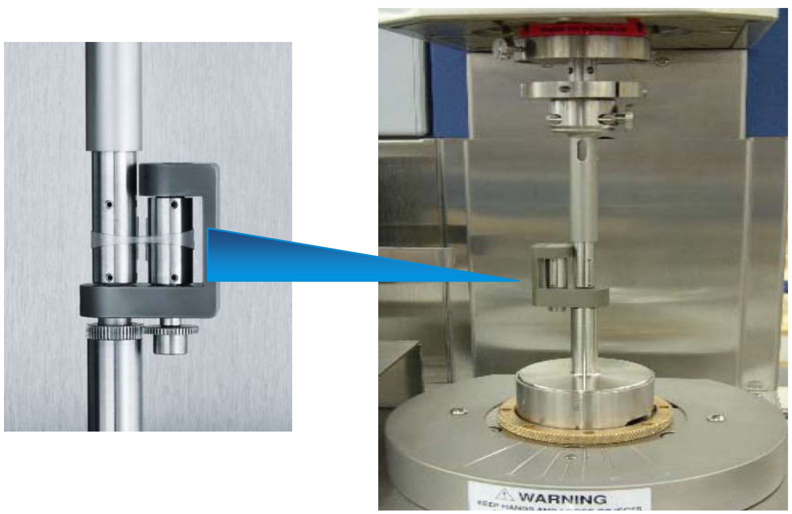




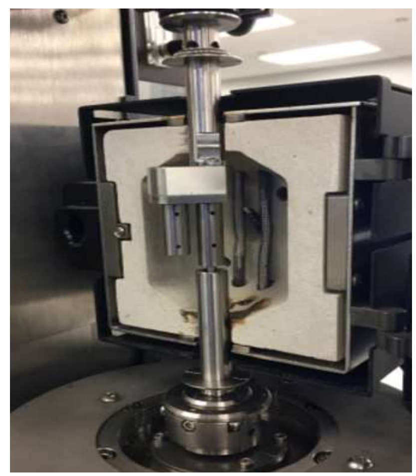
Extensional Viscosity Measurements

- Nonlinear elongation flow is more sensitive for some structure elements (e.g. branching) than shear flows
- Many processing flows are elongation flows. Extensional viscosity measurements can be used to help predict processability

ARES G2 - EVF



ARES G2 - EVA



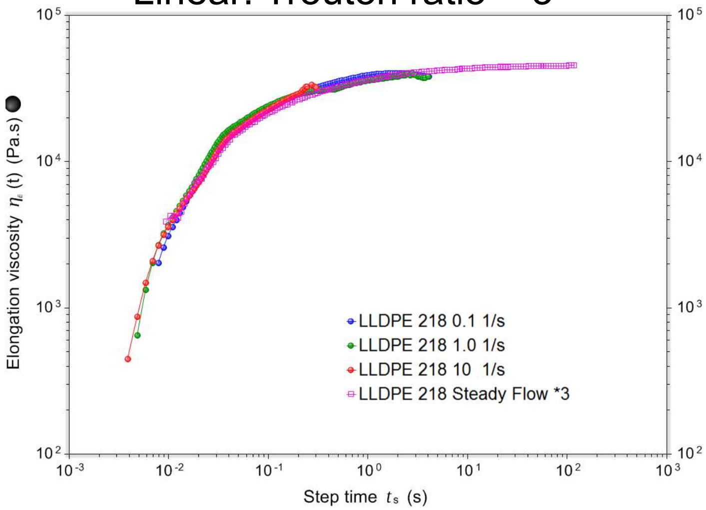
DHR/HR - EVA

Extensional Viscosity

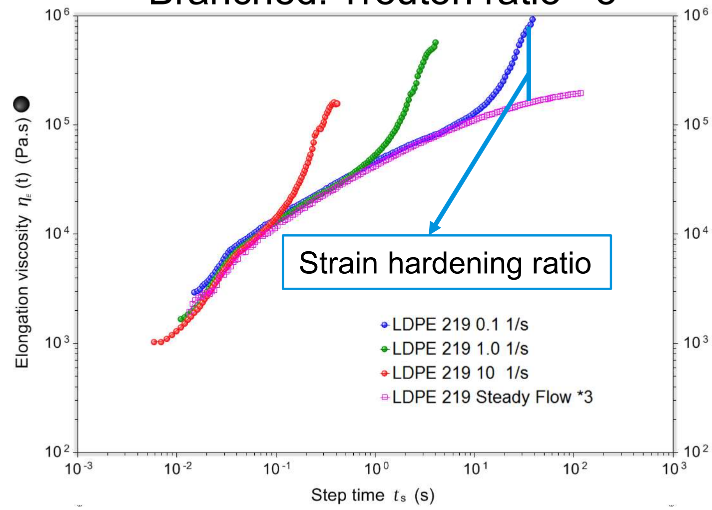
- Extensional rheology is very sensitive to polymer chain entanglement. Therefore it is sensitive to LCB
- The measured extensional viscosity is 3 times the steady shear viscosity
- LCB polymer shows the strain hardening effect – Trouton ratio

$$\text{Trouton Ratio} = \eta_E\,(t, \dot{\varepsilon})\,/\,\eta_0\,(t)$$

Linear: Trouton ratio = 3



Branched: Trouton ratio >3

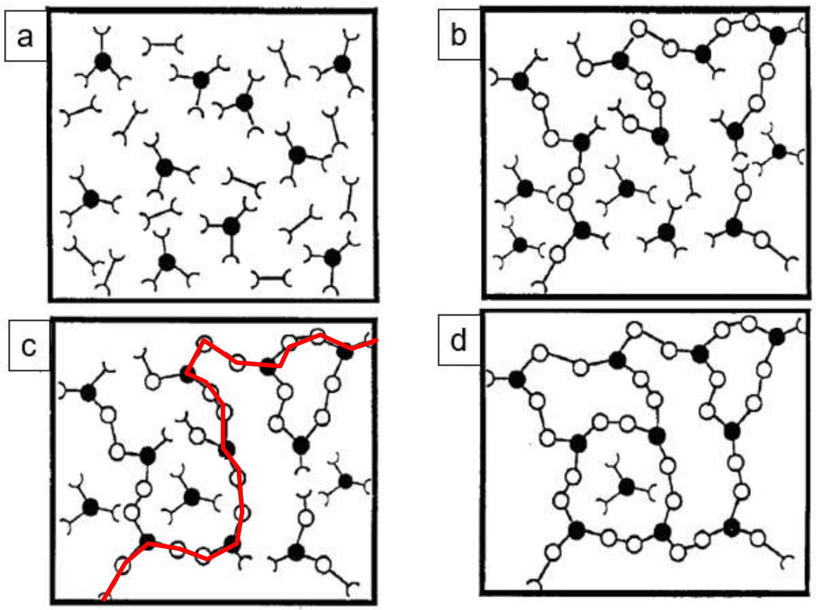


Thermosetting Polymers Analysis

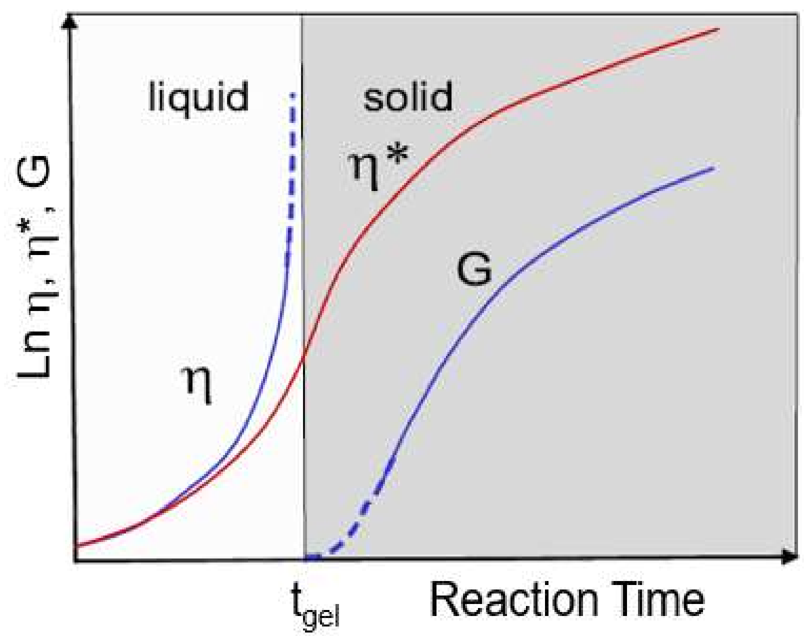
- Monitor the curing process
  - Viscosity change as function of time or temperature
  - Gel time or temperature
- Test methods for monitoring curing
  - Isothermal time sweep
  - Temperature ramp
  - Combination profile to mimic process
- Analyze cured material's mechanical properties (G', G'', $\tan \delta$, T_g etc.)

Thermoset Curing Process

Gelation and Vitrification



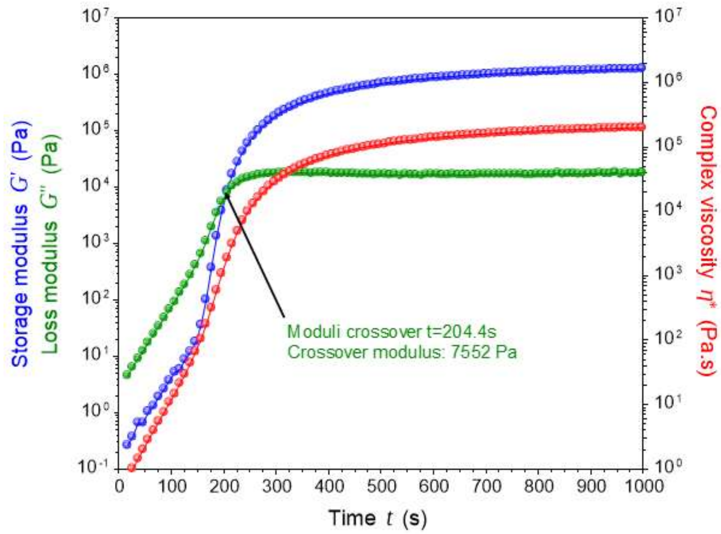
What Rheology Measures



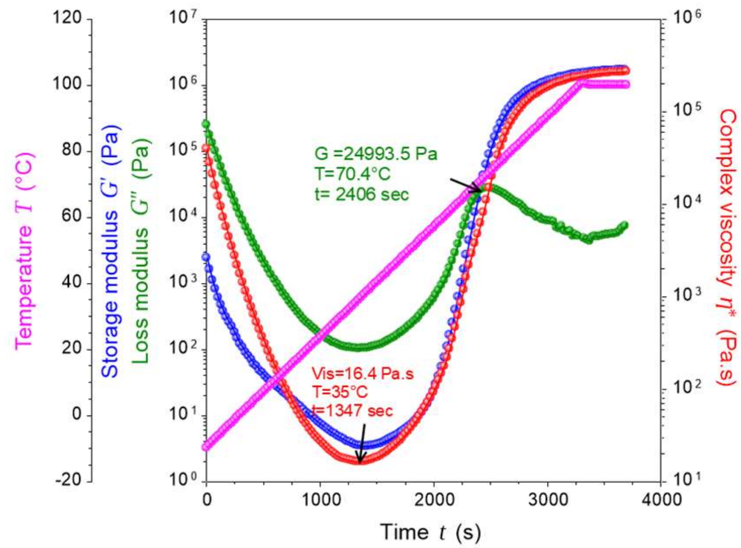
Rheology for Thermoset Characterization

- Measure viscosity change before crosslinking
- Monitor gelation and measure the gel point
- Monitor sample viscoelastic property change (G' and G") during curing
- Evaluate the mechanical properties of the end-use product

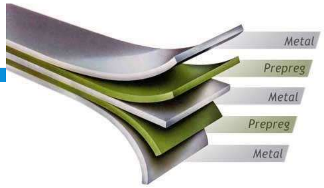
Isothermal Curing



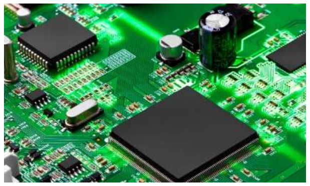
Temperature Ramp Curing



Monitoring Shrinkage

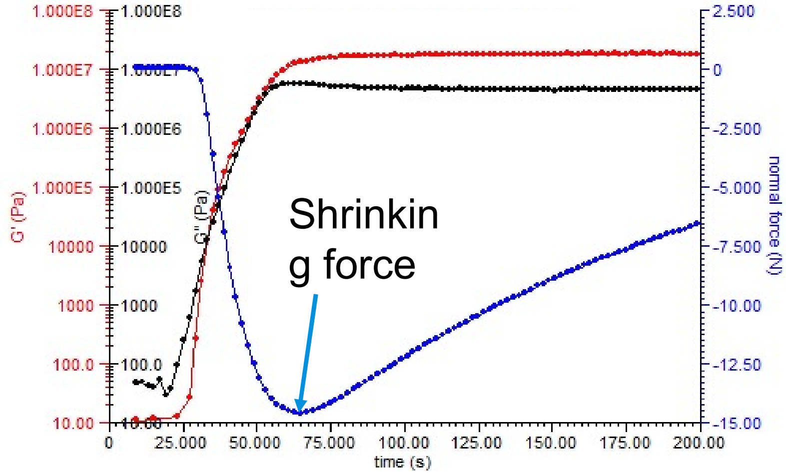


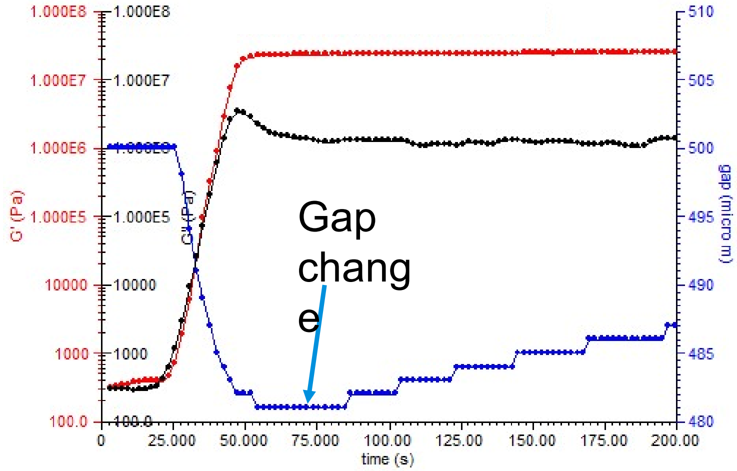
- Thermoset material shrinks during curing
- The amount of shrinkage could cause cracking or failure to the end products

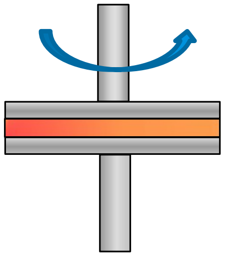


(1) Set Gap Constant
monitor shrinking force

(2) Set Axial Force = 0
monitor dimension(gap) change

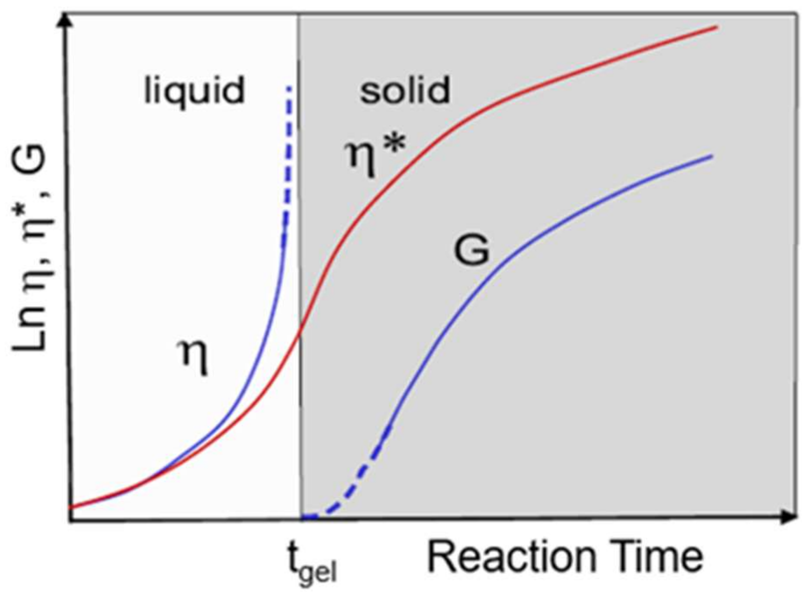






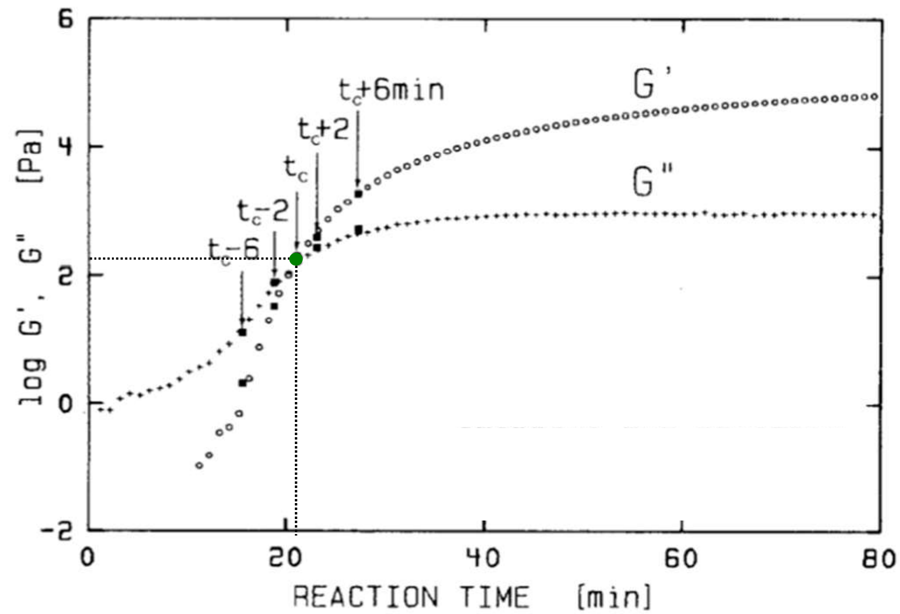
Measure Gel Point

- Viscosity goes to infinity
- System loses solubility
- Molecular weight M_w goes to infinity



Empiricism of Y. M. Tung and P. J. Dynes (1982)

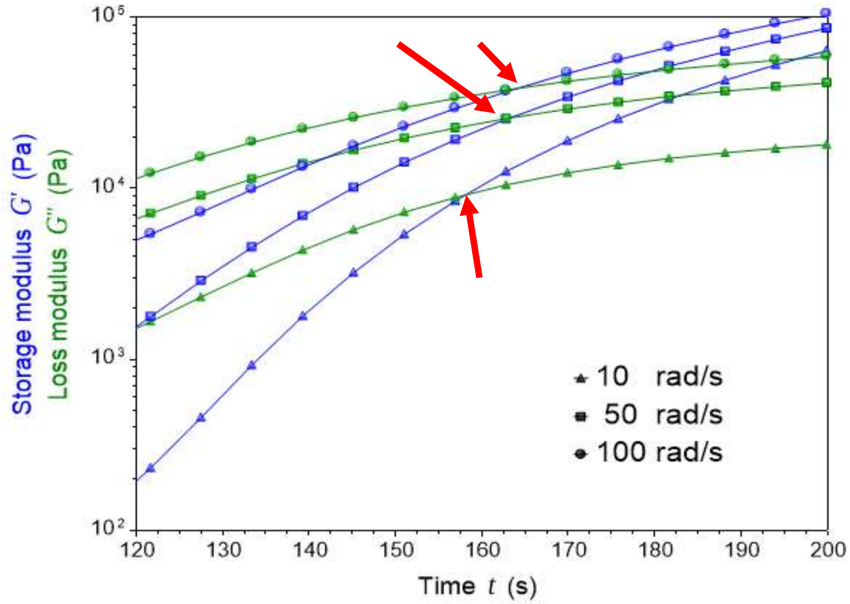
When G’ = G’’ and Tan δ = 1



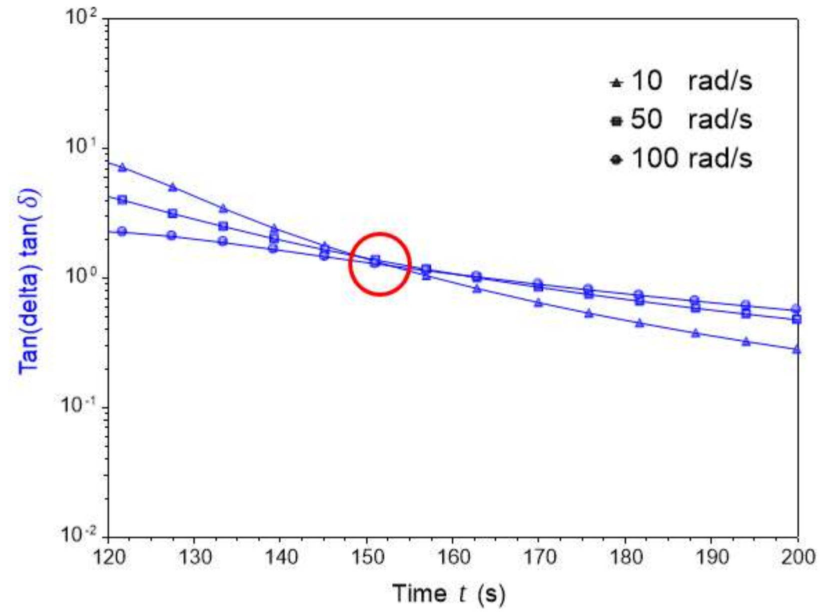
F. Chambon and H. H. Winter (1985)

The "True Gel Point"

G'/G" crossover: frequency dependent



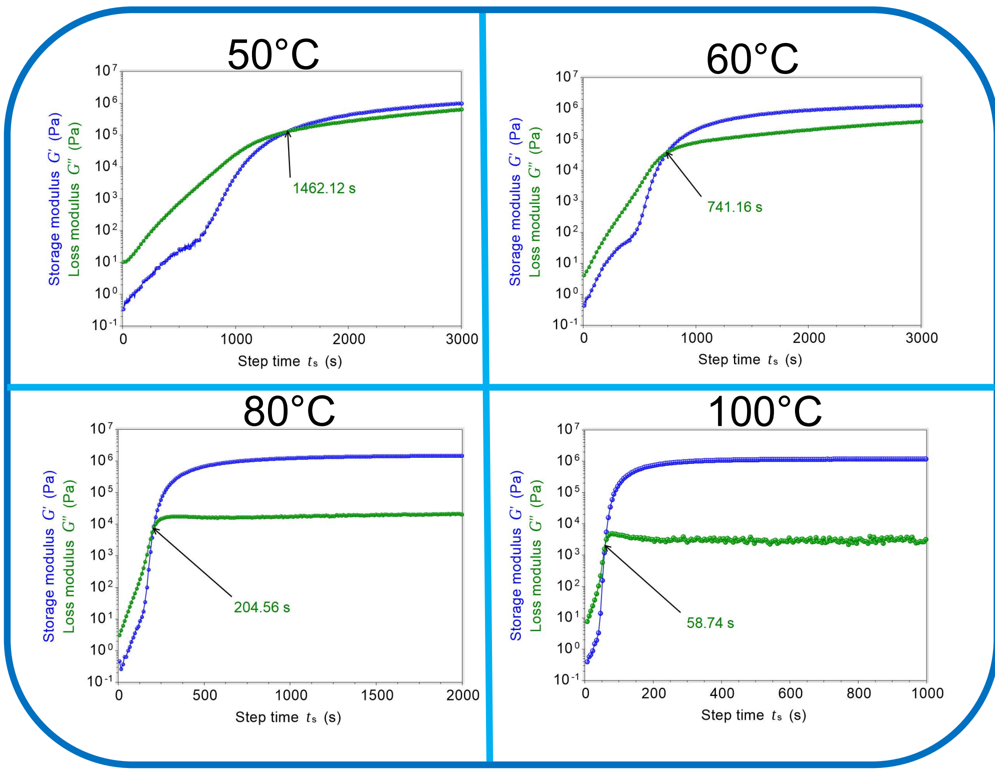
Gel Point: tan δ crossover point



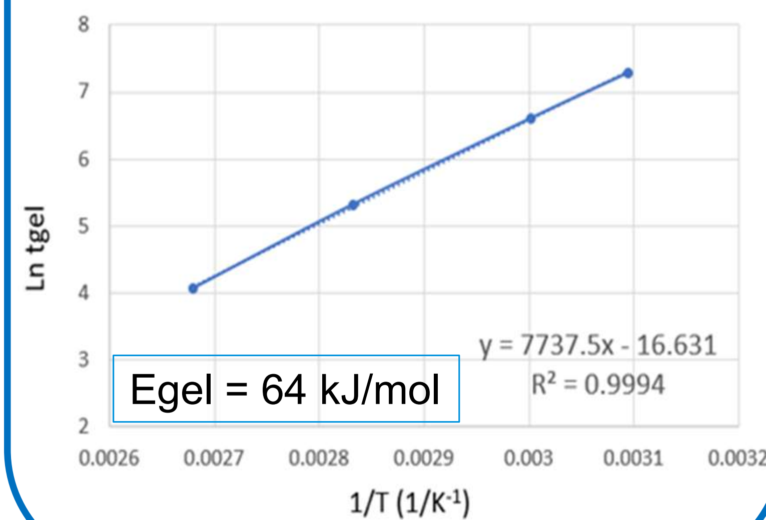
G. Kamykowski; T. Chen, **The Use of Multi-wave Oscillation to Expedite Testing and Provide Key Rheological Information. ANTEC, 2020**

Gelation Kinetics

- The gelation kinetics can be described using the empirical Arrhenius model
- Perform isothermal curing at different temperatures

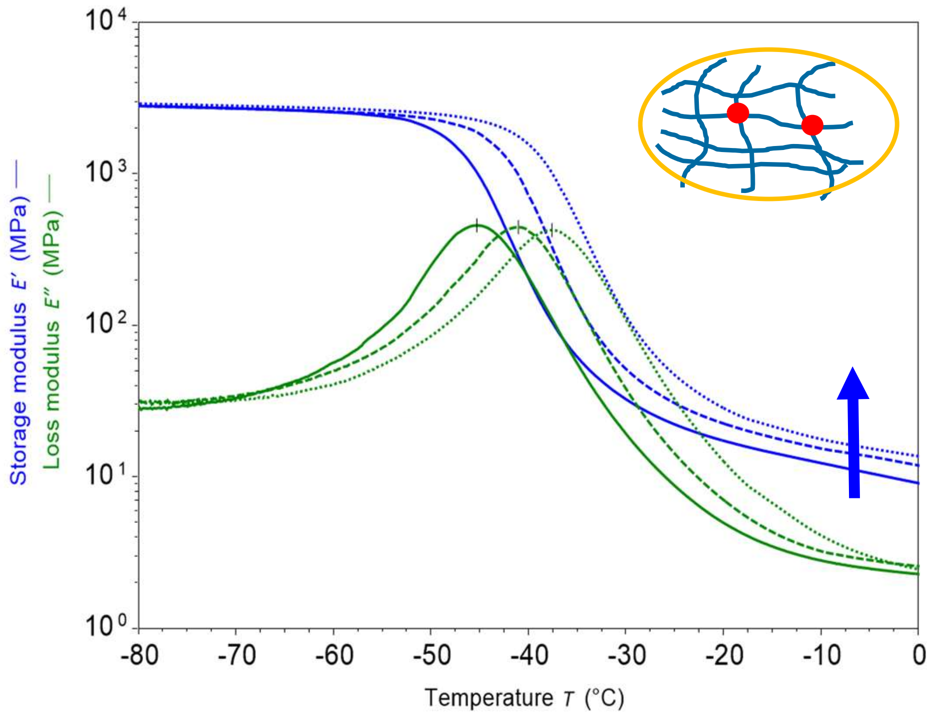


$$t_{gel} = t_{gel}^{\infty} \exp\left(\frac{\Delta Eg}{RT}\right)$$



Quantify Crosslinking Density

- For unfilled polymers, crosslinking density can be quantitatively measured using rheology
- Calculation uses storage modulus in rubber plateau region (G'$_{rubbery}$ or E'$_{rubbery}$)



$$M_c = \frac{3RTd}{E'_{rubbery}} \quad \text{or} \quad M_c = \frac{RTd}{G'_{rubbe}}$$

M_c = Molecular weight between crosslinks
R = Universal gas constant
T = Absolute temperature (K)
d = Polymer density

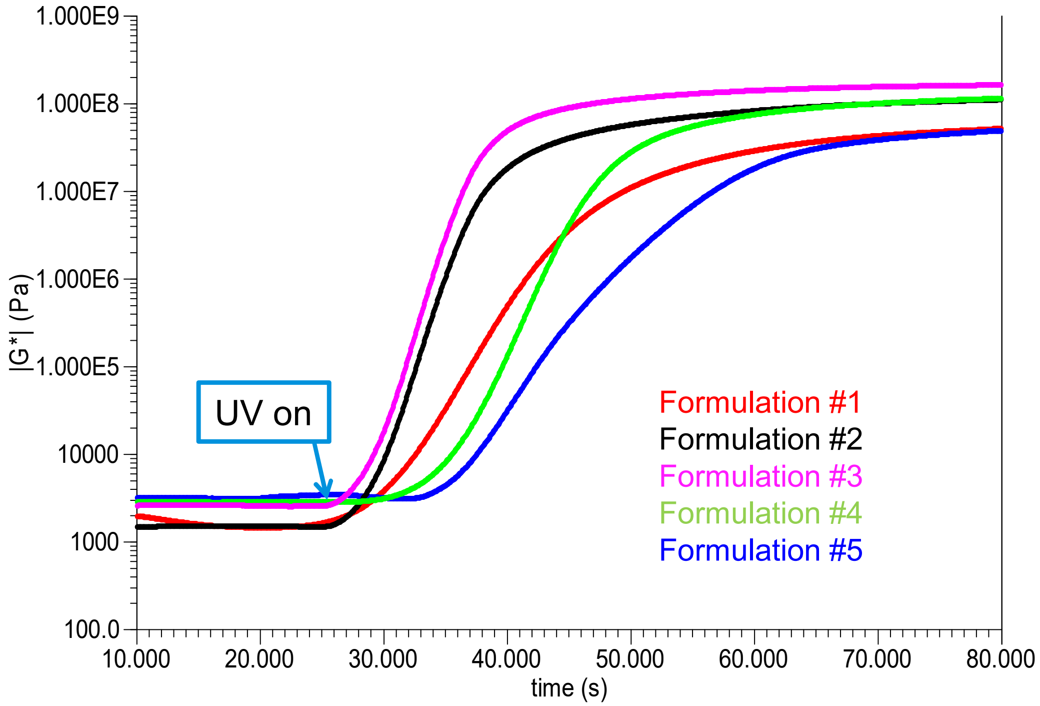
$$Crosslinking\ density, q = \frac{Mw}{Mc}$$

Mw = Molecular weight of the monomer

M. Barszczewska-Rybarak et al; Acta of Bioengineering and Biomechanics, vol 19, 1, 2017.
M. H. Abd-El Salam, J of Applied Polymer Sci, vol 90, 1539-1544, 2003.

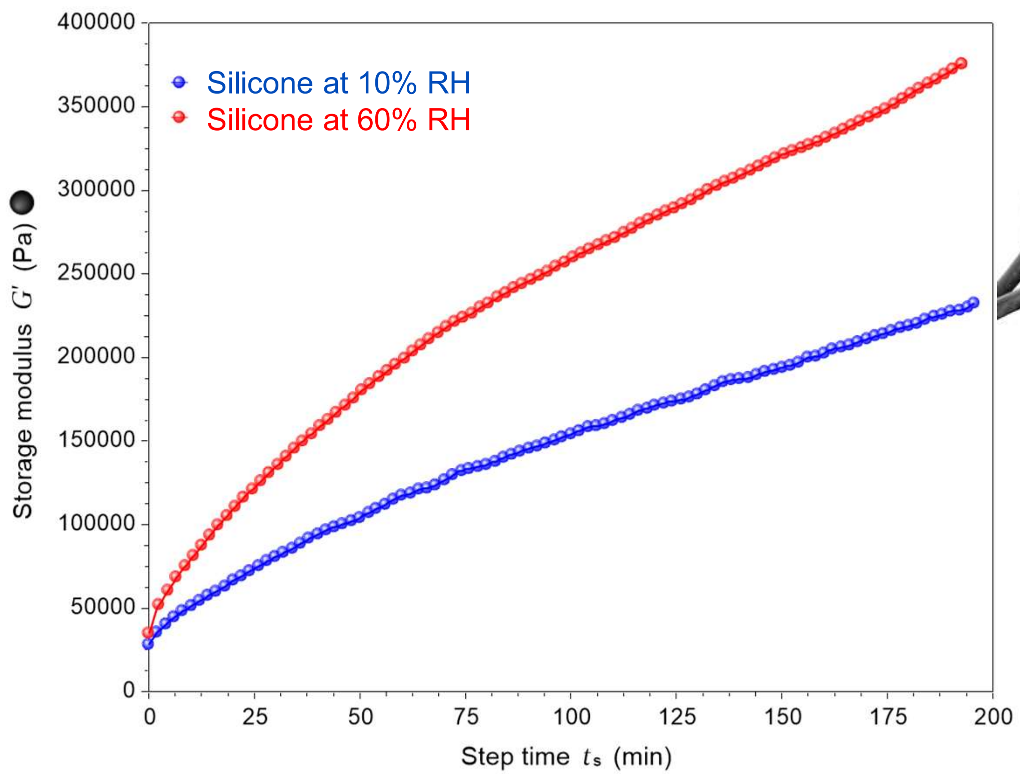
UV Curing

- Monitor UV curing: Dynamic time sweep
- Measure curing time with different formulations, UV intensity and temperature
- Measure cured adhesive modulus



Curing with Controlled Humidity

- Silicone adhesive curing under 25°C and 10%; 60% relative humidity
- Higher humidity, faster curing



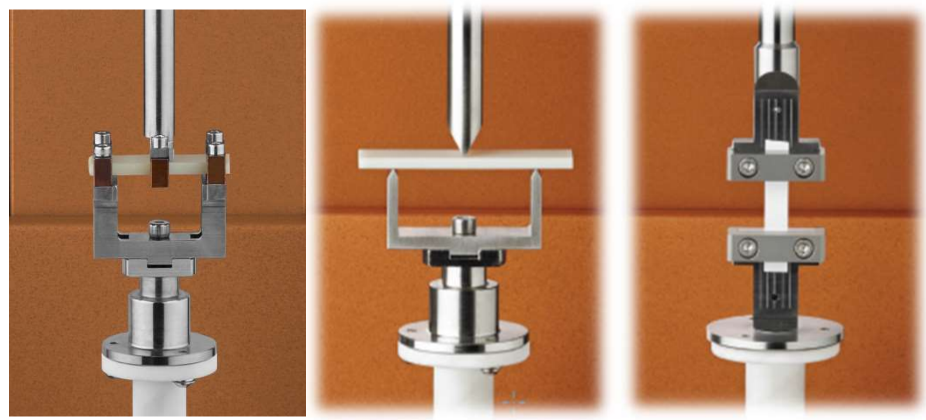
Testing Solids: Torsion and DMA

- Torsion and DMA geometries allow solid samples to be characterized in a temperature controlled environment
  - Torsion measures G', G", and Tan δ
  - DMA measures E', E", and Tan δ
    - DMA mode on ARES G2 (max 50 μm amplitude)
    - DMA mode on DHR (max 100 μm amplitude)

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

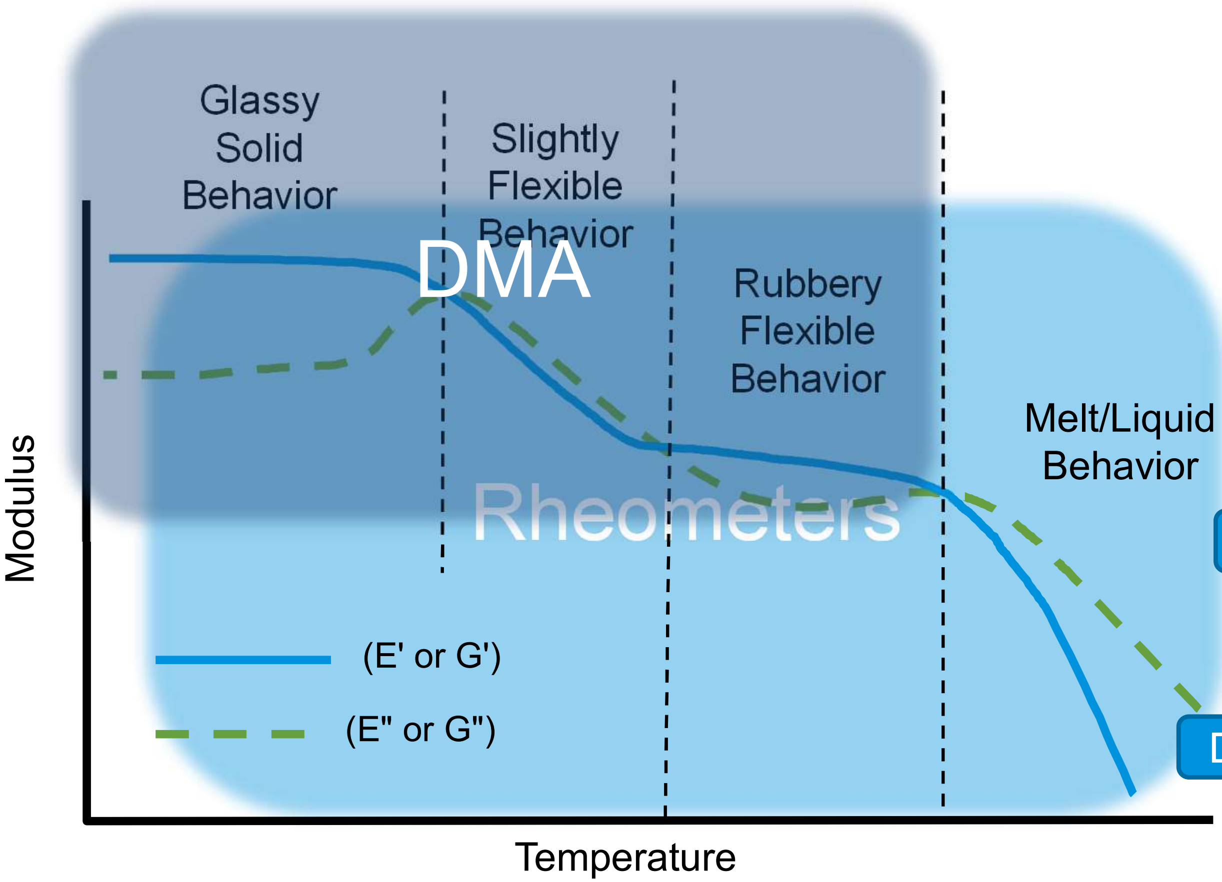
ν : Poisson's ratio

Torsion rectangular and cylindrical clamps

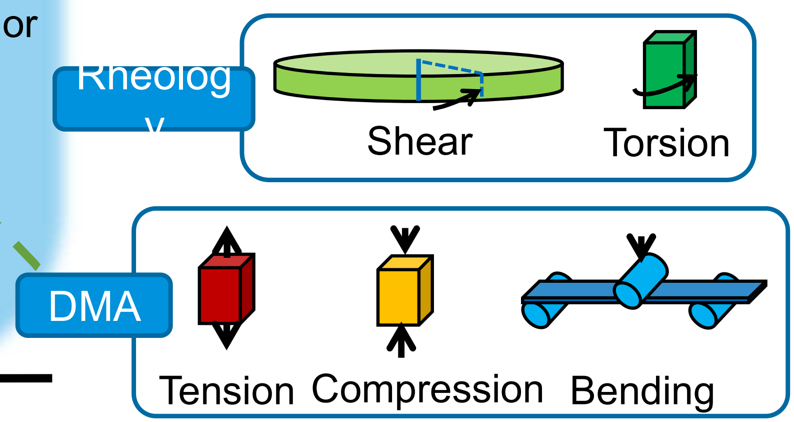


DMA cantilever, 3-point bending and tension clamps

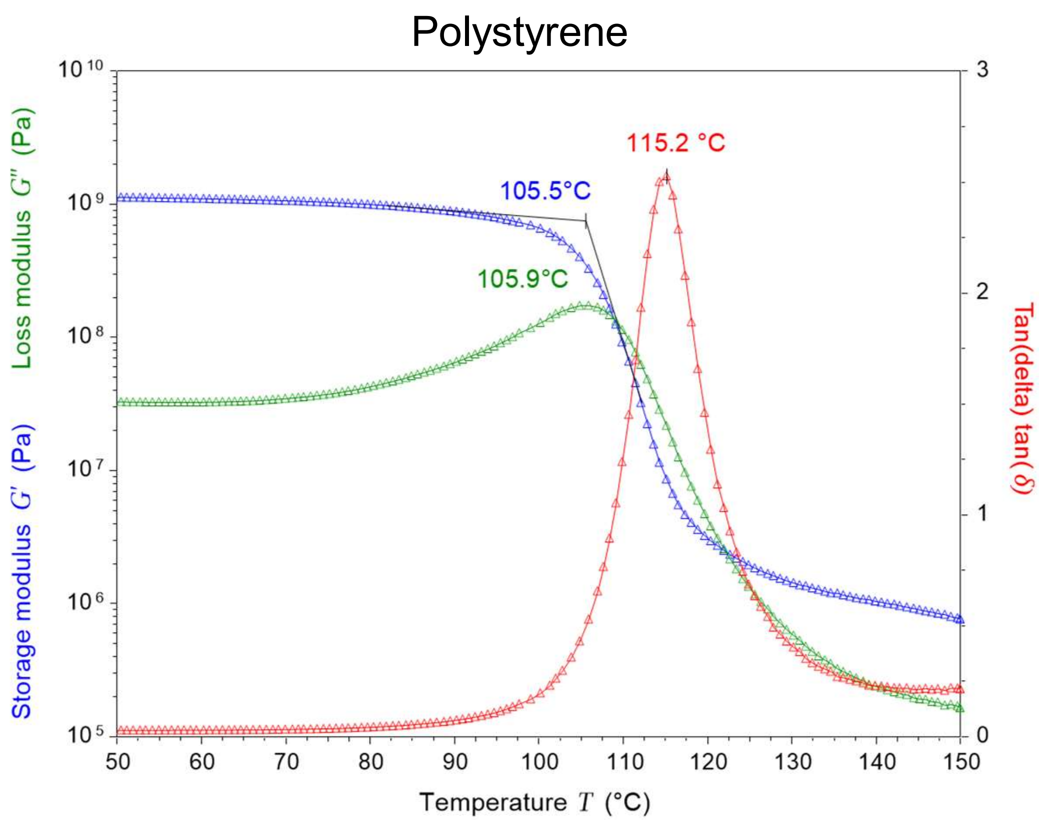
DMA and Rheology Measurement Windows



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



Dynamic Temp Ramp Test – Measure Tg



How to define Tg in a Temp Ramp test:

(1) G' onset - Occurs at lowest temperature

(2) G" peak - Occurs at middle temperature

(3) Tan delta peak - Occurs at highest temperature - used historically in literature

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

The Glass & Secondary Transitions

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

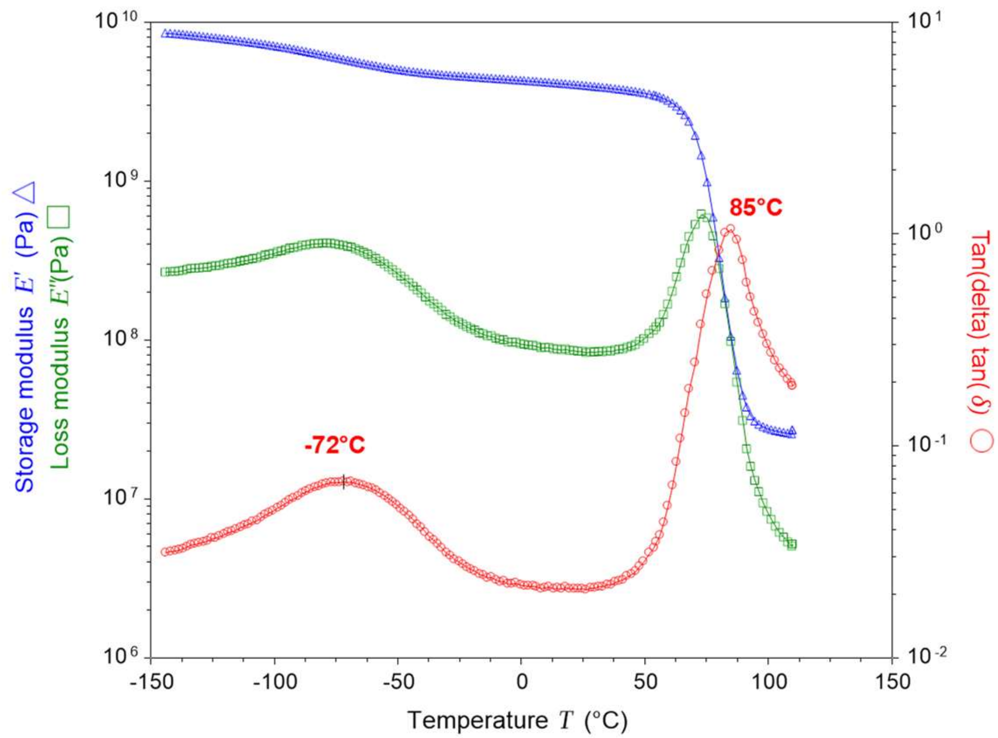
Secondary Transitions

- 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)

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

Rheometers and DMAs are more sensitive to weak amorphous transitions than DSC

PET film: Tested in tension



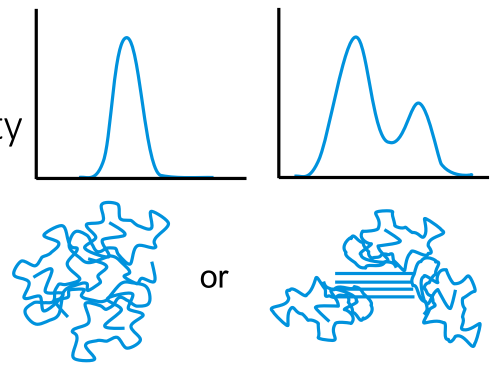
Glass Transition (T_g): Cooperative motion among a **large number** of chain segments

Secondary Transitions (T_β, T_γ): Local or side group motion

DMA is 100-1000× more sensitive than DSC for identifying weak amorphous transitions

Monitor Tg using DMA to study:

- Blend Miscibility
- Crystallinity
- Crosslinking density

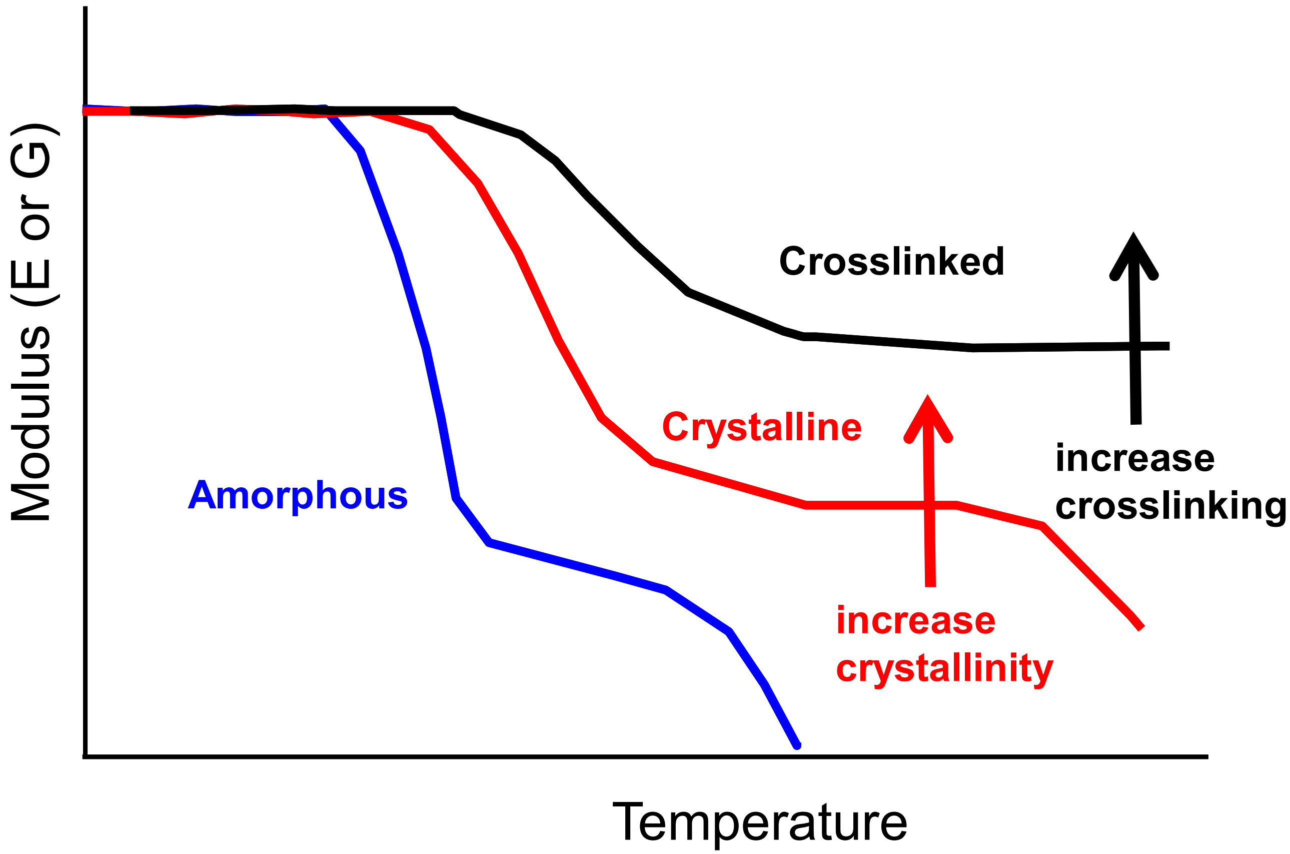


Polymer Structure-Property Characterization

- 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

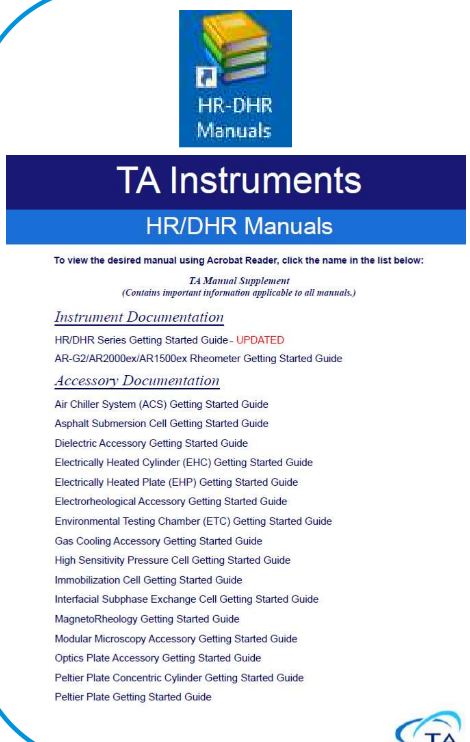
Reference: Turi, Edith, A, Thermal Characterization of Polymeric Materials, Second Edition, Volume I., Academic Press, Brooklyn, New York, P. 489.

Amorphous, Crystalline and Crosslinked Polymers



Where to Find Help

On your desktop



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Instrument Documentation

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AR-G2/AR2000ex/AR1500ex Rheometer Getting Started Guide

Accessory Documentation

Air Chiller System (ACS) Getting Started Guide
Asphalt Submersion Cell Getting Started Guide
Dielectric Accessory Getting Started Guide
Electrically Heated Cylinder (EHC) Getting Started Guide
Electrically Heated Plate (EHP) Getting Started Guide
Electrorheological Accessory Getting Started Guide
Environmental Testing Chamber (ETC) Getting Started Guide
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High Sensitivity Pressure Cell Getting Started Guide
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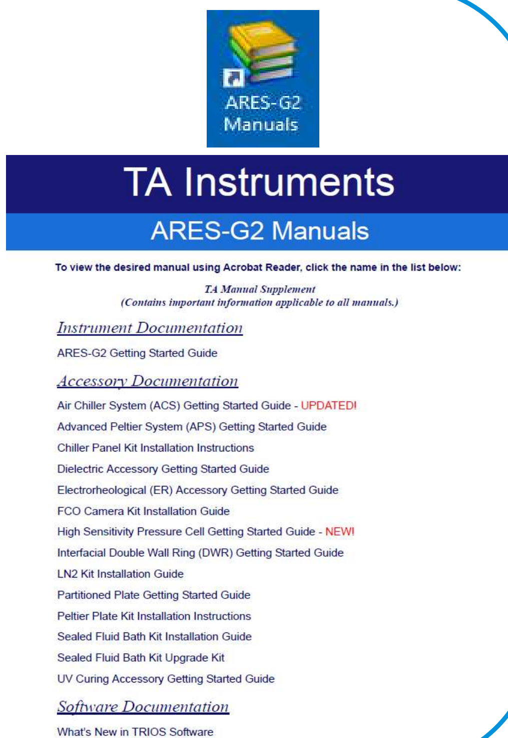
Interfacial Subphase Exchange Cell Getting Started Guide
MagnetoRheology Getting Started Guide
Modular Microscopy Accessory Getting Started Guide
Optics Plate Accessory Getting Started Guide
Peltier Plate Concentric Cylinder Getting Started Guide
Peltier Plate Getting Started Guide



ARES-G2 Manuals

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ARES-G2 Manuals

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(Contains important information applicable to all manuals.)

Instrument Documentation

ARES-G2 Getting Started Guide

Accessory Documentation

Air Chiller System (ACS) Getting Started Guide - UPDATED!
Advanced Peltier System (APS) Getting Started Guide
Chiller Panel Kit Installation Instructions
Dielectric Accessory Getting Started Guide
Electrorheological (ER) Accessory Getting Started Guide
FCO Camera Kit Installation Guide
High Sensitivity Pressure Cell Getting Started Guide - NEW!
Interfacial Double Wall Ring (DWR) Getting Started Guide
LN2 Kit Installation Guide
Partitioned Plate Getting Started Guide
Peltier Plate Kit Installation Instructions
Sealed Fluid Bath Kit Installation Guide
Sealed Fluid Bath Kit Upgrade Kit
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ARES G2

Discovery HR

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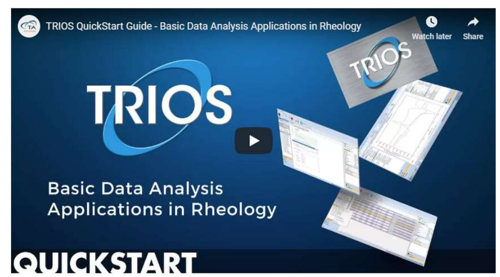

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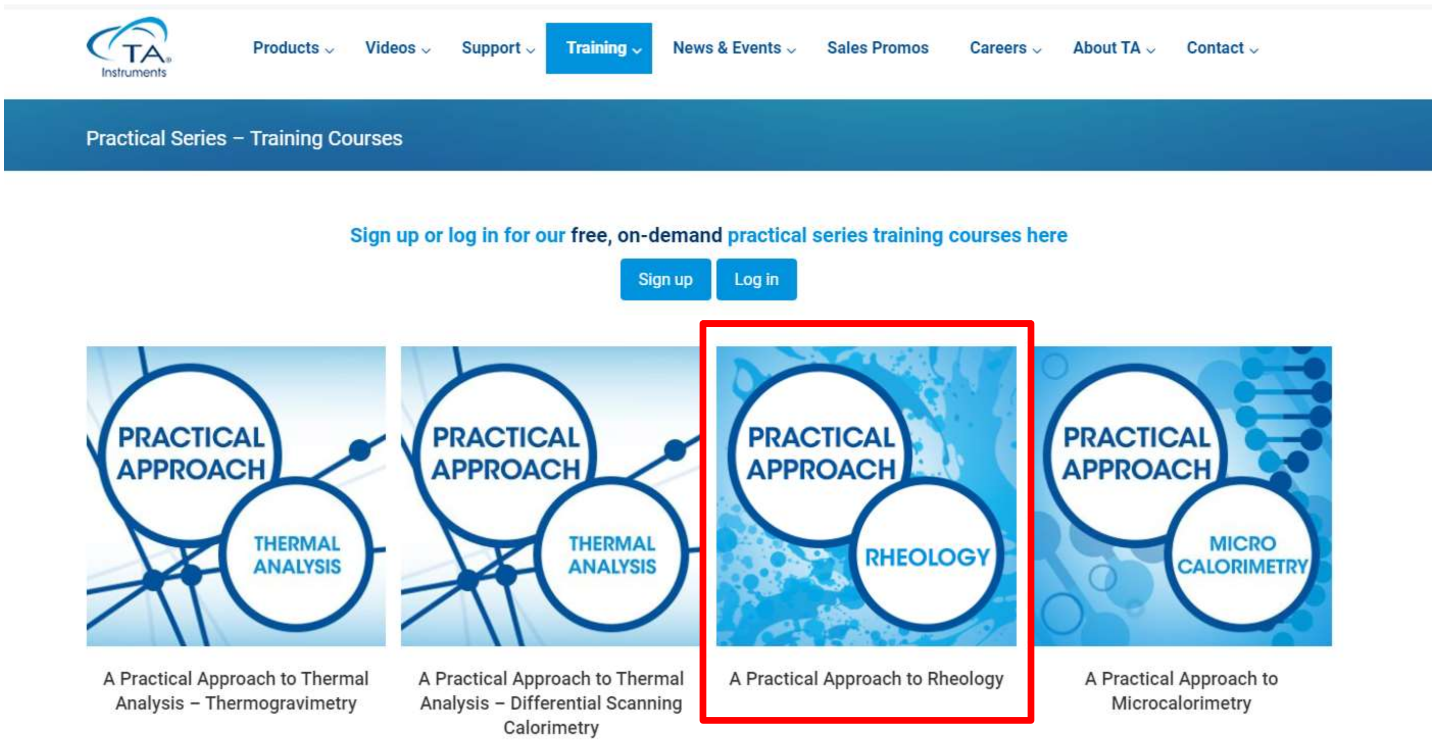

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Extensional Rheology in Polymer Processing

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Rheo-Microscopy: Bridging Rheology, Microstructure & Dynamics

Extensional Rheology & Analytics of Material Characterization

TA Website – Other Resources

Tech Tips


Installation & Calibration of the Relative Humidity Accessory for the Discovery Hybrid Rheometer


Shear Sandwich Clamp Installation & Calibration for the Discovery DMA 850


Three Point Bend Clamp Installation & Calibration for the DMA850

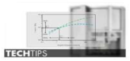

Installation and Calibration for the UV Accessory on the Ares G2 Rheometer


Single Cantilever Installation & Calibration – DMA 850


Dual Cantilever Installation & Calibration – DMA 850

Linear Film Tension Clamp for DMA using the ARES-G2

Loading the Powder Clamp on the Q800 DMA with 35mm Dual Cantilever Clamp



Frequency Sweep Tests for RPA Flex and RPA Elite

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Applications Notes Library

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rheology

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Tianhong (Terri) Chen, Ph.D.

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Jason Saienga, Ph.D.

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Justin Wynn

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