



RUBBER TESTING



## Rubber Testing

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## Rubber Testing

TA Instruments introduces a complete line of new instruments for the measurement of rheological and physical properties of polymers, rubber and rubber compounds at all stages of manufacture. The new rubber testing instruments include a Rubber Process Analyzer (RPA), Moving Die Rheometer (MDR), Mooney Viscometer, Automated Density Tester and Automated Hardness Tester.

All TA Instruments rubber testing systems are manufactured to exacting mechanical standards and with the latest measurement technology for the most accurate, reliable, and reproducible data available. Available automation systems allow for maximum unattended laboratory productivity in all test environments. Relevant ASTM, DIN, and ISO standards are easily met, as are demands for advanced testing, making these instruments the ideal choice for quality control, analytical, and research needs.

As the world leader in viscoelastic measurements for over forty years, TA Instruments brings technical expertise in making the most accurate physical property measurements and provides a world-renowned global support network.



The TA Instruments RPA elite Rubber Process Analyzer (RPA) is the most advanced rotorless rotational shear rheometer dedicated to the complete characterization of polymers, rubber and rubber compounds at all stages of manufacture. The RPA elite provides invaluable viscoelastic data on materials that are uncured, through the curing process, and in situ cured materials. The ultra-rigid test frame, high-resolution variable direct drive motor, ultra-stiff wide-range torque transducer, and precision temperature control provide the most precise and accurate torque, viscosity and viscoelastic properties of elastomers over the widest ranges of testing conditions. The fully flexible architecture of the RPA elite enables advanced testing capabilities beyond any other rubber rheometer including: complete post cure viscoelastic characterization, fully programmable sealing pressure, large amplitude oscillatory shear (LAOS) and arbitrary waveform deformations.



Features

- The most advanced design for testing flexibility and unmatched data precision and accuracy
- High resolution variable direct drive motor for absolute strain control
- Proprietary high-stiffness, wide torque range transducer with high sensitivity for noise-free data
- Extremely rigid test frame for accurate compliance-free data
- Fully programmable testing parameters and methods including: strain, frequency, temperature, time, and sealing pressure
- Widest range and combination of tests and testing conditions available
- Available autosampler for unattended operation
- Pneumatic locking cylinders with adjustable platen closing force and pressure sensor
- User calibration and user-replaceable seals
- Includes Air Cooling System for temperature control and stability

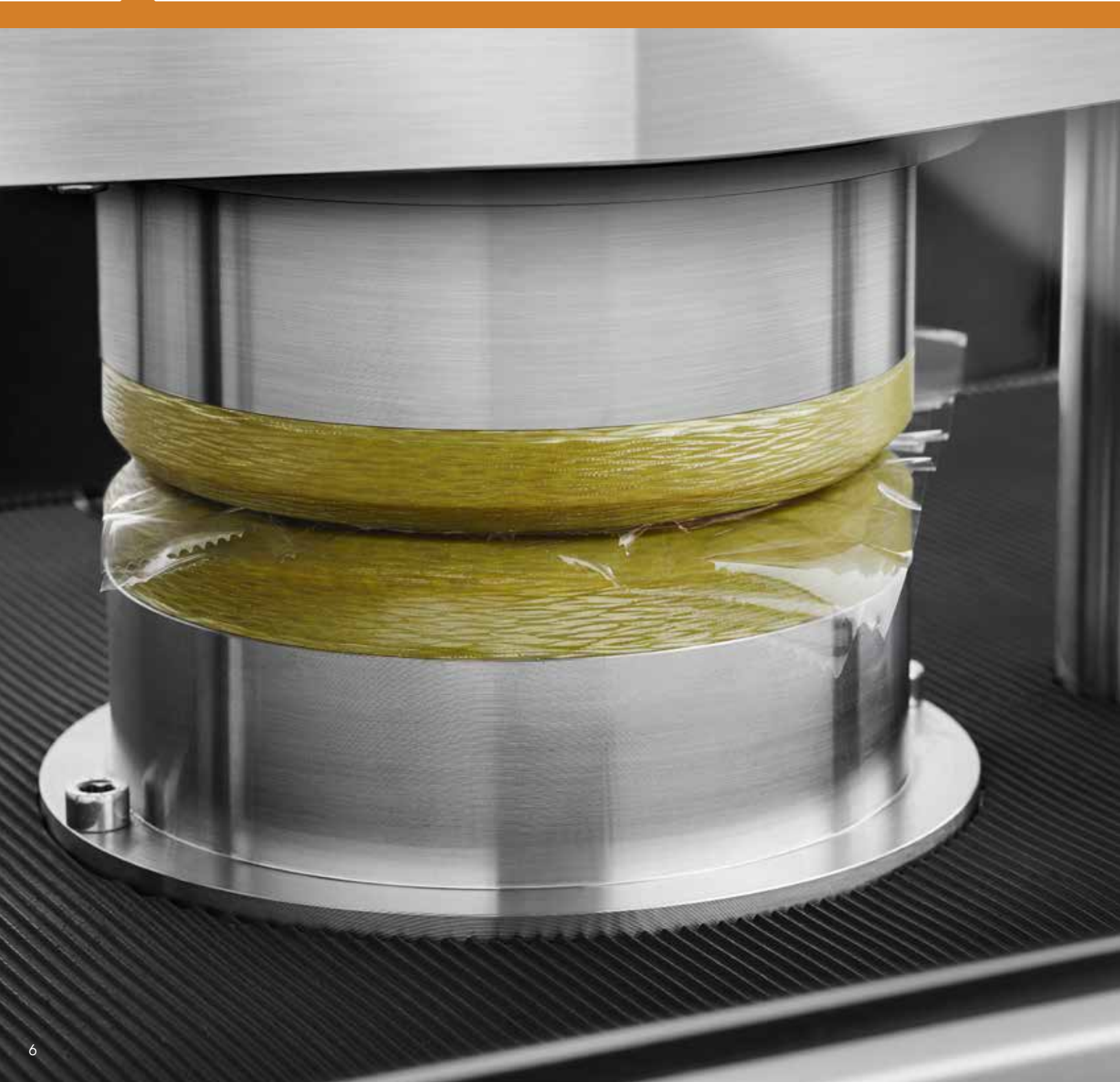


Specifications

Frequency	0.001 to 50 Hz (0.06 to 3,000 cpm)
Amplitude	±0.005° to ±360° arc (continuous)
Strain	±0.07 % to ±5000 %
Torque	0.01 to 25 N.m
Temperature	Standard: Ambient to 230 °C Optional: 18 °C to 230 °C with Enhanced Cooling System
Maximum Ramp Rate	80 °C/min (1.33 °C/s)
Die Type	Sealed bicone, 0.48 mm gap
Sample volume	4.5 cm³
Platen Sealing Pressure	1 to 8 bar Adjustable
Sample Pressure	Optional: 0 to 8,000 kPa
Test Modes	Cure (isothermal, ramp, step) Strain (sweep, offset, LAOS) Frequency Sweep Stress Relaxation Advanced (multi-frequency, arbitrary waveforms)
Measured Data	Torque, Temperature, Frequency, Amplitude, Sample Pressure (optional)
Calculated Data	Viscoelastic properties including: G', G'', G*, S', S'', S*, tan δ, η', η'', η*, LAOS Lissajous curves, non-linearities in stress and strain, and process parameters including: ts1, TC10, TC50, TC90, S'min, S'max, scorch time, cure rate
Standards	ASTM D5289, D6048, D6204, D6601, D7050, D7605; ISO 6502, 13145; DIN 53529



The RPA flex provides the highest quality of rubber rheometer data in a user-configurable platform, making it the perfect fit for labs that need more testing capability than an MDR alone can provide. The RPA flex includes all the same high quality features of the RPA elite, including ultra-rigid test frame, variable direct drive motor, proprietary high-stiffness torque transducer, precision temperature control with optional cooling, available Autosampler, and powerful Scarabaeus Software for control and analysis. The base level model includes a wide continuous strain range and fixed frequency enabling all MDR standard cure testing (ASTM/ DIN/ISO). In addition, the RPA flex can be configured to include, or be upgraded to include, any or all of the features of the RPA elite including variable strain, frequency, stress relaxation, advanced oscillation, LAOS testing, and sample pressure measurement.



Features

- High resolution variable direct drive motor for absolute strain control
- Proprietary high-stiffness, wide torque range transducer with high sensitivity for noise-free data
- Extremely rigid test frame for accurate compliance-free data
- Upgradeable to the widest range of tests and testing conditions
- Fully programmable variable testing parameters (strain, frequency, temperature, and closing pressure)
- Available autosampler for unattended operation
- Pneumatic locking cylinders with adjustable platen closing force and pressure sensor
- User calibration and user-replaceable seals



Specifications

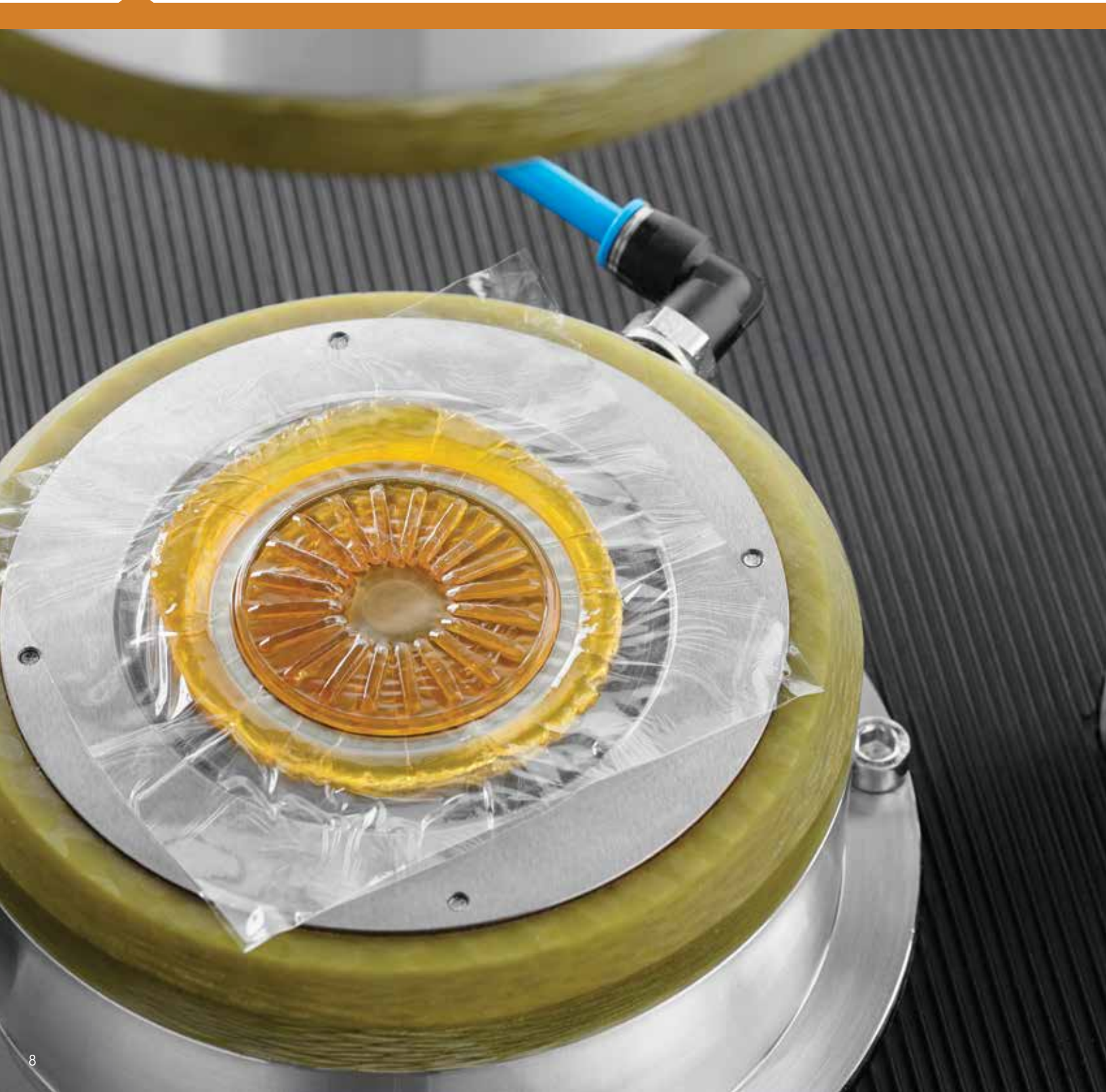
Frequency	Fixed: 1.67 Hz (100 cpm) Optional: 0.001 to 50 Hz (0.167E-3 to 3,000 cpm)
Amplitude	Standard: ±0.1° to ±7° arc (continuous) Optional: ± 0.005 to 360° arc (continuous)
Strain	Standard: ±1.4 % to ±100 % Optional: ±0.07 % to ±5000 %
Torque	0.01 to 25 N.m
Temperature	Ambient to 230 °C 18 °C to 230 °C with Enhanced Cooling Option
Maximum Ramp Rate	80°C/min (1.33°C/s)
Die Type	Sealed bicone, 0.48 mm gap
Sample Volume	4.5 cm³
Platen Sealing Pressure	Fixed: 4.5 bar    Optional: 1 to 8 bar Adjustable
Sample Pressure	Optional: 0 to 8,000 kPa
Test Modes	<b>Standard method</b> Curemeter/Vulcanization both isothermal and temperature ramp <b>Optional methods</b> Strain (sweep, offset, LAOS), Frequency Sweep, Stress Relaxation, Advanced (multi-frequency, arbitrary waveforms)
Measured Data	Torque, Temperature, Frequency, Amplitude, Sample Pressure (optional)
Calculated Data	<b>Standard:</b> Process parameters including: ts1, TC10, TC50, TC90, S' min, S' max, scorch time, cure rate, and viscoelastic properties including: G', G'', G*, S', S'', S*, tan δ, η', η'', η* <b>Optional:</b> LAOS Lissajous curves, non-linearities in stress and strain
Standards	<b>Standard:</b> ASTM D5289, ISO 6502, DIN 53529 <b>Optional:</b> ASTM D6048, D6204, D6601, D7050, D7605; ISO 13145



# MDR one

MOVING DIE RHEOMETER

The **MDR one** Moving Die Rheometer (MDR) is a reliable, accurate, and easy-to-operate rotorless curemeter perfect for routine and standards-driven testing of rubber curing. The **MDR one** is configured for measuring curing profiles of rubber compounds under isothermal and non-isothermal test conditions at constant strain and frequency. The **MDR one** employs sealed biconical dies meeting all relevant ASTM, ISO, and DIN standards. The unique design includes an ultra-rigid test frame, direct drive motor, precision temperature control with optional cooling, available Autosampler, and intuitive Scarabaeus Software for control and analysis making it the ideal platform for QC or R&D environments.



## Features

- Unmatched data precision, accuracy, and reproducibility
- Robust, field-proven torque transducer for high stability, reliable torque measurements
- Extremely rigid test frame for accurate compliance-free data
- Available autosampler for simple unattended operation
- Pneumatic locking cylinders for repeatable sample sealing
- Powerful and Intuitive Scarabaeus Software available in multiple languages & compatible with other manufacturers' instruments
- User calibration and user-replaceable seals



## Specifications

Frequency	Fixed: 1.67 Hz (100 cpm)
Amplitude	±0.2°, 0.5°, 1.0°, 3.0° arc
Strain	±2.-8 %, 7 %, 14 %, 42 %
Torque	0.1 to 20 N.m
Temperature	Ambient to 230 °C 18 °C to 230 °C with Enhanced Cooling Option
Maximum Ramp Rate	80°C/min (1.33°C/s)
Die Type	Sealed bicone, 0.48 mm gap
Sample volume	4.5 cm³
Platen Sealing Pressure	Fixed: 4.5 bar
Test Modes	Curemeter/Vulcanization both isothermal and temperature ramp
Measured Data	Torque, Temperature, Frequency, Amplitude, Sample Pressure (optional)
Calculated Data	Process parameters including: ts1, TC10, TC50, TC90, S' min, S' max, scorch time, cure rate, and viscoelastic properties including: G', G'', G*, S', S'', S*, tan δ, η', η'', η*
Standards	ASTM D5289, ISO 6502, DIN 53529



The **MV one** Mooney Viscometer is a fully-featured instrument incorporating the latest technology for traditional Mooney testing. It is configured for standard viscosity, scorch and stress relaxation testing of rubber polymers and compounds under isothermal test conditions at constant speed of 2 rpm. An optional continuously variable motor mode allows tests over a speed range of 0.1 to 10 rpm. The **MV one** Mooney Viscometer is equipped with low mass rotors that meet all relevant ASTM, ISO, and DIN standards. All TA Instruments rubber testing instruments are constructed on ultra-rigid test frames and include direct drive motors, precision temperature control and the powerful and intuitive Scarabaeus Software for control and analysis.



Features

- Superior design for unmatched data precision and accuracy
- Extremely rigid test frame for accurate compliance-free data
- Low mass rotor design and direct heating for fast and accurate temperature control
- Available high resolution variable speed direct drive motor
- Automated internal torque calibration
- Long-life user-replaceable seals
- Powerful and Intuitive Scarabaeus Software available in multiple languages
- Large (38.10 mm) and small (30.48 mm) diameter rotors
- Mooney viscosity, stress relaxation, scorch



Specifications

Rotational Speed	Standard: 2 rpm Optional: 0.1 to 10 rpm
Temperature	Ambient to 200°C
Torque	0.01 to 200 MU
Rotors	Large: 38.10 mm diameter Small: 30.48 mm diameter
Test Modes	Mooney Viscosity Mooney Scorch Stress Relaxation (Linear, Logarithmic, ISO, Mooney Stress-relaxation Rate)
Standards	ASTM D1646, ISO 289, DIN 53525

TA Instruments is the world's leading supplier of analytical instrumentation for the measurement of viscosity and viscoelastic properties. The new rubber testing instruments are uniquely designed to deliver the highest quality of torque, amplitude, frequency, temperature, and pressure measurement and control. TA Instruments is the **CLEAR CHOICE** for testing rubber products at all stages of manufacture.

## Rigid Testing Platform

All TA Instruments rubber rheometers and viscometers are built with an ultra-stiff testing frame and crosshead which eliminates the **effects of instrument compliance** on test data. Instrument compliance, or instrument deformation, produces erroneously low values of measured properties such as modulus and torque, irregular strain and torque waveform signals, and other errors.

Large diameter steel rods and a thick crosshead brace in the H-shaped load frame provide unmatched rigidity to resist instrument deflection while the motor deforms the sample. This special design ensures that the commanded strain is achieved with each cycle of deformation, even for highly filled, fully cured rubbers. Additionally, a non-compliant system allows for truly sinusoidal strain profiles under all conditions. This can be verified by continuous Fourier Transform analysis of the deformation and measured torque signals which is available in the Scarabaeus Software. The superior design also guarantees smooth travel, proper alignment, and precise application of vertical load.

## Direct Drive Motor

Powerful direct drive motors apply precise deformation in all TA Instruments rubber rheometers and viscometers. A high quality rheological or dynamic measurement relies on the precise application of a constant rate, step, or periodic deformation. In a direct drive system the start-up delays, compliance, and translational losses seen in clutch or belt-driven configurations are eliminated. The superior TA Instruments motor design ensures that the most accurate and repeatable deformations are always applied to the sample.

The *RPA elite* and *RPA flex* provide continuously variable strain and frequency ranges for flexible testing. The *RPA elite* applies the **highest combination of frequency and amplitude** in any rubber rheometer. This provides important material information such as:

- The linear viscoelastic response of highly filled rubbers at low strains
- Behavior at extreme processing and use conditions characterized by high strains
- Terminal material behavior exhibited at low frequencies
- Response to high speed deformations measured at high frequencies

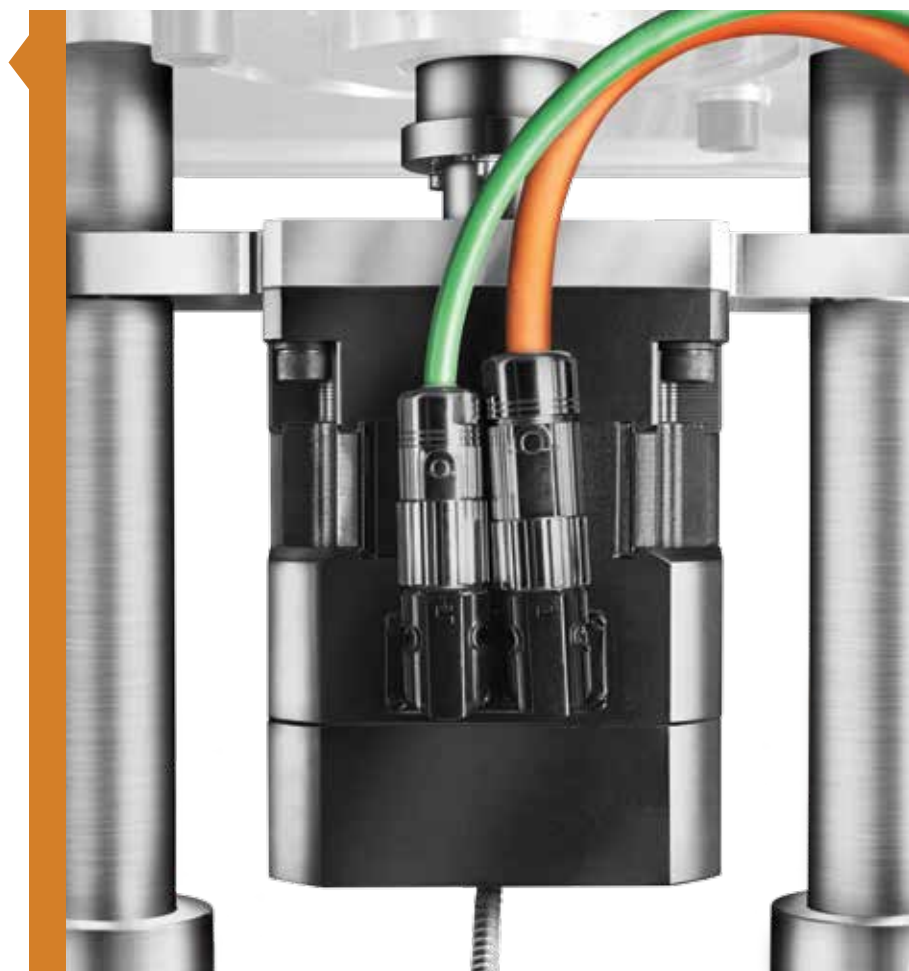
## High-Stiffness Torque Transducer

The *RPA elite* and *RPA flex* benefit from a proprietary wide range ultra-stiff torque transducer. This rugged, non-compliant device measures the widest range of torques accurately and precisely. This greatly improves the accuracy and precision of measured torque, modulus, and viscosity values.

## Advanced Data Processing

The complex deformations and stress-strain response common to rubber testing demand the most advanced data processing techniques. TA Instruments rubber rheometers utilize a state-of-the-art 20-bit encoder and advanced data sampling technique to perform calculations based on a Fast Fourier Transform (FFT) analysis using 90 data points for each cycle of oscillation.

The *RPA elite* and *RPA flex* are capable of measuring and reporting non-linearities in torque and displacement. Higher harmonics that indicate non-linearity in the applied displacement or measured torque are reported for each data point, alerting the operator with a simple indicator if test conditions are not ideal and storing this information for subsequent data validation.







Crosshead Bearing

## High Pressure Pneumatic System

All TA Instruments rotorless rheometers and curemeters employ a high pressure pneumatic system to **seal the sample properly and reproducibly**. The high capacity pneumatic system applies up to 8 bar nominal pressure to the sample during gap closure. Proper alignment and the use of mechanical bearings ensure efficient transfer of load from the system to the sample without load frame losses. Actual sealing pressure is measured directly and recorded. This high pressure automated sample containment removes operator dependence and tightly contains the test specimen. This sealing process is particularly important for materials that undergo positive or negative volumetric changes with curing and highly stiff materials such as carbon-filled fluoroelastomers.



## Cooling Options

All rotorless rheometers are compatible with either the Air Cooling System or Enhanced Cooling System. The **Air Cooling System** uses ambient air to expedite temperature changes above ambient conditions and improve temperature stability near room temperature.

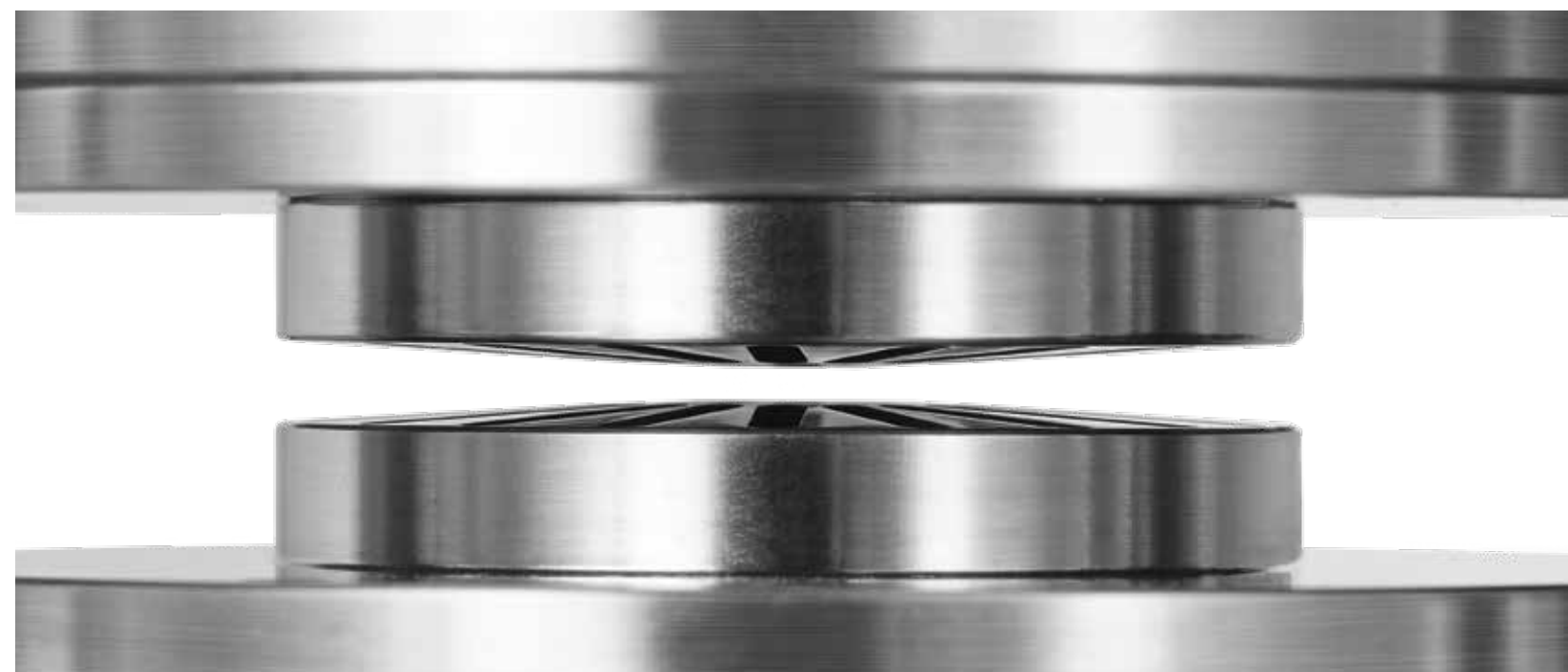
The **Enhanced Cooling System** is a mechanical device that employs pressurized air to cool the test environment, allowing characterization of rubbers at temperatures as low as 18 °C and greatly accelerating cooling time between non-isothermal experiments. The system has no moving parts, making it extremely reliable and easy to use.



## Testing Dies and Rotors

The **MDR one**, **RPA flex**, and **RPA elite** rotorless shear rheometers employ the industry-standard sealed cavity biconical die design. The dies are constructed from durable, high-stiffness, low thermal expansion stainless steel to **minimize system compliance and prevent gap changes** with temperature. The test fixtures are connected directly in line with the motor below for precision deformation control and the torque transducer above for accurate measurement.

Direct contact electric heaters mounted within the dies provide exceptional temperature control and stability under isothermal, step and temperature ramp conditions. This highly responsive system returns rapidly to the programmed test temperature upon the addition of a cold sample, providing the most representative values for scorch time and other cure characteristics. Extremely durable user-replaceable seals provide absolute sample containment at all temperatures and conditions.





**Rotorless Rheometer**

RPA and MDR die surfaces feature an optimized arrangement of radial serrations to guarantee constant sample contact at even the highest strain values. Polyester or polyamide films may be used to facilitate sample release and avoid the need to clean dies between experiments.

Torque calibration is made simple with a certified torque calibration standard. This allows the user to calibrate the instrument directly, increasing data confidence and operation time, and reducing the reliance on service engineers for calibration.

**Mooney Viscometer**

The *MV one* Mooney Viscometer includes both large (38.1 mm) and small (30.48 mm) diameter rotors. Both rotors are endorsed by international standards and can be selected for measurement of low or high viscosity rubbers or polymers. Both rotor types can be used in conjunction with polyester or polyamide films to simplify instrument cleaning and reduce time between runs. Rotors are designed with low mass to optimize thermal response and transient speed changes at the beginning and end of shearing steps.

Calibration is software-driven and does not require the use of external weights, fixtures, or reference materials. A weight of known mass is connected by a well-defined radius, creating a constant torque value. The software-driven torque calibration routine uses this internal standard to ensure utmost data accuracy.



**Sample Preparation**

Sample preparation for RPA, MDR, and Mooney instruments is made safe and simple with the VS Volumetric Sample Cutter. This dual-action pneumatic system allows for the preparation of uncured rubber specimens of a user-defined volume.

Preparing samples in this well-controlled fashion **reduces operational variability, greatly improving overall experimental precision.**

The VS comes standard with a closing pressure of 6 bar. The sample is first compressed to the user-prescribed thickness, then cut to the die diameter. The closing pressure, and sample volume are user-adjustable. An optional booster is available to increase operating pressure to 8 bar for highly filled and stiff materials. Two-handed operation and lateral guards guarantee safe operation at all times.



**Sample Cutting Dies**

Sample dies for either the Mooney Viscometer or rotorless rheometers and curemeters can be removed and exchanged quickly and easily. The *MV one* Mooney Viscometer uses two 40 mm diameter samples, one above and one below the rotor. A hole is punched in the center of the sample to ease insertion. Standard RPA and MDR samples are single piece discs cut to meet volume specifications per ASTM, DIN, and ISO standards.



# reliable automation

RPA AND MDR

All TA Instruments rotorless curemeters and rheometers are compatible with the highly reliable rubber automation system. This carousel-based autosampler allows for the unattended testing of rubber samples. Coupled with the Scarabaeus Software automated analysis, statistics, and control chart generation, the automated rheometer becomes a highly integrated part of the manufacturing control process. This improved data throughput is also invaluable for screening multiple formulations in a research or product development environment.



Samples are moved from the autosampler tray to the test position using a suction transfer system. This system is highly tolerant of non-ideal sample geometries, so uncured rubber from many sources can be used. Samples are loaded on a carousel and more specimens may be added while another test is in progress, allowing for uninterrupted productivity.



An automated film transfer system removes the previously tested specimen and advances the film roll to prepare for the next experiment. An integrated sensor alerts the operator at the end of the roll so it can be replaced in a timely manner.

Density testing is made simple with the TA Instruments fully Automated Density Tester. This fully programmable, automated system measures the density of cured rubber materials using the finite difference (buoyancy) method. Active measurement of the fluid temperature increases accuracy by accounting for small changes in the density of the immersion fluid with temperature.

Walk-away Automation

Sequential, reliable, and unattended density measurements are made using an automatically fed sample tray with 20 or 30 sample capacity. This true walk-away automation is enhanced with software-driven test set-up, data collection, and pass/fail criteria.

Specifications

Test method	Finite Difference (buoyancy) ISO 2781 ASTM D1817
Sample diameter	30 - 45 mm
Sample thickness	3 - 6 mm
Measurement range	< 1.0 g/cm <sup>3</sup> to 2.5 g/cm <sup>3</sup>
Autosampler capacity	20 30 (optional)
Fluid Temperature Measurements	Standard



The finite difference method for density measurement relies on the measurement of sample weight dry, and immersed in a fluid, usually water. The difference between the dry and immersed weight is used with the known density of the fluid to calculate the volume of the specimen to a high degree of accuracy, irrespective of geometry.

A double gripper and carriage system is used to guarantee that dry weight values are entirely uninfluenced by system moisture or cross-contamination. Each sample is fully wetted by a user-defined number of separate immersions prior to immersed-mass measurement. This prevents error brought about by incomplete wetting and improves both accuracy and precision.





# AHT

AUTOMATED HARDNESS TESTER

The **AHT** Automated Hardness Tester streamlines the measurement of Shore A hardness for cured rubber materials. This fully programmable, automated system measures the hardness of cured rubber materials according to all international standards for Shore A hardness. Each measurement involves the determination of a user-defined number of single point Shore A values. The individual readings, mean and median of this set are reported for each sample.

## Reliable Automation

An automatic sample feed with 20-sample capacity provides sequential, reliable, unattended measurements. An optional 30-sample upgrade extends automation to even larger sample sets. Software-driven test set-up, data collection, and pass/fail criteria make the **AHT** Automated Hardness Tester a truly automated system.



## Specifications

Test method	Shore A ISO 868 ASTM D2240 ISO 7619 NFT 51-174 BSI BS 903-A26
Sample diameter	30 – 45 mm
Sample thickness	4 – 6 mm
Indenter	Hardened steel rod Truncated 35° cone 0.79 mm diameter
Measurement range	0 - 100 Shore A
Pressing force	Contact pressure, pressure weight: 12.5 N Spring Force: 8.065 N
Resolution	0.1 Shore
Autosampler capacity	20 30 (optional)



Shore A hardness measurements are based on the precise application of force and the subsequent measurement of probe displacement.

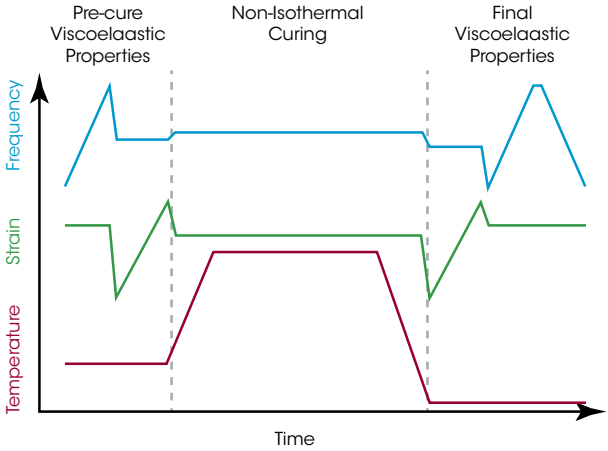
A 12.5 N weight is applied to the measurement device that consists of a hardened steel probe of a prescribed shape. The measurement is performed multiple times, with the sample being rotated automatically between measurements to ensure representative sampling. The individual values, and the mean and median for the specimen are reported for each sample.



The Scarabaeus Software for instrument control and data analysis is a powerful and versatile system for programming experiments, providing quick feedback of results, and managing data from all rubber testing instruments. The Scarabaeus Software was developed with customers from the rubber industry and is designed to meet the specific need of production and research.

## Simple Instrument Control, Flexible Programming

Instrument control software is preloaded with test programs for the most common experiment types, enabling simple operation by new users. Multi-step tests can be easily programmed to collect many types of data from a single specimen, or to mimic an industrial curing or other processing sequence.

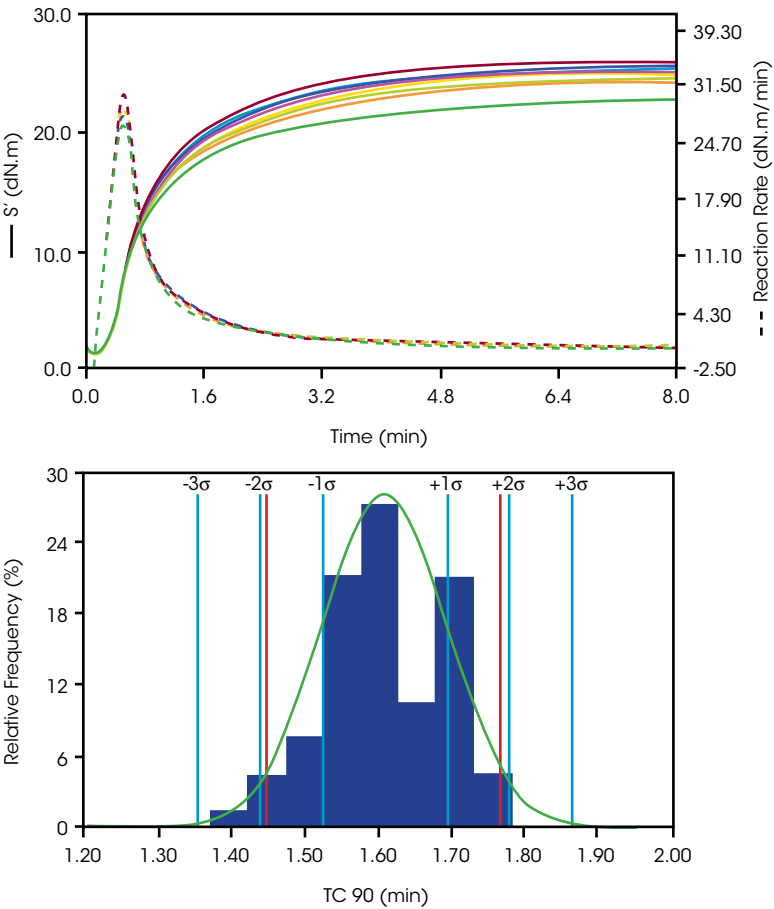
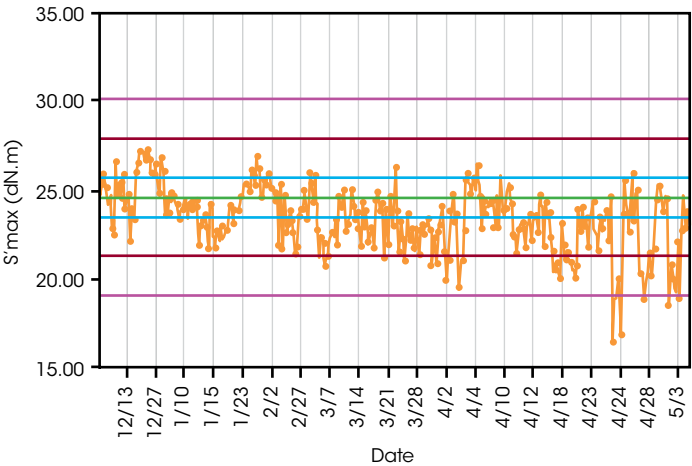


## Quick Operator Feedback

Qualification of multiple lots of similar materials is made easy with quick operator feedback. Predefined test parameters with tolerances can be assigned for a given material. Upon completion of a test, a simple pass/fail indicator shows whether the specimen falls within the acceptable limits for the selected material, allowing meaningful decisions to be made quickly and easily.

## Statistical Process Control

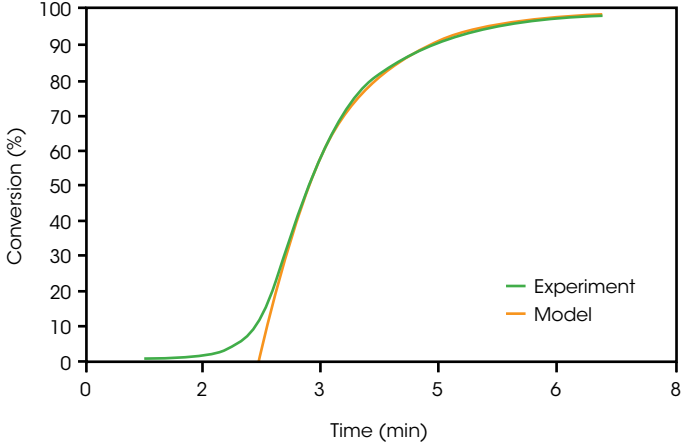
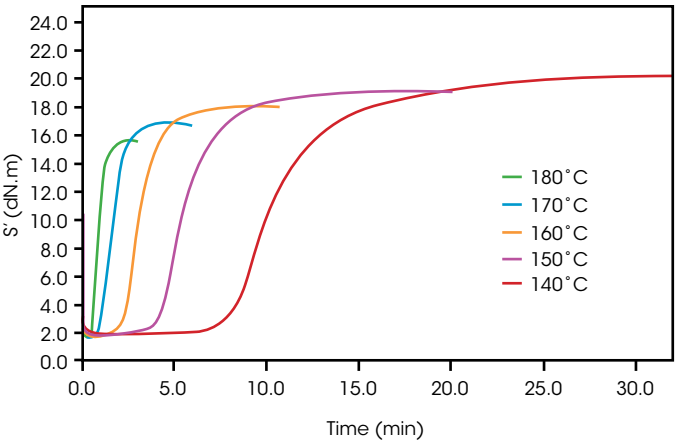
Test data is readily converted into actionable information for process control and manufacturing. Automated data analysis can be programmed based on typical performance metrics, such as minimum and maximum torque, scorch times, conversion times, and more. These data are compared against user-defined limits and are used to track processes using histograms, control charts, and summary reports.



## Advanced Data Analysis and Modeling: Curing Kinetics

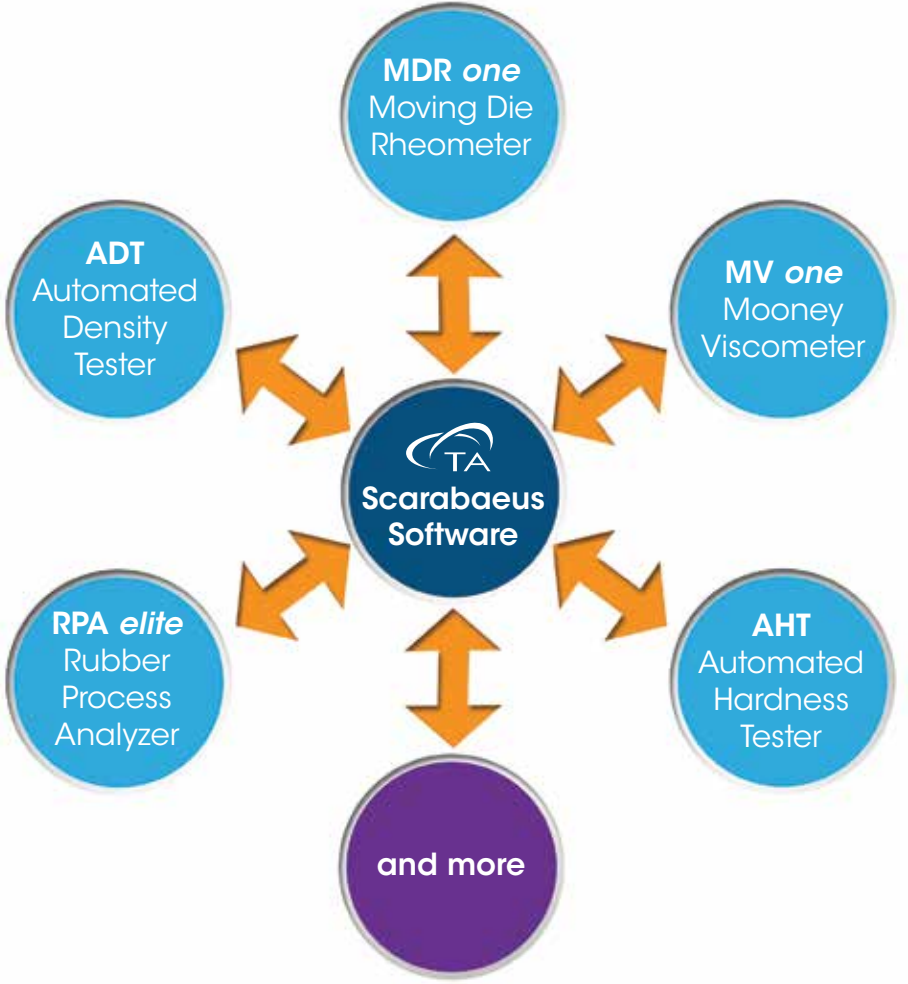
Isothermal curing data at multiple temperatures can be analyzed according to a rubber-specific methodology to determine curing kinetics parameters. This modeling system can determine:

- Reaction Rate
- Reaction Order,  $n$
- Rate Constant,  $k$
- Incubation Time,  $t_i$
- Arrhenius Activation Energy,  $E_a$



## Designed for Integration

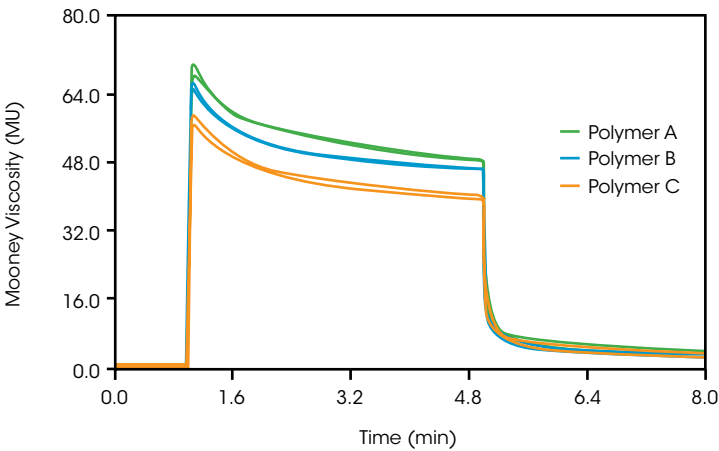
The Scarabaeus Software system for instrument control and analysis integrates and organizes data from multiple instruments and historical tests. Data from RPA, MDR, Mooney Viscometer, Hardness, and Density tests can be organized, compared, and analyzed by material type, inventory order, date, and more. Advanced integration with even greater capability is also available.





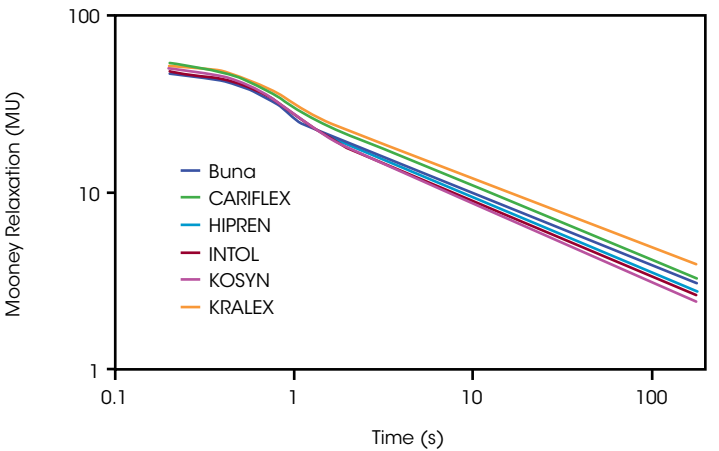
Mooney Viscosity

The Mooney Viscosity test is a well-established method for characterizing uncured rubber materials. Following well-defined standard procedures, the sample is preheated for a defined period, then sheared at a constant rate. The Mooney Viscosity is recorded from the end of this deformation stage. In the present example, the outstanding precision of the *MV one* Mooney Viscometer is demonstrated. Three polymer samples were tested in duplicate. The outstanding run-to-run reproducibility and the ease of distinguishing one polymer from another is clear.



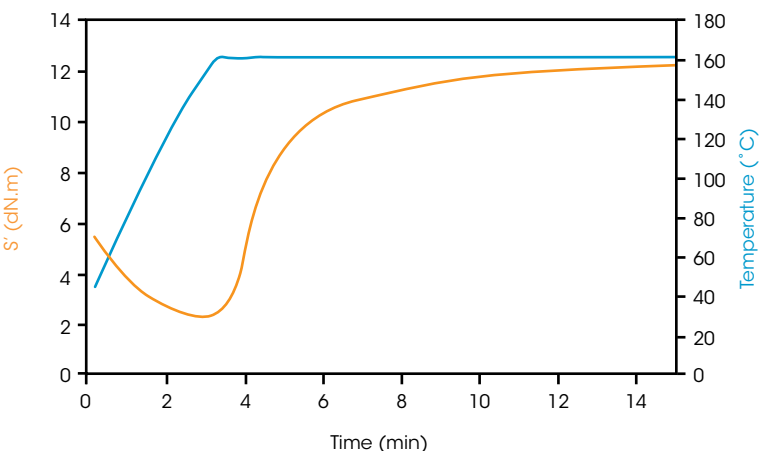
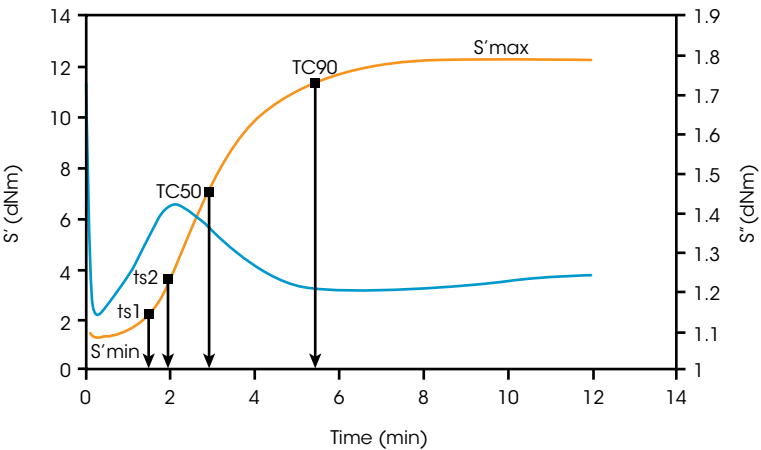
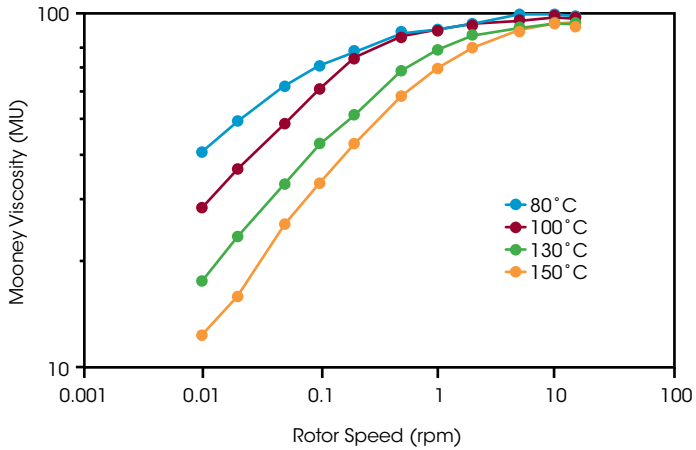
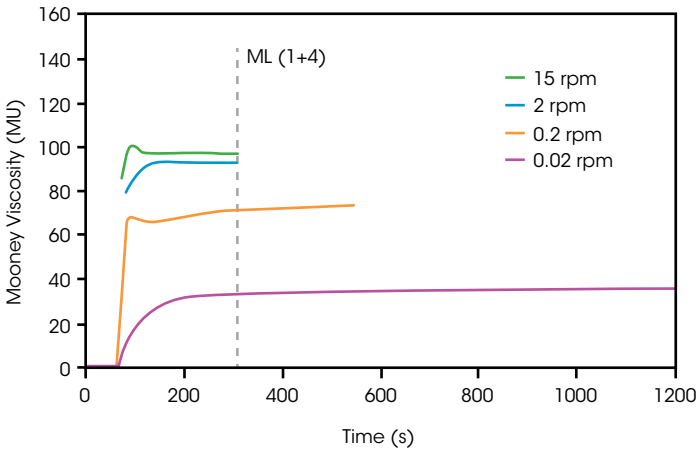
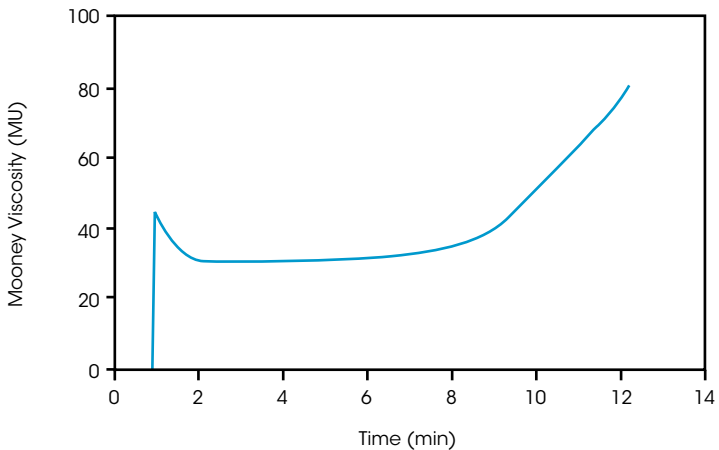
Mooney Stress Relaxation

While the Mooney Viscosity experiment is typically indicative of polymer viscosity, stress relaxation can be used to identify elasticity. Upon completion of the Mooney Viscosity measurement, the rotor is stopped immediately and the torque decay is observed. The slope of this decay is indicative of polymer elasticity, which may be related to a branched architecture and correlates well with extrudate swell in rubber processing.



Mooney Scorch

The Mooney Viscometer can also be used to measure the initial rate of vulcanization. In this example, a styrene butadiene rubber (SBR) was tested for prevulcanization characteristics at 150°C using the small rotor. For this simple experiment the initial Mooney viscosity, minimum viscosity, scorch times, and cure index are the most commonly reported values.



Mooney Viscosity at Multiple Rates

In addition to the viscosity at a single rate and temperature, the *MV one* Mooney Viscometer can measure viscosity at a range of shear rates and temperatures. This range of rates allows a more complete understanding of the polymer behavior, especially a tendency for shear thinning. Low rates in Mooney Viscosity experiments can also be beneficial for measuring highly elastic materials that are otherwise inaccessible to Mooney Viscosity measurements.

Isothermal Cure

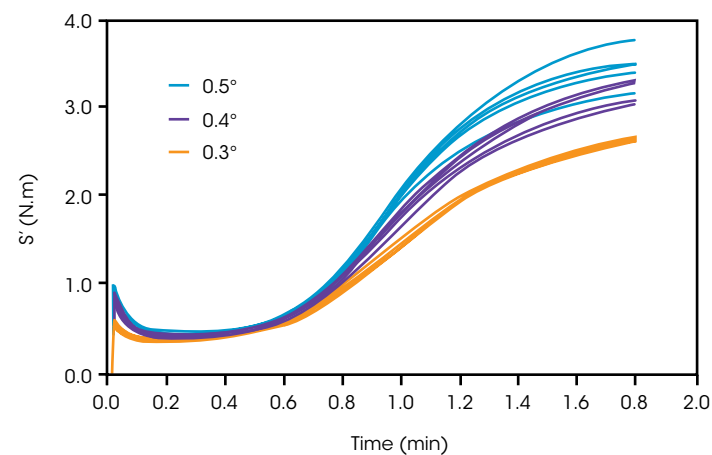
Isothermal cure experiments are critical for rubber and elastomer processing. The TA Instruments rubber rheometers provide high precision data that is simple to analyze. All the important characteristics, such as minimum and maximum viscosity, scorch time, and conversion time can be calculated easily and automatically. The data can also be handled in its complete graphical form for comparison or alternative analyses.

Non-isothermal Cure

In addition to the industry-standard isothermal cure methods, the RPA and MDR can perform non-isothermal cure experiments. These experiments can be programmed to follow virtually any temperature profile and are especially valuable when simulating manufacturing processes that are not isothermal. Non-isothermal curing experiments may also be coupled with isothermal tests such as strain and frequency sweeps before or after cure to provide a more complete material data set before, through, and after cure.

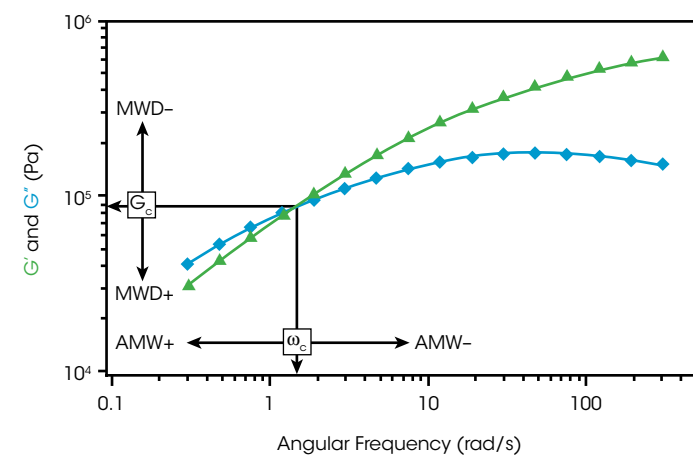
## Isothermal Curing at Variable Strain

While standard test methods often call for a single strain and frequency value to be used for all materials (0.5°, 1.67 Hz), these are not always the ideal conditions for every material. In the present example, the sample material is tested by isothermal cure at three deformation amplitudes, five times each. At the standard of 0.5° and 0.4° the experimental variability is extremely broad. This is because these experiments are performed at strains beyond the linear viscoelastic limit for this material. Testing at a smaller amplitude (0.3°) produces valid data with greatly improved reproducibility.



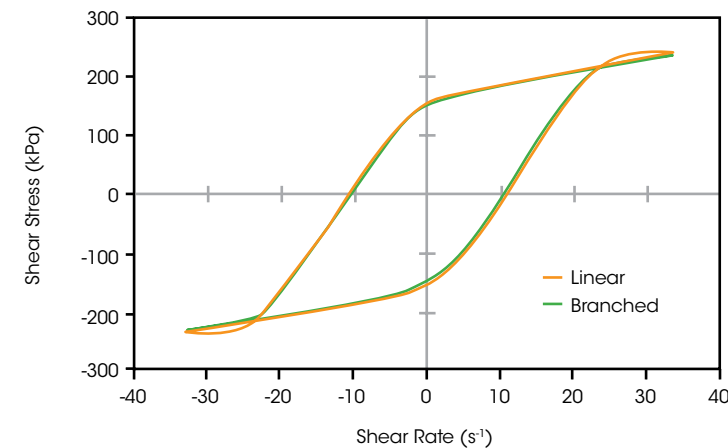
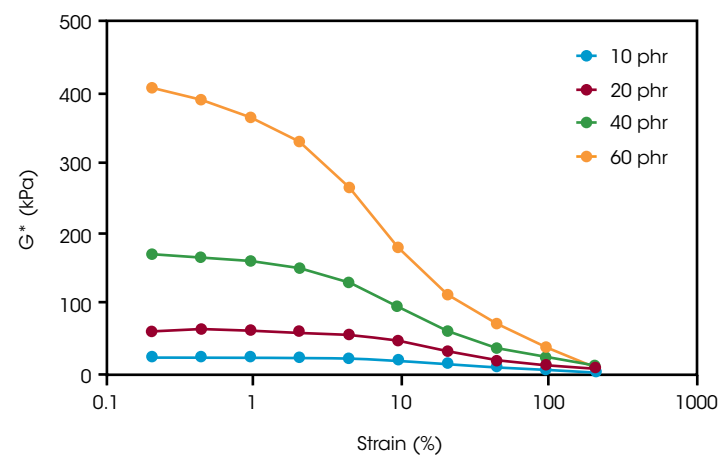
## Isothermal Frequency Sweep

Measuring the frequency-dependent viscoelastic properties of a material is a powerful way to understand its molecular structure. A frequency sweep as shown can reveal information about the average molecular weight (crossover frequency) and molecular weight distribution (crossover modulus).



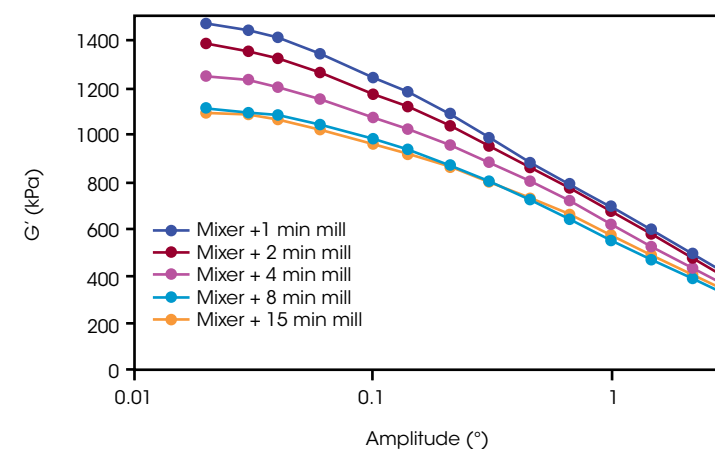
## Strain Sweep for Filler Loading

The strain-dependent modulus is particularly important as an indicator of the amount and type of rubber filler dispersion and interaction. In the present example, the impact of carbon black addition at five different levels is seen in the low strain region. High strain behavior is generally insensitive to filler addition, as it is less sensitive to filler-filler interaction and more dependent on polymer molecular weight, and polymer-filler interactions.



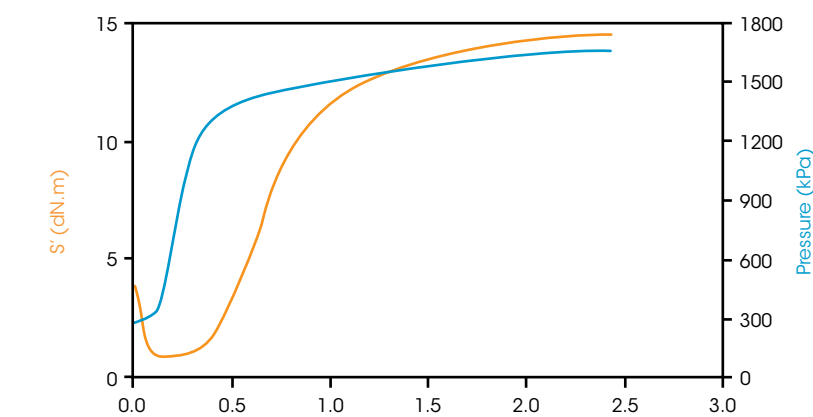
## High Strain Non-Linear Behavior

The viscoelastic response of a branched material at very high strains differs not only in magnitude from its linear counterpart, but also in type. The careful examination of a polymer's stress-strain response at high strains reveals features associated with filler content and structure, as well as polymer architecture. In the present example, qualitatively different features are observed at large strains for two EPDM materials: a linear polymer and a branched polymer. Both exhibit identical Mooney viscosities, but markedly different high strain behavior. Both the uncorrelated data, and the FT analysis of periodic data are available through the Scarabaeus Software to allow in-depth analysis of this new type of data.



## Time Dependent Structure Breakdown

The van der Waals interactions that lead to increased modulus in carbon black filled rubber are highly sensitive to processing. In this example, identical samples are subjected to different lengths of milling after being removed from the mixer. Carbon network structure is reduced with each increase in milling time up to 8 minutes, after which the modulus was unchanged with increased milling. This provides critical information about the amount of milling needed to create a consistent workable material.



## Cure with Blowing Reaction

Final product density and mechanical performance are often enhanced through the use of blowing agents to create a cellular architecture. These blowing agents generate gas during decomposition in parallel with the curing reaction. Monitoring sample pressure through the curing reaction is an effective way to quantify the blowing reaction, allowing for the characterization of curing and blowing in a single experiment. These two processes must be balanced in order to form the desired cell architecture in the finished product.



Feature Summary

	MDR one	RPA flex	RPA elite
Torque Transducer	High-Stiffness	Proprietary Ultra-High-Stiffness	Proprietary Ultra-High-Stiffness
Torque Range	0.01 to 25 N.m	0.01 to 25 N.m	0.1 to 20 N.m
Motor	Direct Drive	Direct Drive	Direct Drive
Strain			
0.2°, 0.5°, 1.0°, 3.0°	●	●	●
0.1° to 7° (continuous)	—	●	●
0.005° to 360° (continuous), Strain Sweep, Offset, LAOS	—	○	●
Frequency			
1.67 Hz (100 cpm)	●	●	●
0.001 Hz to 50 Hz, Frequency Sweep	—	○	●
Sealing Pressure			
Fixed: 4.5 bar	●	●	●
Variable: 1 to 8 bar	—	○	●
Sample Pressure Measurement	—	○	○
Air Cooling System (ambient to 230°C)	○	○	●
Enhanced Cooling System (18°C to 230°C)	○	○	○
Isothermal and Non-Isothermal Curing	●	●	●
Non-Linearity Measurements	—	○	●
Stress Relaxation	—	○	●
Advanced Oscillation (arbitrary wave, multi-frequency)	—	○	●
Autosampler	○	○	○

●

Included

○

Optional

—

Not Available

