**DMA: The Technique**

Dynamic mechanical analysis (DMA) measures the modulus (stiffness) and damping (energy dissipation) properties of materials as the materials are deformed under periodic stress. Such measurements provide quantitative and qualitative information about the performance of the materials. DMA can be used to evaluate a wide variety of material types (elastomers, thermoplastics, viscous thermosetting liquids, composites, coatings & adhesives, ceramics, metals). It is particularly useful for evaluating polymeric materials, which exhibit time, frequency, and temperature effects on mechanical properties because of their viscoelastic nature.

Specific material properties provided by DMA include modulus, damping, glass transition and softening temperatures, rate and degree of cure, viscosity, onset of gelation, sound absorption and impact resistance, creep, and stress relaxation. DMA results are used primarily in research and development for investigation into the structure of materials, material development and selection for specific end-use situations, competitive product evaluations and material lifetime performance evaluations. The technique is also used in quality control for process simulation and optimization, vendor certification, and troubleshooting.

**DMA: The Theory**

DMA characterizes materials by applying a sinusoidal stress and measuring the resulting sinusoidal strain (Figure 1). If the material is purely elastic, the phase difference between the stress and strain sine waves is zero degrees. If the material is purely viscous, the phase difference is 90 degrees. Most real-world materials are viscoelastic and, therefore, exhibit a phase difference between those extremes. This phase difference, together with the amplitudes of the stress and strain waves, is used to determine a variety of fundamental material parameters including storage and loss modulus, tan δ, complex and dynamic viscosity, as well as storage and loss compliance. The diagram in Figure 2 shows the relationship between several of those parameters.

The frequency of the applied sinusoidal stress can be extremely low (creep and stress relaxation) or as high as 200Hz. The frequency can also be multiplexed to facilitate extrapolation using time-temperature superposition theory to project material properties at conditions beyond the scope of the DMA.

**DMA: Principles of Operation**

There are several components which are critical to the design and resultant performance of a dynamic mechanical analyzer. These components are the drive motor (which supplies the sinusoidal deformation force to the sample material), the drive shaft support and guidance system (which transfers the force from the drive motor to the clamps which hold the sample), the displacement sensor (which measures the sample deformation that occurs under the applied force), the temperature control system (furnace), and the sample clamps. The TA Instruments DMA 2980 Dynamic Mechanical Analyzer is based on a unique patent-pending design (Figure 3) which optimizes the combination of these critical components. Specifics include:

- **Air Bearing Drive Shaft Support & Guidance System**
  The DMA 2980 drive shaft is attached to the direct drive motor and guided by eight air bearings grouped into two sets of four each near the top and bottom of a rectangular air bearing slide. Pressurized air or nitrogen flows through these bearings and creates a thin layer of air (an air cushion), between the surface of the bearings and the surface of the slide, on which the slide “floats” without contact in a “frictionless” fashion. The slide moves smoothly and freely vertically but lateral movement is prevented by the high resistance to compression of the thin air.
layer. Furthermore, the unique rectangular design of the slide eliminates any possibility for “torquing” (twisting) of the slide, which could occur if the slide were circular. This reduced torquing prevents damage to the sample and results in a purer deformation. The range of continuous vertical travel in the DMA 2980 is 25 mm. This means that large samples (e.g., fibers as long as 30 mm) can be evaluated in the tension mode or that large displacements (oscillation amplitudes to 10,000 microns) can be utilized for determination of the linear viscoelastic region and for fatigue testing. In addition, the inherent resistance of the air bearing to vertical movement is so low that even 10 micron films and 5 denier fibers can be evaluated. The air bearings in the DMA 2980 are made from a porous long-life material and are designed for low air consumption as well as low susceptibility to contamination. The bearings can be operated using “house air” or air generated by an optional compact compressor (Figure 7).

**Non-Contact Direct Drive Motor**

The DMA 2980 uses a non-contact, direct drive motor to provide the oscillatory force which deforms the sample material. The motor is built from high performance composites and other materials which ensure low system compliance and allow the motor to deliver reproducible forces over a wide dynamic range 0.0001 to 18N. The motor is thermostated to eliminate heat build-up even when using large oscillation amplitudes in combination with high deformation forces. Furthermore, the electronics associated with the motor enable the current to the motor to be rapidly adjusted in small increments so that measurements at amplitudes as small as ±0.5 micron can be made.

**Optical Encoder Displacement Sensor**

The DMA 2980 uses an optical encoder to measure displacement. Based on diffraction patterns of light through gratings (one movable and one stationary), optical encoders provide a much higher resolution and better linearity than traditional LVDT’s. The resolution of the DMA 2980 optical encoder is 1 nanometer over the whole displacement range (25 mm), or 1 part in 25,000,000. This high resolution of oscillation amplitude means that both $E'$ and $E''$ precision (±1%) as well as tan delta ($\delta$) sensitivity (0.0001) are excellent. Another benefit of high displacement resolution is the ability to evaluate high modulus materials where, even with the high drive force of the DMA 2980 motor, it is possible to sustain only very small oscillation amplitudes.

**Bifilar Wound Furnace**

The DMA 2980 incorporates a bifilar wound furnace complemented by a liquid nitrogen-based Gas Cooling Accessory (GCA) to cover a broad range of temperature (-150 to 600°C) with excellent temperature precision for transitions (±1°C).

**Automated Gas Cooling Accessory**

A low temperature gas cooling accessory (GCA) provides automated controlled cooling for the DMA 2980. The GCA utilizes cold nitrogen gas generated from controlled heating of liquid nitrogen (Figure 5). Automated filling of the GCA tank can be programmed to occur after a scan. The level of liquid nitrogen in the tank is displayed real-time in percent (%) on the Signal Display screen. Typical cooling times to -100°C are under ten (10) minutes.

**Low Mass, High Stiffness Sample Clamps**

The DMA 2980 features a variety of sample clamps (see later section for details). These clamps were designed using “finite element analysis” to provide high stiffness (minimizes clamp compliance), yet low mass (ensures rapid temperature equilibration). In addition, the clamps are easy to load (assures clamping consistency for reproducible results) and easy to adjust (reduces time and effort to change and recalibrate).
Features and Benefits

The DMA 2980 is the most versatile, cost-effective system available for characterizing the mechanical and viscoelastic properties of materials. Specific features contributing to this versatility include:

- **Multiple Modes of Deformation**, permitting better correlation of measured properties with specific material applications. Single and dual cantilever, 3-point bend, shear sandwich, and compression are available for evaluating solids. Tension is available for fibers and thin films. Additional details on these deformation modes are described on pages 6 and 7.

- **Wide Frequency Range & Frequency Multiplexing**, facilitating a more complete assessment of rheological behavior from a single experiment. The frequency range is 0.01 to 200 Hz (over 4 decades). Up to 28 operator-selected frequencies can be multiplexed at each temperature during an experiment. Furthermore, the ability to work at higher frequencies facilitates material evaluations at multiple decades of frequency for time-temperature superposition studies without sacrificing productivity.

- **Broad Temperature Range**, providing measurement of subtle low temperature transitions as well as characterization of high temperature (mechanical) stability. The range is -150 to 600°C. Heating is provided by a bifilar wound furnace that automatically “swings-away” for easy access to the sample (Figure 4) and which is automatically air-cooled between experiments for rapid turnaround time (increased productivity). Subambient cooling is provided by a high efficiency liquid nitrogen-based Gas Cooling Accessory.

- **Versatile Sample Geometries**, allowing the evaluation of solids, viscous liquids, films (as thin as 5 microns) and fibers (down to 5 denier). Only a small quantity of sample is required to provide precise and accurate viscoelastic information. However, samples as large as 50 mm (L) x 15 mm (W) x 7 mm (T) can be accommodated if necessary to simplify sample preparation.

- **Broad Force and Deformation Ranges**, permitting quantitative modulus evaluations over the range 10³ to 3 x 10¹² Pascals, as well as measurements to determine a material’s linear viscoelastic region and fatigue properties. The DMA 2980 force range is 0.0001 to 18N and deformations of ±0.5 to 10,000 microns are possible depending on sample geometry.

- **High Resolution of Force and Sample Position**, providing the ability to detect subtle material differences. The resultant tan delta sensitivity is 0.0001 and modulus precision is better than ±1%.

- **Static Force & Percent Dynamic Force (ForceTrack)**, dynamic mechanical evaluation in tension, compression, and 3-point bend deformation modes requires a “static force” to be applied to the material. This static force (which is superimposed on the dynamic force) can be constant, or it can be automatically adjusted (ForceTrack) to compensate for modulus changes. The ForceTrack system used in the DMA 2980 allows the static force to be continuously varied as a percent of the dynamic force. For example, as the sample’s modulus decreases (i.e., the material softens), the static force is decreased to prevent undesired dimensional changes.

- **Preview Measurement/Real-Time Signal Display**, after the experimental conditions have been set-up for an experiment, the drive motor can be activated at room temperature and the real-time signals examined to check that the conditions chosen are appropriate for the material. Similarly, the signal display can be monitored during an experiment allowing the operator to closely follow progress of the test.

- **Compact Instrument Design**, reducing bench space requirements. The DMA 2980 measurement transducer and electronics are in a single cabinet.
Multiple Modes of Operation, permitting simulation of a wide variety of end-use time, temperature, force and sample strain situations. Available options are:

- **Temperature Ramp / Single Frequency**
  A linear heating rate is applied while measuring the viscoelastic response at a single frequency. This is the most common mode of DMA operation.

- **Temperature Ramp / Frequency Sweep**
  A linear heating rate is applied while simultaneously scanning through a frequency table pre-selected with up to 28 frequencies. This mode is ideal for evaluating frequency dependent transitions in materials.

- **Temperature Step & Hold / Single Frequency**
  A step & hold temperature profile is applied, and measurements are taken at a single frequency at each isothermal temperature. This mode is recommended for absolute modulus measurements as the sample is allowed to come to thermal equilibrium at each temperature prior to taking measurements.

- **Temperature Step & Hold / Frequency Sweep**
  A step & hold temperature profile is applied, and a frequency sweep is made at each isothermal temperature. This is the recommended mode for time-temperature superposition studies.

- **Strain Sweep**
  Temperature and frequency are held constant while measuring the viscoelastic response to changing operator-selected amplitudes of oscillation. This mode is primarily used to determine the range of linear viscoelastic behavior.

- **Stress / Strain**
  The temperature is held isothermal while force is ramped at a constant rate. This mode is used for generation of stress/strain plots.

- **Creep / Recovery**
  A constant stress is applied to the sample and the resulting strain is measured as a function of time. The creep compliance is calculated by dividing the time dependent strain by the applied stress. Once the creep compliance has reached steady state, the sample recovery can be measured by removing the stress and monitoring the recovered strain as a function of time.

- **Stress Relaxation**
  A constant strain is applied to the sample and the stress required to maintain that strain is measured as a function of time. The stress relaxation modulus is calculated as the time dependent stress divided by the constant strain.

- **TMA Mode**
  This mode, which simulates Thermomechanical Analysis (TMA), enables the user to measure thermal expansion and contraction of materials under a constant load.

Versatile Data Handling, facilitating display of the results in an easily understood format. Data is collected at a rapid rate (2 data points/second) for better resolution of transitions without smoothing. The data can be analyzed using TA Instruments' powerful Thermal Solutions software to yield a wide selection of output signals. The data can also be readily transported to other commercial or custom analysis software if desired.

Compatibility With Other Techniques, permitting cost-effective expansion of your DMA 2980 system as laboratory measurement needs change. Other complementary thermal analysis techniques, including DSC, TGA, TGA/DTA, TMA and DEA, as well as controlled stress and controlled rate rheometers, can be run interchangeably or simultaneously using the same computer-based Thermal Analyst Controller/Data Analyzer.
Modes of Deformation

The DMA 2980 offers all the major deformation modes required to characterize solid bars, thin films, and fibers. The following sections describe those modes which include bending (single cantilever, dual cantilever, 3-point bend), shear, compression, and tension.

SINGLE/DUAL CANTILEVER

In this mode, the sample is clamped at both ends and either flexed in the middle (dual cantilever) or at the one end (single cantilever) [Figure 8]. Single & dual cantilever are good general purpose modes for evaluating thermoplastics and highly damped materials (e.g., elastomers). The dual cantilever is also ideal for studying the cure of supported thermosets.

Several single/dual cantilever clamps are available to accommodate different sample sizes:

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Size</th>
<th>P/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Cantilever</td>
<td>4mm (L). Up to 15mm (W) and 5mm (T)</td>
<td>984048.901</td>
</tr>
<tr>
<td>Dual Cantilever</td>
<td>8mm (L). Up to 15mm (W) and 5mm (T)</td>
<td></td>
</tr>
<tr>
<td>Single Cantilever</td>
<td>10mm (L). Up to 15mm (W) and 5mm (T)</td>
<td>984047.901</td>
</tr>
<tr>
<td>Dual Cantilever</td>
<td>20mm (L). Up to 15mm (W) and 5mm (T)</td>
<td></td>
</tr>
<tr>
<td>Single Cantilever</td>
<td>17.5mm (L). Up to 15mm (W) and 5mm (T)</td>
<td>984015.901</td>
</tr>
<tr>
<td>Dual Cantilever</td>
<td>35mm (L). Up to 15mm (W) and 5mm (T)</td>
<td></td>
</tr>
</tbody>
</table>

3 POINT BEND

In this mode, the sample is supported near its extremities and a probe applies force in the middle (Figure 9). This arrangement is a “purser” deformation mode than single/dual cantilever or tension because clamping effects are eliminated. Furthermore, the 3-point bend mode conforms with the ASTM standard bending test method.

Two 3-point bend clamps are available for the DMA 2980:

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Size</th>
<th>P/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-point bend (small)</td>
<td>5, 10, or 15mm (L). Up to 15mm (W) and 7mm (T)</td>
<td>984026.901</td>
</tr>
<tr>
<td>3-point bend (large)</td>
<td>20 or 50mm (L). Up to 15mm (W) 7mm (T)</td>
<td>984014.901</td>
</tr>
</tbody>
</table>

SHEAR SANDWICH

In this mode, two equal size pieces of the same sample material are sheared between a fixed outer plate and the moving center plate (Figure 10). This arrangement provides a “theoretically pure shear” deformation and is ideal for gels, adhesives, high viscosity resins and other highly damped materials.

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Size</th>
<th>P/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear Sandwich</td>
<td>10mm square. Up to 4mm (T)</td>
<td>984017.901</td>
</tr>
</tbody>
</table>
**COMPRESSON**

In this mode, the sample is placed on a fixed flat surface and force is applied by an oscillating upper plate (Figure 11). Compression is suitable for low to moderate modulus materials (e.g., foams, elastomers), provided the material has some elasticity (i.e., restoring force when compressed). With minor changes, this mode is also capable of making expansion and penetration static force measurements.

Compression clamps are available in two plate sizes. For quantitative results, the sample diameter should be the same as the plates.

<table>
<thead>
<tr>
<th>Type</th>
<th>Diameter (mm)</th>
<th>Thickness (mm)</th>
<th>Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression (small)</td>
<td>15 up to 10</td>
<td>10</td>
<td>984018.901</td>
</tr>
<tr>
<td>Compression (large)</td>
<td>40 up to 10</td>
<td>10</td>
<td>984018.901</td>
</tr>
</tbody>
</table>

**TENSION**

In this mode, the sample is clamped between movable and fixed points and then “stretched” by applying a small static offset force (pretension) prior to evaluation. This static force allows the test oscillation to be sustained by the sample without “buckling”. Hence, this mode is ideal for fibers and thin films, but is also suitable for evaluating smaller samples of high modulus materials. In addition, constant force and force ramp measurements are possible.

A thin film tension clamp (Figure 12) and a fiber tension clamp (Figure 13) are available. The former accommodates both films and fibers, but the latter clamp is recommended for fibers because it provides easier and more uniform clamping.

<table>
<thead>
<tr>
<th>Type</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Thickness (mm)</th>
<th>Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (film)</td>
<td>5 to 30</td>
<td>up to 8</td>
<td>2</td>
<td>984016.901</td>
</tr>
<tr>
<td>Tension (fiber)</td>
<td>5 to 30</td>
<td>0.57 to 0.8</td>
<td></td>
<td>984023.901</td>
</tr>
</tbody>
</table>

**GENERIC GEOMETRY FACTORS & DIMENSIONS**

The DMA 2980 can accommodate a variety of standard sample shapes. These include rectangles, solid cylinders, hollow tubes, and fibers. The calculation of modulus and other parameters from the experimental results for these standard shapes generally requires accurate measurement of sample dimensions, such as length, width and thickness for rectangles, and length, inside and outside diameters for tubes. However, the DMA 2980 also allows modulus and related parameters to be calculated for non-standard sample shapes using only generic geometry factors. In the bending deformation modes, for example, the sample length, cross-sectional area and geometric moment are used. This flexibility allows “real-world” shapes such as elastomeric windshield wiper blades to be evaluated directly without special sample preparation.
Applications

The following examples illustrate some typical DMA applications and highlight the quality of results provided by the DMA 2980.

Material Selection for Specific End-Use Applications

The task of evaluating new materials and projecting their performance for specific applications is a challenging one for engineers and designers. Often materials are supplied with short-term test information such as deflection temperature under load (DTUL), which is used to project long-term, high temperature performance. However, because of factors such as polymer structure, filler loading and type, oxidative stability, part geometry, and molded-in stresses, the actual maximum long-term use temperatures may be as much as 150°C below or above the DTUL. Dynamic mechanical analysis, on the other hand, continuously monitors material modulus with temperature and hence, provides a better indication of long-term, elevated temperature performance. Figure 14 shows the DMA modulus curves for polyphenylene sulfide obtained using the 3-point bend mode. In this case, the amorphous phase in the semi-crystalline structure of the material causes it to lose a substantial portion of its modulus at the glass transition. This means that the material’s actual long-term performance will probably be worse than projected by the DTUL which occurs closer to the melt.

Evaluation of Elastomer Properties

The DMA is a convenient method for rapidly comparing the performance of materials. Figure 15, for example, shows a comparison of automobile wiper blades from two different suppliers over a temperature range which covers the extremes potentially seen in end-use. The DMA results indicate that Blade A maintains its flexibility to a lower temperature (e.g., it has a lower glass transition temperature). More importantly, because of the unique ability of the DMA 2980 to quantitatively evaluate materials in their “real-world” form, this comparison can be made easily without cutting pieces to achieve well-defined dimensions.

Figure 15 shows the changes in modulus and damping properties as a function of temperature. In elastomers, there are also situations where modulus changes with amount of strain (deformation) are important. Figure 16 shows an automotive elastomer evaluated at ambient temperature under varying strain levels. Many elastomers exhibit a phenomenon called the “Mullens effect”, where the elastomer’s modulus not only decreases as the % strain increases, but on subsequent reruns remains at a lower value. This modulus decrease is the result of breakdown of low energy bonds in the elastomer. If sufficient time is allowed, however, these bonds “rebuild” and the elastomer’s modulus returns to its initial level. Understanding this phenomenon is important in applications like wiper blades where the modulus decreases as the blade moves across the windshield at different speeds and recovers once the blade is again at rest.
Polymeric materials, because of their viscoelastic nature, exhibit behavior during deformation and flow which is both temperature and time (frequency) dependent. For example, if a polymer is subjected to a constant load, the deformation or strain (compliance) exhibited by the material will increase over a period of time. This occurs because the material under a load undergoes molecular rearrangement in an attempt to minimize localized stresses. Hence, compliance or modulus measurements performed over a short time span result in lower/higher values respectively than longer-term measurements. This time-dependent behavior would seem to imply that the only way to accurately evaluate material performance for a specific application is to test the material under the actual temperature and time conditions the material will see in the application. This implication, if true, would present real difficulties for the materials scientist because the range of temperatures and/or frequencies covered by a specific instrument might not be adequate, or at best might result in extremely long and tedious experiments.

Fortunately, however, there is a treatment of the data, designated as the method of reduced variables or time-temperature superposition (TTS), which overcomes the difficulty of extrapolating limited laboratory tests at shorter times to longer-term, more real-world, conditions. This TTS treatment is well grounded in theory and can be applied to the data obtained from DMA multi-frequency experiments.

The underlying bases for time-temperature superposition are (1) that the processes involved in molecular relaxation or rearrangements in viscoelastic materials occur at accelerated rates at higher temperatures and (2) that there is a direct equivalency between time (the frequency of measurement) and temperature. Hence, the time over which these processes occur can be reduced by conducting the measurement at elevated temperatures and transposing (shifting) the resultant data to lower temperatures. The result of this shifting is a “master curve” where the material property of interest at a specific end-use temperature can be predicted over a broad time scale.

Figures 17-19 show TTS results for an epoxy composite. Figure 17 shows the DMA multifrequency curves obtained over four decades (0.1 to 100Hz). The ability of the DMA 2980 to obtain data at 100Hz and above shortens the experimental time required to obtain the 4 decades of frequency required for good TTS extrapolations. Figure 18 shows the master curve obtained by combining the multifrequency experiments. Note that the behavior of the epoxy (at 148°C) can be projected to higher frequencies that simulate end-use conditions well beyond the 4 decades used in the experiment. Figure 19 represents the fit of the data to the William-Landel-Ferry (WLF) equation. The good fit verifies the quality of the extended projections and confirms that the epoxy follows this model.
DMA provides a variety of information about viscoelastic materials such as the silicone gum shown in Figures 20 and 21. To accurately evaluate the relationship between molecular structure and viscoelastic behavior it is important to conduct measurements in the material’s linear viscoelastic region. Dynamic oscillatory experiments at a constant temperature should yield a constant modulus value with increasing stress (applied force) or strain (oscillation amplitude) unless the conditions used force the material to depart from linear viscoelastic behavior. Figure 20 shows that the linear viscoelastic region is exceeded once the oscillation amplitude exceeds roughly ±300 microns for this gel.

As described in the previous section on time-temperature superposition, the behavior of viscoelastic materials depends to some extent on the time frame of measurement (oscillation frequency). Figure 21 indicates that this gel has more elastic behavior above 1 Hz and more viscous behavior at longer measurement times (lower frequencies). Shear deformation is the best mode for evaluating low modulus materials particularly at low frequencies because the level of elasticity present is insufficient to sustain oscillation in the compressional mode.

**Determination of Curing Behavior**

Thermosetting liquids such as prepregs, adhesives, and paints/coatings can be evaluated by DMA (dual cantilever mode) using a supporting structure such as fiberglass braid. In these experiments, information about the curing properties (e.g., onset of cure, gel point, vitrification) can be obtained as the material progresses from a liquid to a rigid solid. Figure 22 illustrates the results for an epoxy. By following the changes in modulus with time, it is possible to observe the initial softening of the material as the temperature is raised to the final cure temperature, as well as the onset and completion of a two-stage curing process.

**Evaluation of Thin Films**

Films as thin as 5 micron (about 0.02 mils) can be evaluated by the DMA 2980 using the tension mode. Figure 23 illustrates typical results obtained on a 100 micron polyethylene terephthalate (PET) packaging film. The glass transition and onset of melting are easily observed in both modulus and damping curves. In addition, the weaker β transition is seen at -75°C. The curves shown represent three experiments on three separate pieces of the film overlaid to illustrate the excellent reproducibility of the DMA 2980. Not only does the level of reproducibility show that the potential “operator effects” associated with clamping are eliminated by the design of the DMA 2980 tension clamps, but the results also show the excellent subambient temperature control of the DMA 2980. This latter point is most evident in Specimen 2 where the experiment was started at essentially the β transition peak temperature in the tan δ curve, and yet the tan δ values obtained are in excellent agreement.

In polymers, the molecular motions of side groups or smaller sections of the polymer chain result in the appearance of secondary damping peaks in the DMA tan δ curve, such as seen in Figure 23 at -75°C. In addition, the DMA can quantitatively measure the Activation energy associated with this transition. Damping transitions account for desirable end-use properties such as noise abatement, vibration dissipation, and impact strength.
**Determination of Orientation Effects in Films**

The properties of films measured in the DMA tension mode are influenced by orientation effects resulting from production of the film. Figure 24 shows the shrinkage behavior of a biaxial polyester film evaluated both parallel to and perpendicular to (transverse) the roller direction (machine direction) during processing. The film shrinks more significantly with temperature in the machine direction due to the release of tension built-up during the rolling process. These results were obtained during a standard DMA autotension experiment at 1Hz where the static force changed throughout the experiment to maintain a constant “offset displacement”. The DMA 2980 also allows the static force to be held constant throughout the experiment.

**Film and Fiber Stress/Strain Measurements**

Stress/strain measurements are widely used to characterize films and fibers over a broad range of viscoelastic behavior. Although conventional physical testing devices can accommodate thin films and single-filament fibers, the results are difficult to obtain and the accuracy is doubtful since the mass and inertia of the grips is much greater than the tensile strength of the material being evaluated. The clamping arrangements and force range of the DMA 2980 are more suitable for examining these materials. Curves like that shown in Figure 25 for a polyethylene film can be obtained by ramping the force (stress). The broad range of travel for the DMA 2980 (25mm) allows the behavior of this 4mm long film to be completely characterized through breaking.

**Characterization of Monofilament Fibers**

The quality of results obtained from the DMA 2980 is high even in demanding applications such as the characterization of monofilament fibers (Figure 26). In this example, evaluation of a 20 micron diameter PET monofilament in stepwise isothermal multifrequency mode produces smooth curves which are ideal for TTS evaluation.

**Analysis of Foods**

Although DMA is primarily used to characterize polymers (thermoplastics, thermosets and elastomers), the technique also is applicable to metals, biological materials, and foods. The compression mode, for example, provides insight into the texture and transition temperatures of non-homogeneous materials such as cooked potatoes (Figure 27), where the modulus varies with temperature as the surface moisture evaporates (modulus increase), softening occurs as cooking “initiates” (modulus decrease), and starch gelation occurs (modulus increase).
**SPECIFICATIONS**

**Viscoelastic Measurement Performance:**
- **Modulus Range (dependent on geometry):** $10^4$ to $3 \times 10^{12}$ Pascals
- **Modulus Precision:** ±1%
- **Frequency Range:** 0.01 to 200 Hz in 0.01 increments at lower frequencies, 1.0 Hz increments at higher frequencies
- **Maximum Force:** 18 Newtons
- **Minimum Pretension (for tensile):** 0.001 Newtons
- **Tan δ (delta) Range:** 0.0001 to 10
- **Tan δ Sensitivity:** 0.0001
- **Dynamic Sample Deformation Range:** ±0.5 to 10,000 µm
- **Strain Resolution:** 1 nanometer

**Temperature Control Performance:**
- **Temperature Range:** -150 to 600°C
- **Heating Rate:** 0.1 to 50°C/min in 0.1°C/min increments
- **Cooling Rate:** 0.1 to 10°C/min to -100°C
- **Isothermal Stability:** ±0.1°C
- **Automated Furnace Movement:** Yes

**Deformation Modes & Sample Sizes:**
- **3-Point Bend:** 5, 10, 15, 20 and 50 mm lengths, width to 15 mm, thickness to 7 mm
- **Single Cantilever:** 4, 10 and 17.5 mm lengths, width to 15 mm, thickness to 5 mm
- **Dual Cantilever:** 8, 20 and 35 mm lengths, width to 15 mm, thickness to 5 mm
- **Shear Sandwich:** 10 mm square, to maximum of 4 mm thickness each side
- **Tension:** 5 to 30 mm length, width to 8 mm, thickness to 2 mm
- **Compression:** Parallel plates, 15 and 40 mm diameter

*Sample sizes do not include material in clamp*

**Modes of Operation:**
- **Autotension Modes:** Constant Force; Percent Dynamic Force
- **Preview Measurement:** Quick single modulus measurement at one frequency at room temperature
- **Temperature Ramp/Single Frequency:** Linear heating rate applied while measuring the viscoelastic response at a single frequency
- **Temperature Ramp/Frequency Sweep:** Linear heating rate applied while simultaneously scanning through a frequency table preselected with up to 28 frequencies
- **Temperature Step & Hold/Frequency Sweep:** Temperature stepped and held isothermal for a selectable amount of time followed by a frequency sweep after which the temperature is stepped to the next isothermal for another frequency sweep
- **Constant Temperature/Strain Sweep:** Isothermal temperature and constant frequency while measuring the viscoelastic response to operator-selected amplitudes of oscillation

**Output Values Available:**
- Storage Modulus
- Loss Modulus
- Tan Delta (δ)
- Complex Viscosity
- Dynamic Viscosity
- Storage Compliance
- Loss Compliance
- Stress

**Temperature Ramp/Linear heating rate applied while measuring the viscoelastic response at a single frequency**

**Temperature Step & Temperature stepped and held isothermal for a selectable amount of time followed by a frequency sweep after which the temperature is stepped to the next isothermal for another frequency sweep**

**Constant Temperature/Isometric temperature and constant frequency while measuring the viscoelastic response to operator-selected amplitudes of oscillation**

Specifications are subject to change.

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**TA INSTRUMENTS COMMITMENT**

TA Instruments thermal analysis and rheology products are designed and engineered to assure easy, reliable, trouble-free operation. It is supported by a full range of services, including an applications laboratory, publications, training courses, seminars, training and applications CD’s, an internet website and a telephone Hotline for customer consultation. Highly qualified service personnel, specializing in thermal analyzer/rheometer maintenance and service, are available throughout the world. All of these items reflect TA Instruments commitment to providing thermal analysis & rheology products and related support services that deliver maximum value for your investment.

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