TA Instruments Rheometers

The TA Instruments Rheometer

Sensitive, Accurate, Rugged, and Reliable, these words describe a TA Instruments rheometer. Our exciting new rheometers are fifth generation products from the pioneer of controlled stress rheology. Designed with the customer in mind, and backed by the superior customer support, which is the hallmark of TA Instruments, these rheometers have set a new standard for performance.

*The **AR 2000** is the world's most advanced rheometer. Its innovative **Mobius Drive**™ offers unprecedented controlled strain and controlled stress performance. The AR 2000's unique features are its broad torque range, superior strain resolution, wide frequency range, and ingenious convenience features, like the **Smart Swap**™ interchangeable temperature control options. It is well equipped to handle the most demanding rheological applications.*

*The **AR 1000** is a research grade rheometer incorporating a unique motor design, and advanced material air bearing. It has excellent torque performance, very low inertia, and easily outperforms competitive research grade systems. The AR 1000 can be equipped with multiple temperature control options, normal force sensor, and custom geometries.*

*The **AR 500** is a general purpose rheometer with many of the features of our research grade systems. The AR 500 is an upgradeable system that can grow as your applications expand. It is the ideal rheology system for users interested in a robust, cost-effective system with outstanding basic performance.*

*Are you ready to transfer rheological tests from the lab to manufacturing facilities, or quality control labs ? Based on the successful AR 500, the **QCR II** is a robust rheometer that easily automates the analysis of a broad range of samples.*

Technical Specifications

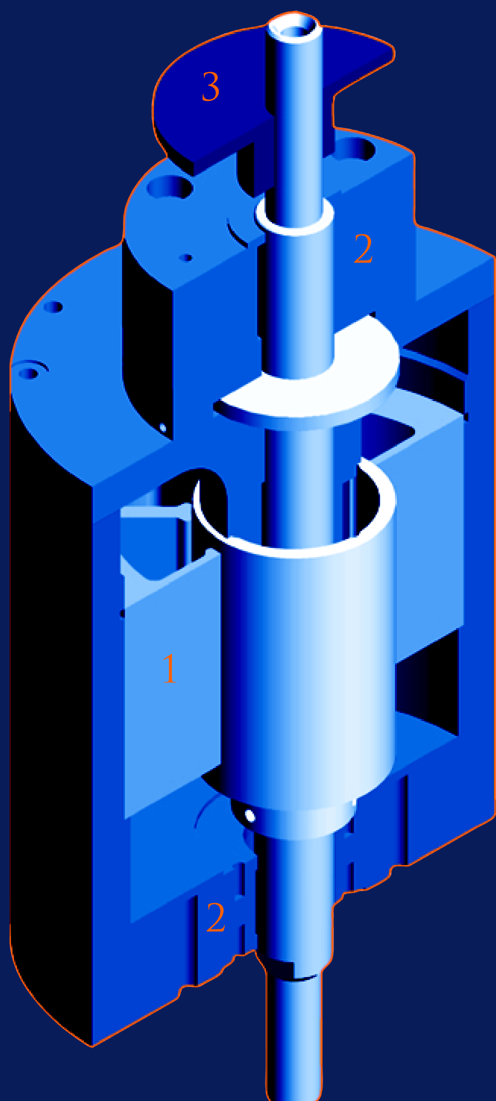
	AR 2000
Minimum Torque	0.1 µN.m
Maximum Torque	200 mN.m
Motor Inertia	15 µN.m.s^2
Angular Velocity Range	1 E-8 - 300 rad/s
Mobius Drive™	Standard
Frequency Range	1.2E-7 - 100 Hz
Displacement Resolution	0.04 µrad
Air Bearing	Porous Carbon
Auto Gap Set	Standard
Gap Resolution	0.06 µm
Normal Force Range	0.01 to 50 N
Temperature Control Options	
Peltier Plate	-20 to 200°C (2)
Environmental Test Chamber	-150 to 600°C
Concentric Cylinder-Peltier Control	-10 to 150°C
Extended Temperature Module	Not Available
Concentric Cylinder-with Circulator	Not Available
Advanced Features	
Smart Swap™ System	Standard

AR 1000	AR 500 / QCR
0.1 µN.m	1.0 µN.m
100 mN.m	50 mN.m
14 µN.m.s^2	26 µN.m.s^2
1 E-8 - 100 rad/s	1 E-8 - 100 rad/s
Not Available	Not Available
1 E-4 - 100 Hz	1 E-4 - 40 Hz
0.62 µrad	0.62 µrad
Porous Carbon	Jet
Standard	Standard
0.06 µm	0.06 µm
0.01 to 50 N	0.01 to 50 N
-10 to 100°C [1,2]	-10 to 100°C [1,2]
-150 to 400°C	-150 to 400°C
Not Available	Not Available
-100 to 400°C	-100 to 400°C
-20 to 150°C	-20 to 150°C
Not Available	Not Available

[1]Extended Peltier available with temperature range -20 to 180°C.
[2]Lower temperature can be reduced to -40°C by use of a suitable fluid in the external circulator.

Instrument Design Features and Benefits

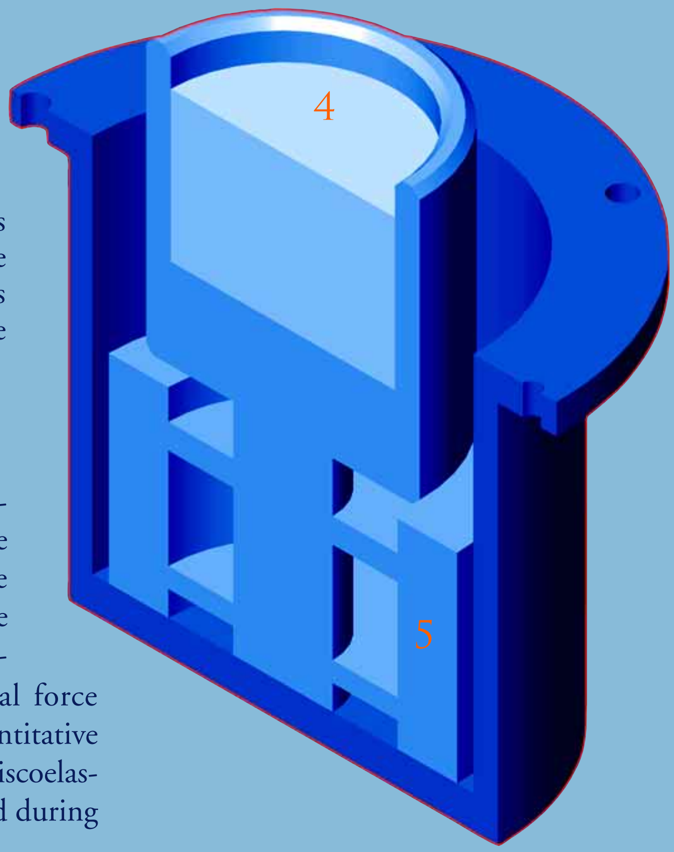
A Rheometer is only as good as its ability to apply torque and measure displacement. Our engineers use custom-designed components and proprietary materials (described below) to achieve unequalled stress and strain performance.



1. Drive Motor Non-contact, with an excellent torque to inertia ratio, and no overheating problems, the Mobius Drive™ motor provides torque over a very wide range. Our engineers used finite element analysis of the high efficiency AR 1000 motor to optimize the performance, torque range, and very low inertia of the AR 2000 motor. ***Benefits:*** A wide variety of materials can be studied from very low viscosity materials to polymer melts and solids.

2. Air Bearing TA Instruments' unique, custom-designed, air bearings provide frictionless support for the drive shaft and measuring geometry. Our long-life jet bearings (AR 500) and porous carbon bearings (AR 2000/1000) provide low levels of residual torque. *Rotational Mapping* automatically corrects for residual torque in the system. The ultra-stiff air bearing on the AR 2000 prevents measurement errors due to axial forces. ***Benefits:*** TA bearings provide excellent torque resolution, and allow the application of a wide range of torque (stress). The porous carbon air bearing on the AR 2000/1000 extends the low torque performance of the instrument.

3. Optical Encoder Measures angular deflection with high resolution. ***Benefit:*** Sample measurements can be conducted at low shear rates, small displacements (strain), and high velocities.



4. Smart Swap™ This unique magnetic device is the location point for all AR 2000 temperature control options. ***Benefit:*** The Smart Swap base allows rapid exchange of temperature options while maintaining precise location.

5. Normal Force Transducer This highly sensitive, ultra-stiff transducer located below the sample plate provides a direct measure of a wide range of normal forces exerted by samples, without a change in gap. The performance, fast response, and temperature isolation found in the AR 1000/500 normal force sensors are improved in the AR 2000. ***Benefits:*** Quantitative normal forces exhibited by materials with different viscoelastic properties are measured. Normal forces generated during sample loading can be monitored.

•Linear Ball Slide Mounts the motor and air bearing to the casting. The high precision slide is driven vertically by a motor in the base. A second optical encoder is located in the base to measure the movement of the slide. ***Benefits:*** Precise geometry location relative to the sample is assured. The long travel permitted by the ball slide allows for a large working space to simplify sample loading and cleaning.

•Auto Gap Set The software provides automatic setting of gap, and programmed gap closure via several methods (linear, exponential). *Thermal Gap Compensation* automatically corrects for any change in sample gap due to thermal expansion. ***Benefits:*** Automatic and reproducible setting of the sample gap ensures accuracy and reproducibility. By monitoring the normal force exerted by the sample during closure, delicate material structures are protected rather than destroyed prior to the experiment.

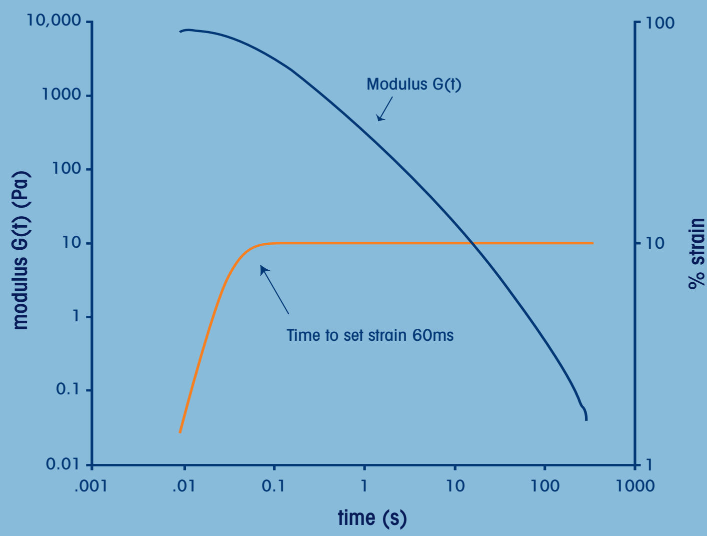
•Rigid One-Piece Aluminum Casting The key components of the rheometer are mounted in this stiff high mass casting. ***Benefit:*** Low system compliance with high mechanical integrity.

Mobius *drive*

Traditionally there are two approaches to characterizing materials using rheometers. The controlled stress approach applies a torque (stress) to the sample and measures the resultant strain. The controlled strain approach applies a strain to the sample and measures the resultant stress. While results from each type of experiment are often identical, there are some material properties best measured in one mode or the other. Until today, this often required two different instruments, or a compromise in the materials and properties that could be evaluated.

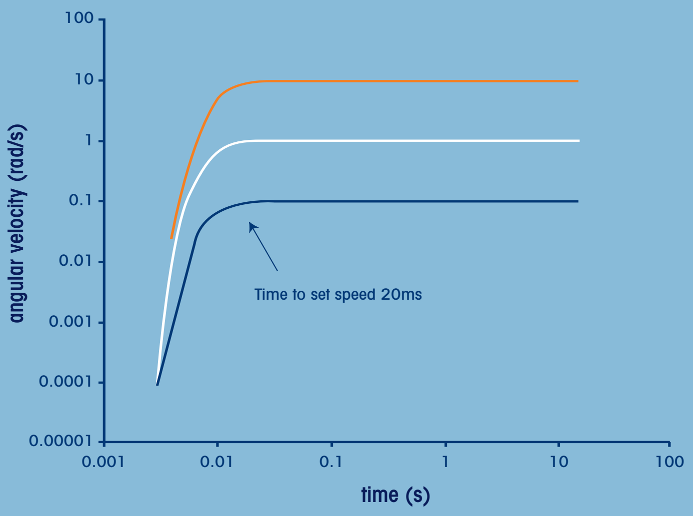
The new **Mobius Drive**™ solves this dilemma by providing superior controlled stress and controlled rate performance in one instrument. Named after August Ferdinand Möbius, a 19th century German mathematician, a Möbius strip can be made by joining together two ends of a strip, after twisting one end. The result is a loop that, instead of having two sides, has only one. The Mobius Drive is so named because it takes the two classical "sides" of rheology (controlled stress and controlled strain) and combines them into a single seamless whole. Made possible by its low inertia motor and air bearing coupled with a 2,000,000 to 1 torque range, and high-speed electronics, the AR 2000 rheometer automatically engages the Mobius Drive as required by experimental conditions. Rheologists no longer have to buy two instruments, or choose one optimized for one approach or another.

Figure 1.
Stress Relaxation



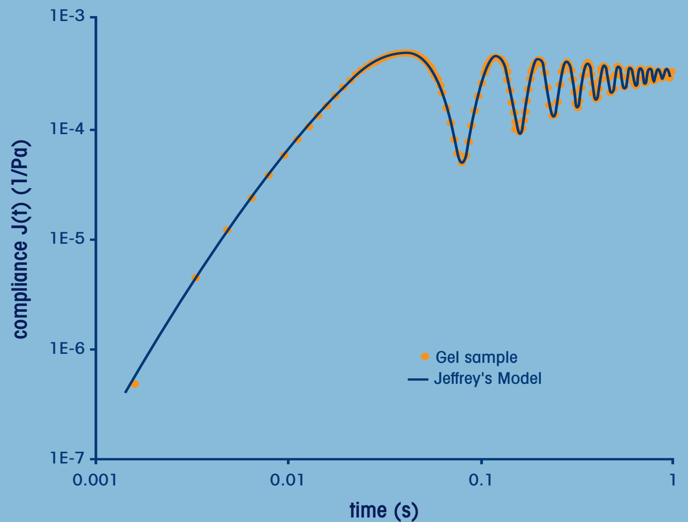
The ability to perform stress relaxation experiments has long been synonymous with controlled strain rheometers. However, with limited torque range transducers the measured data can quickly disappear into the noise. With its 2,000,000 to 1 torque range the AR 2000 with Mobius Drive™ actually improves upon data from dedicated controlled strain rheometers by reaching the set strain in a comparable time and extending the G(t) data well past the time where traditional controlled strain rheometer data would have become too noisy for accurate measurements (figure 1).

Figure 2.
Step Speed



Rapid step changes in shear rate (angular velocity) to model thixotropic behavior and to control the shear rate through a ramp are experiments also generally associated with controlled strain rheometers. The AR 2000 with Mobius Drive easily performs these tests, with the time taken to make a step change in speed comparable to that from a dedicated controlled strain rheometer (figure 2).

Figure 3.
Creep Ringing



The implementation of the Mobius Drive has not compromised the controlled stress performance of the AR 2000. Creep (step stress) data can be acquired as quickly as a point every millisecond. This can reveal interesting short timescale properties and materials such as gels and emulsions can show 'ringing' behavior (figure 3) that can be modeled to derive viscoelastic parameters from less than 1 second of data.

AR 2000 Temperature Control Options

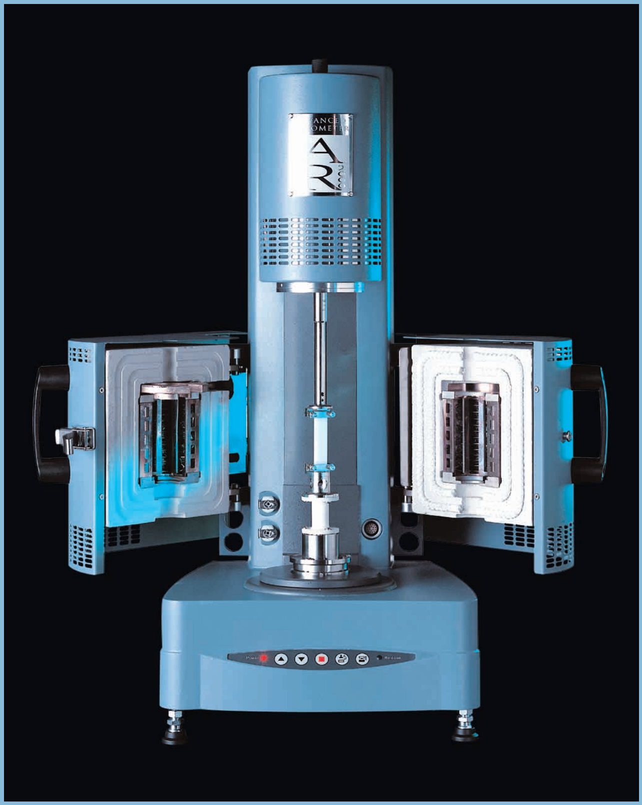
Smart Swap™

Our new "Smart Swap" technology allows an AR 2000 user to interchange temperature control systems and be operational much quicker than ever before. The intelligent firmware automatically senses the type of temperature system present, configures the software accordingly, and loads all relevant calibration data. Disconnecting an existing system is a simple push button release on the rheometer front panel. Smart Swap technology ensures an error-free installation every time. This feature is available only for the new AR 2000 Advanced Rheometer.

Peltier Plate

The Peltier Plate, with Smart Swap technology, is the common temperature control system for the AR 2000. Operational from –20 to 200°C, it provides a temperature accuracy of +/- 0.1°C and a typical heating rate of 20°C per minute.

The Peltier Plate is the rheologist's choice for most fluid applications. It is ideally configured for parallel plate or cone and plate use, since the narrow gaps used permit rapid conduction of heat to the sample. The open design of the Peltier Plate also facilitates easy sample loading and cleaning of the durable hard chrome surface. A Pt 100 sensor positioned at the center of the sample plate ensures accurate measurement and control of sample temperature. With Smart Swap technology the AR 2000 Peltier Plate is user replaceable.



Environmental Test Chamber

The ETC connects easily to the AR 2000 and provides controlled convection / radiant heating and cooling (LN_2) over the extended temperature range of –150 to 600°C, with heating rates up to 15°C per minute. The ETC is ideal for the analysis of polymer melts using cone and plate and parallel plate measuring geometries, and for curing studies of thermosetting resins using disposable plates. It is also commonly used to analyze solids in torsion and can accommodate standard samples specified in ASTM D4065 Test Method. Smart Swap™ technology allows rapid interchange between parallel plates for polymer melts and torsional clamps for solids. The ETC is thus a very flexible and easily-used accessory that covers a wide temperature range and allows the rheologist to measure diverse samples over their complete viscoelastic spectrum.

Concentric Cylinders

The AR 2000 Concentric Cylinder System is based on efficient Peltier temperature control, and brings a whole new dimension in operational and economic efficiency to viscosity measurements using concentric cylinder systems. The Peltier system provides much more rapid heating and cooling of the sample than is available from systems involving circulating external fluids. In particular, it results in significant time savings, especially when large changes in temperature are necessary. Also, since the new system does not require an expensive controlled-temperature fluid circulator, significant cost savings can be realized.

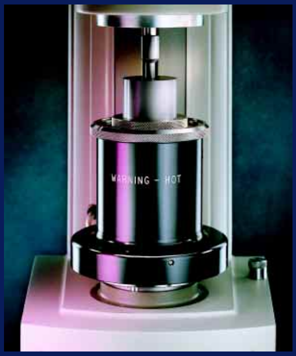
The AR 2000 Concentric Cylinder System can be operated over the temperature range –10 to 150°C, and incorporates Smart Swap technology for rapid interconversion of temperature control systems – available only with the AR 2000 Advanced Rheometer.

AR 1000 & 500 Temperature Control Options

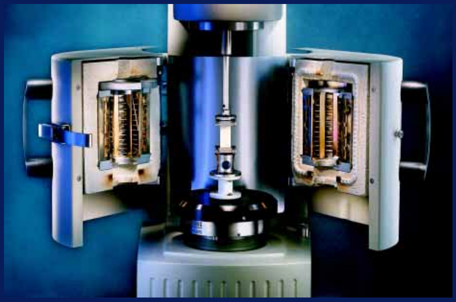
Peltier Plate

The Peltier Plate is the standard temperature control device for the TA Instruments AR 1000 / 500 Rheometers and is available in two temperature ranges. The Standard Peltier Plate has a temperature range of -10 to +100°C while the Extended Peltier Plate operates from -20°C to +180°C. Over these ranges they will provide an accuracy of ± 0.1°C and a typical heating rate of 20°C per minute. A Pt100 sensor is positioned at the center of the sample plate to ensure accurate measurement and control of sample temperature.

Concentric Cylinders



The Fluid Jacket Temperature System for the AR 1000/500 Rheometers is designed to provide precise temperature control for concentric and double concentric cylinder geometries over a wide range of temperatures. Concentric cylinders are best used for low viscosity samples, and those with large particles and/or limited stability. A range of systems (conical, recessed, vaned, and double concentric) are available. The system is self-aligning, and is quick and easy to change from cone & plate to concentric cylinder use.



Environmental Test Chamber

The ETC provides controlled convection/radiant heating and cooling (LN_2) over the temperature range -150 to 400°C with heating rates up to 15°C per minute. Its main use is in the analysis of polymer melts using cone and plate and parallel plate geometries. Disposable plates are available for thermoset studies. It is also commonly used to analyze solids in torsion.

Extended Temperature Module

The ETM is designed to provide rapid heating and cooling (up to 120°C/min) with very precise temperature control over a wide temperature range (-100 to 400°C). This outstanding performance is possible because the ETM is a unique induction heating system. It is ideal for analyzing the isothermal cure of thermosetting polymers, where it is critical to rapidly reach and stabilize at the test temperature.

Measurement Geometries

TA Instruments offers a wide range of measurement geometries (cones, parallel plates, concentric cylinders). Most are available with solvent traps and covers. Materials include stainless steel, hard anodized aluminum, acrylic and titanium. For elevated temperature Peltier Plate operation, a series of stainless steel geometries with composite heat breaks is available. Disposable/reusable cones and plates are available for applications involving thermosets. TA Instruments can supply custom geometries using a variety of materials to meet special requirements. Details of our standard geometries, including dimensions, and minimum / maximum shear rates are shown in the tables.

Parallel Plate Geometries

Diameter	AR 2000 Shear Rate max, 1/s	1000 / 500 Shear Rate max, 1/s	AR Series Shear Rate min, 1/s
8mm	1.20E3	4.00E2	4.000E-07
20mm	3.00E3	1.00E3	1.000E-06
25mm	3.75E3	1.25E3	1.250E-06
40mm	6.00E3	2.00E3	2.000E-06
60mm	9.00E3	3.00E3	3.000E-06

Note: Shear rates calculated at gap of 1mm. Shear rates will vary with gap.

Cone and Plate Geometries

Cone Angle	AR 2000 Shear Rate max, 1/s	1000 / 500 Shear Rate max, 1/s	AR Series Shear Rate min, 1/s
20 mm 0.5°	3.438E4	1.146E4	1.146E-05
20 mm 1°	1.719E4	5.730E3	5.730E-06
20 mm 2°	8.595E3	2.865E3	2.865E-06
20 mm 4°	4.296E3	1.432E3	1.432E-06
40 mm 0.5°	3.438E4	1.146E4	1.146E-05
40 mm 1°	1.719E4	5.730E3	5.730E-06
40 mm 2°	8.595E3	2.865E3	2.865E-06
40 mm 4°	4.296E3	1.432E3	1.432E-06
60 mm 0.5°	3.438E4	1.146E4	1.146E-05
60 mm 1°	1.719E4	5.730E3	5.730E-06
60 mm 2°	8.595E3	2.865E3	2.865E-06
60 mm 4°	4.296E3	1.432E3	1.432E-06

Concentric Cylinders

Geometry	AR 2000 Shear Rate max, 1/s	1000 / 500 Shear Rate max, 1/s	AR Series Shear Rate min, 1/s
Din (Conical)	4.356E3	1.452E3	1.452E-06
Rec. Rotor	4.356E3	1.452E3	1.452E-06
Double CC	1.594E4	5.314E3	5.314E-06

Applications

The AR Series Rheometers, with powerful, user-friendly Rheology Advantage 32-bit software and appropriate accessories combine to provide rapid characterization (with complete mathematical data modeling) of a broad range of materials from water to asphalt (~12 decades in viscosity). Commonly analyzed groups of materials include oils, gels, dispersions, pastes, slurries and polymers (melts and solids). Rheology is used in new product research, prediction of end-use properties, competitive comparisons, selection of processing conditions, and quality control. The major areas of interest today, the technical challenges faced, and related rheological solutions using TA Instruments rheometers are shown. The analytical methods used to determine the shown rheological properties are commonly performed in Flow (Steady State Flow or Continuous Ramp), Creep and Oscillation modes. More sophisticated modes and data analysis techniques are also available (e.g. multiwave and time-temperature superposition). Illustrative examples of the common modes of operation using data from dispersions and polymer samples are also presented. The choice between the three AR Series rheometers for a particular test will largely depend upon the performance required and the viscosity of the sample. For advice on an optimum configuration contact your local TA Instruments representative. More information can be obtained from our applications literature available on CD-ROM or from our website at http:/www.tainst.com.

Major Applications
Polymers - Thermoplastics
Polymers - Thermosets
Polymers - Elastomers
Adhesives
Coatings - Paints
Coatings - Inks
Coatings - Powders
Foods - Pastes, Gels, Dispersions (Suspensions, Emulsion)
Pharmaceuticals & Personal Care products - Pastes, Gels Dispersions (Suspensions, Emulsions)
Ceramics - Slurries
Oils, Greases, Lubricants

Process/Product Concerns	Related & Measurable Rheological Properties
Processability and Product Performance *Die Swell* *Structure (MW, MWD)* *Effects of Branching, Fillers, Melt Flow* *Regrind Materials - Detection & Use*	Viscosity, Shear Thinning, Elasticity, Compliance Normal Force Elasticity, Viscosity Profile, Zero Shear Viscosity (η_0) Changes in η_0, Elasticity, Compliance Comparison of Viscoelastic Properties (η_0, G', G", tan δ, compliance) with virgin material
Minimum Viscosity *Gel Point (Time / Temperature)* *Cure Profile / Cure Kinetics* *Cross-link Density*	Minimum in Viscosity Profile Intersection of Storage (G') & Loss (G") Moduli Examine Modulus Profile with Temperature or Time (G', G" vs T or t) Examine Plateau Modulus (G') - is G' in acceptable range?
Cross-link Density *Effect of Fillers* *Effect of Compounding* *Tire Traction / Tire Wear*	Examine Plateau Modulus (G') or Complex Viscosity (η^*) Profiles Comparison of Viscoelastic Properties (G', G", η^*) Strain Dependence of the Material (Length of Linear Viscoelastic Region) Examine G', G", tan δ
Tack and Peel Characteristics *Dalquist Criterion (pressure sensitive)*	Frequency / Time Dependence of G', G" Examine Plateau Modulus - is G' in acceptable range?
Ease of Application *Sagging - Brush, Spray Applications* *Leveling - Brush Applications* *Ribbing - Roller Applications* *Spatter*	Viscosity, Shear Thinning, Yield Stress Elasticity, Structure Recovery Elasticity, Structure Recovery Viscoelastic Profile, Elasticity, Structure Recovery Normal Force, Elasticity
Stability / Shelf Life *Flowability*	Examine Linear Viscoelastic Region (G' versus Time), Resistance to Creep Viscosity at a given Temperature
Flowability	Viscosity at a given Temperature
Stability / Shelf Life *Phase Separation* *Gelation* *Product Consistency / Texture* *Pourability & Dispensing under Pressure*	Examine Linear Viscoelastic Region (G' vs Time), Resistance to Creep Change of Structure with Time Gain of Structure, Elasticity Viscosity and Viscoelastic Behavior Viscosity, Shear Thinning
Stability / Shelf life *Phase Separations* *Application to Skin / Skin Feel* *Gelation* *Pourability, Pumping (in Plant)*	Examine Linear Viscoelastic Region (G' vs Time), Resistance to Creep Change of Structure with Time Viscosity, Shear Thinning, Structure Breakdown / Recovery Gain of Structure, Elasticity Viscosity, Shear Thinning
Stability / Shelf life *Pouring, Pumping* *Slip Casting, Casting Performance*	Examine Linear Viscoelastic Region (G' versus Time), Resistance to Creep Viscosity at a Given Temperature Viscosity, Yield Stress, Structure Changes
Oils - Pouring, Pumping *Effects of Modifiers* *Outwaxing of Crude Oils* *Greases / Lubes - Composition, Structure* *Mixing & Lubrication*	Viscosity at a Given Temperature, Compliance Viscosity, Shear Thinning, Structure Changes Viscosity at a Given Temperature Structure and Viscosity Changes Viscosity Profile, Yield Stress, Compliance, Structure Changes

Specific Examples

The following examples show the wide range of information routinely obtainable on the flow and structural properties of materials by the use of appropriately configured AR Series Rheometers. Details of these and other measurements can be obtained from your TA Instruments Representative.

Figure 1. TA Rheometers generate a flow curve by measuring shear rate under a ramped shear stress. The data provides information on yield stress, viscosity, shear thinning and thixotropy as well as correlations to real world processes (e.g. pumping, stirring and extrusion). Information on sample breakdown and recovery can lead to more cost-effective manufacturing processes. Figure 1 shows a generalized flow curve for dispersions, together with relevant shear rate ranges for various processes and applications. Most dispersions follow the general shape of this curve. A high zero shear viscosity plateau is linked to a lower infinite shear viscosity plateau by a shear thinning power law region. Simple techniques (e.g. falling ball, U-tube capillary) and spindle viscometers only measure a point or small part of the curve, usually in the power law region. If measurements are not made in the relevant part of the flow curve, predictions of process and product performance can be in error. The shape of the flow curve is also critical in understanding and predicting product performance. TA Rheometers have the torque range to measure at both ultra low and high shear rates and are often able to describe the shape of the entire viscosity curve in one measurement. Rheology Advantage Software can fit experimental data to a wide variety of the latest theoretical models.

Figure 1.
Flow Curve For Dispersions

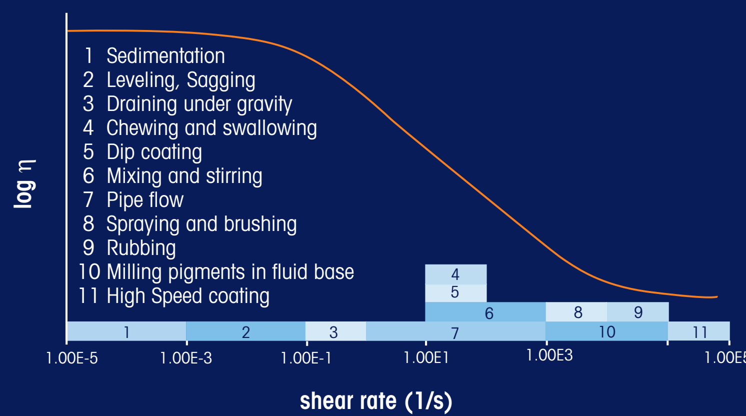


Figure 2 shows a generalized flow curve for a polymer melt together with shear rate ranges that are related to processes that a product may experience during production or where information on its molecular structure may be determined. A polymer's molecular weight greatly influences its viscosity while its molecular weight distribution and degree of branching affect its viscosity shear rate dependence. These differences are most apparent at low shear rates that cannot be attained by other devices such as melt flow index or capillary rheometry. In addition to general model fitting, Rheology Advantage software can be used to determine a molecular weight based on a measured zero shear viscosity and its internal library of K values for most common polymers. For a given polymer, comparisons can be made to study the effect of fillers, plasticizers and other additives. The range covered in a single flow test is often limited due to melt instability and fracture at modest shear rates. However, the curve can be extended well into the power law region by taking oscillatory data and applying the Cox-Merz Rule to the complex viscosity data, and if necessary can be further extended by applying the time-temperature superposition principle.

Figure 2.
Flow Curve For Polymers

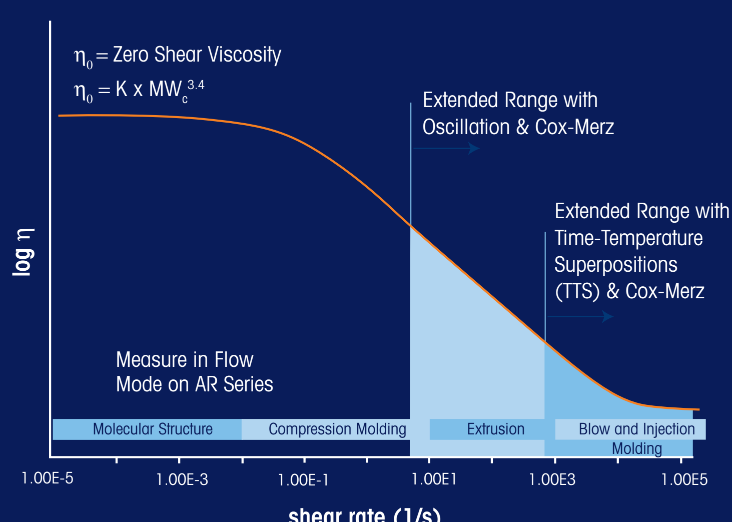


Figure 3. In a creep recovery test, a constant stress is applied to the sample and the resulting strain is measured with time. The stress is then removed and the recovery (recoil) strain is monitored also with time. If the stress is small the sample response is linear. Creep is a powerful and sensitive technique for characterizing the viscoelastic response of a material. Many industrial dispersions (suspensions and emulsions) are structured, viscoelastic fluids. Often viscosity alone cannot predict their processability and performance because elastic response can dictate the latter. Figure 3 shows the results of creep tests performed on good and bad paint samples, with the former being reported to produce a smoother finish upon drying with less evidence of brushmarks. The results show the power of creep for measuring the differences in viscoelastic structure of the two samples under the same conditions. The good sample undergoes a larger displacement than the bad sample indicating lower viscosity. In the recovery zone, it also shows a higher degree of recoil indicating that it is more elastic than the bad sample. Mathematical modeling of creep data in software is a standard feature of TA Rheometers.

Figure 4.
Creep Recovery on Polymer Melt

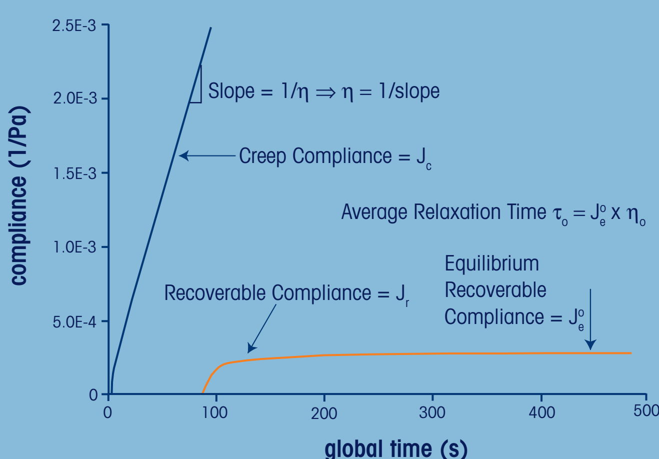


Figure 5. The oscillation mode allows the measurement of key viscoelastic parameters (G', G", η*, tan delta, etc) as a function of stress (torque), strain, frequency, temperature or time. Figure 5 shows that structure and stability comparisons of dispersions can be easily made using oscillation stress sweeps. The plots provide a direct determination of each dispersion's linear viscoelastic region (LVR), the length of which determines the stability of the dispersion. The data also shows that while one sample may have a higher modulus than another, it does not necessarily correspond to a more stable structure under the same stress conditions. Figure 5 also shows that it is possible to predict the relative differences in dispersions as they undergo structure breakdown.

Figure 3.
Creep Curves of Paint Samples

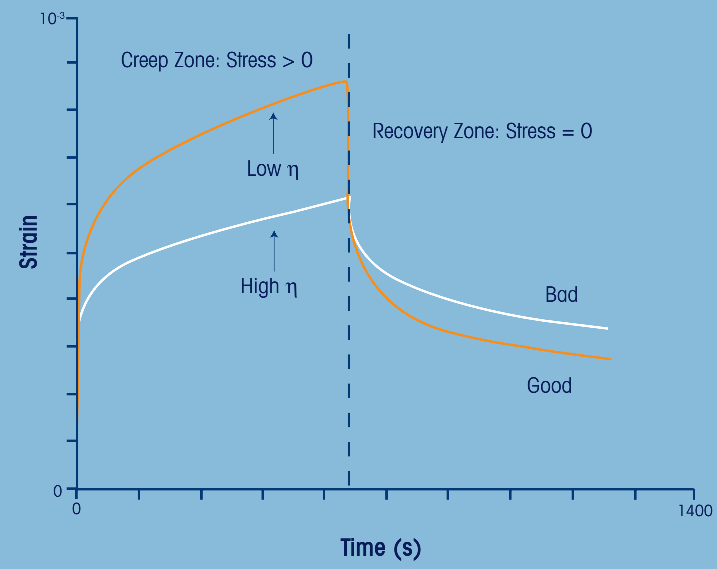


Figure 4. Creep is also a valuable method for studying the viscoelastic properties of polymer melts. In this test, it is useful to plot the creep and recoverable compliance, which are parameters calculated from the creep strain, the recoil strain and the stress applied in the creep zone (See Figure 4). Two important linear viscoelastic properties, which are crucial in flow behavior and give valuable information on molecular structure are the zero shear viscosity (η_o) and the equilibrium recoverable compliance (J_e^o). Figure 4 shows that η_o is calculated from the equilibrium slope of the creep compliance curve (J_c), while J_e^o is the value of the creep compliance curve (J_r) at full sample recoil. These parameters are greatly influenced by the molecular structure of the polymer (MW, MWD, branching). Creep recovery is also the most sensitive rheological test for detecting long chain tails, which can cause difficulty in polymer processing. In addition, the product of η_o and J_e^o is a measure of the average relaxation time of the polymer, another valuable parameter in understanding polymer performance.

Figure 5.
Oscillation Stress Sweeps on Ink Dispersions

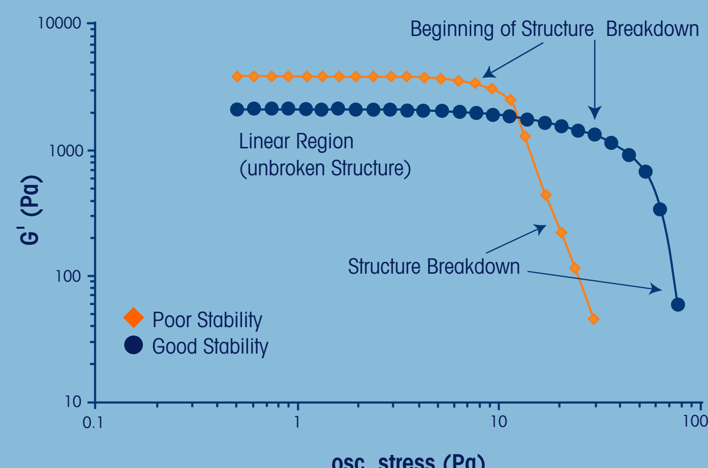


Figure 6. The linear viscoelastic properties of polymer melts are most commonly studied in oscillation mode. Figure 6 shows the storage modulus (G') and loss modulus (G") response as a function of frequency for a typical high molecular weight polymer melt. As polymer melts are viscoelastic, the mechanical response will be time dependent. Low frequencies correspond to long times. The response of the dynamic moduli shown here spans many orders of magnitude. This type of response is called a master curve and is obtained by scanning the material over a wide temperature range and applying the time-temperature-superposition (TTS) principle. The glassy region shows shortest time response and the terminal region shows the longest time response. The linear viscoelastic response of a polymer melt yields valuable information about the molecular structure such as molecular weight and molecular weight distribution. The magnitude and shape of the G' and G" curves will depend on the molecular structure of the polymer. A single frequency sweep test can be conducted to QC incoming raw material or a master curve can be generated to finger print the molecular structure of the material. In addition to the storage and loss modulus, other material parameters such as complex and dynamic viscosity, and material damping are simultaneously measured.

Figure 6.
Frequency Sweep: Material Response

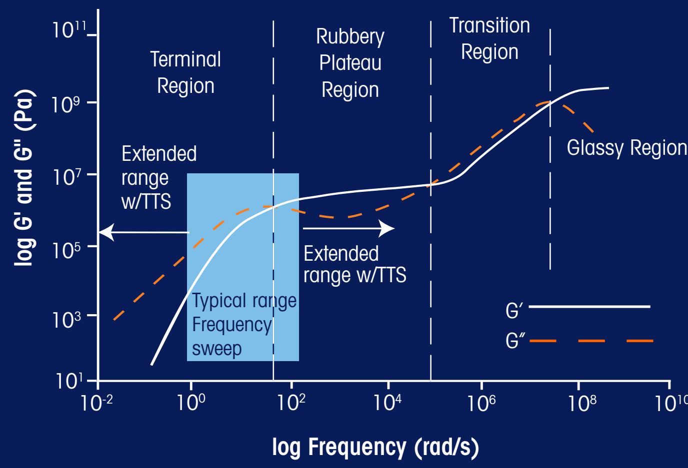


Figure 7.
PC - Polycarbonate

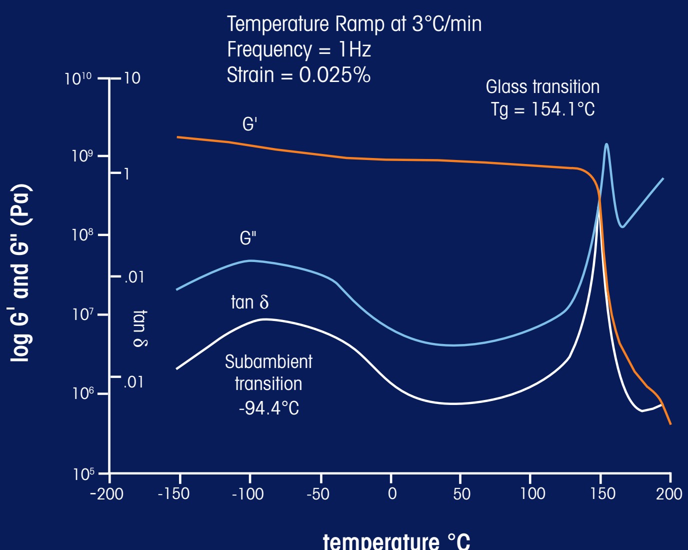


Figure 7. The ability to characterize the solid properties of polymers in torsion is a feature of the TA Instruments rheometers. Polymers are widely used because of their desirable mechanical properties and economical cost. In most applications, the mechanical properties are considered the most important of all properties. Therefore, those working with polymers need to have at least some basic knowledge of the mechanical behavior (strength, modulus), in addition to an understanding of how the mechanical behavior can be modified by varying structural factors such as molecular weight, crystallinity, and cross-linking. The linear viscoelastic response of a solid polymer yields valuable information about the molecular structure. The magnitude and shape of the storage modulus (G'), loss modulus (G"), and damping (tan δ) curves will depend on the chemical composition and molecular structure of the polymer. Figure 7 shows a typical temperature ramp scan from –150°C to 200°C, at a frequency of 1 Hz (6.28 rad/s) and a ramp rate of 3°C/min. for a polycarbonate. Transitions or relaxations of molecular segments in the polymer are observed as step changes in the storage modulus and as peaks in the loss modulus and damping.

Rheology Advantage Software

Rheology Advantage is a powerful, easy-to-use software package, which optimizes the performance of the AR Series rheometers. The intuitive layout, customizable toolbars, helpful Wizards, and extensive on-line help make Rheology Advantage a pleasure to use.

Instrument control modes include:

- Flow
- Creep
- Oscillation
- Parallel superposition
- Squeeze flow and pull-off tests
- Multi-wave operation

Data analysis features include:

- The latest mathematical models
- User-defined variables and models
- A custom report writer built into Rheology Advantage using Microsoft Word® templates
- Dynamic linkage between graphic and spreadsheet views
- Time-temperature superposition (TTS) for prediction of long-term viscoelastic material properties
- On-line molecular weight calculations from zero shear viscosity data
- Interconversion of linear viscoelastic functions for better understanding of material properties
- Optional molecular weight distribution (MWD) capability

Rheology Navigator is an intelligent software package that automates all features of Rheology Advantage instrument control and data analysis. Any feature of the software can be automated, and Navigator can intelligently make decisions about experimental steps and data analysis, based on experimental results.

- Users can easily generate scripts (macros) to link and automate rheometer functions for generation and analysis of data from many experiments
- Automatic development of custom methods using conditional execution functions, where the software makes “decisions” based on experience or previous results
- Simplified transfer of complex methods from R&D to QC. Navigator scripts can be developed on one rheometer and loaded on many units
- Predefined scripts allow inexperienced technicians to obtain research quality results, even for complex applications
- Unattended operation of complex experiments, or repetitive testing

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