

Analyzing & Testing

## Dynamic Mechanical Analysis

Method, Technique, Applications



Leading Thermal Analysis ■

# Dynamic Mechanical Analysis – DMA 242 E *Artemis*

## The Most Versatile DMA in the World

Dynamic Mechanical Analysis (DMA) is an indispensable tool for determining the visco-elastic properties of mainly polymer materials.

The new DMA 242 E *Artemis* combines ease of handling with the user-friendly *Proteus*® measurement and evaluation software. This makes it fast and easy to characterize the dynamic-mechanical properties as a function of frequency, temperature and time.

Its modular design along with a wide variety of sample holders and cooling systems allow the DMA 242 E *Artemis* to handle a broad range of applications and samples. Various add-on options make it the ideal device for any laboratory and a safe investment for the long-term.

### Add-on Options

- Immersion bath for measurement of samples in a defined medium
- Coupling to the dielectric analyzer DEA 288 *Epsilon* for simultaneous measurement of the visco-elastic and dielectric property changes, e.g., during curing of a resin
- Coupling to a UV lamp for measuring curing on light-reactive samples
- Coupling to a humidity generator to determine the influence of humidity on the dynamic-mechanical properties of a material

### Hang-down design

for easy accessibility, handling and changing of the different sample holders

### Controlled gas flow (inert or oxidizing)

with optimal heat transfer on samples for defined measurement conditions

### Various cooling options

Two different cooling systems; liquid nitrogen-controlled cooling to -170°C and compressed-air cooling with vortex tube to cool to 0°C



**Controlled force range up to 24 N**  
(12 N static and 12 N dynamic) for  
measurements of very stiff samples.  
Increased resolution in the measuring  
range 4 N static and 4 N dynamic

**A stepper motor with a 20-mm  
travel range**  
allows for precise testing on materials  
which exhibit substantial changes in  
length during a DMA measurement.  
This is particularly important for the  
different static experiments available  
with the DMA 242 E Artemis; i.e.,  
creep, relaxation and TMA mode

**Over 30 different sample holders**  
for optimal adjustment of measure-  
ment conditions to material properties

DMA 242 E Artemis

# Dynamic Mechanical Analysis – DMA 242 E Artemis

## Functional Principle

Dynamic Mechanical Analysis measures the visco-elastic properties of mostly polymer materials during a controlled temperature and/or frequency program.

During the test, a sinusoidal force (stress  $\sigma$ ) is applied to the sample. This results in a sinusoidal deformation (strain  $\epsilon$ ).

Certain materials, such as polymers, exhibit visco-elastic behavior; i.e., they possess both elastic characteristics (such as ideal spring) and viscous ones (such as ideal dashpot).

This visco-elastic behavior causes shifting of the corresponding stress and strain curves. The deviation is the phase shift  $\delta$ .

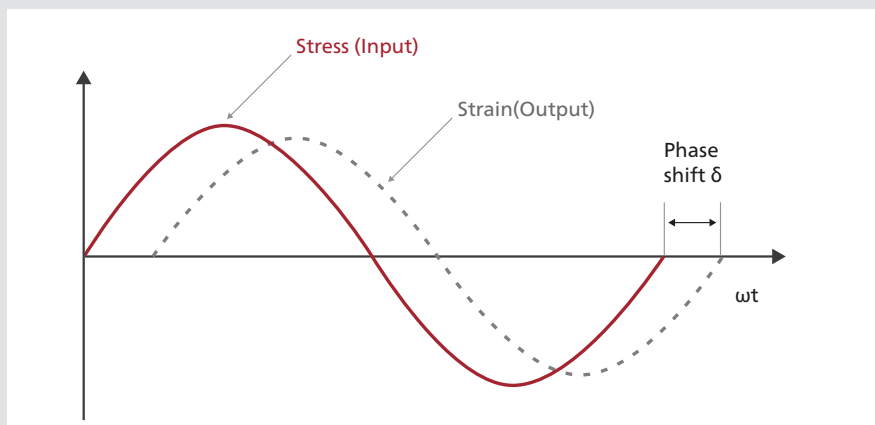
The response signal (strain,  $\epsilon$ ) is split into an "in-phase" and an

"out-of-phase" part by means of Fourier Transformation.

The results of this mathematical operation are the storage modulus  $E'$  (related to the reversible, "in-phase" response) and the loss modulus  $E''$  (related to the irreversible, "out-of-phase" response).

The loss factor  $\tan\delta$  is the ratio between the loss modulus and the storage modulus ( $\tan\delta = E''/E'$ ).

Generally, the storage modulus ( $E'$ ) refers to the material's stiffness whereas the loss modulus ( $E''$ ) is a measure for the oscillation energy transformed into heat.  $\tan\delta$  characterizes the mechanical damping or internal friction of a visco-elastic system.



DMA – Measurement principle

## Resulting Data

Complex DMA Variable	Real Part	Imaginary Part
Complex modulus $/E^*$	Storage modulus $E'$	Loss modulus $E''$
Shear modulus $/G^*$	Storage shear modulus $G'$	Loss shear modulus $G''$
Compliance $/D^*$	$D'$	$D''$
Total amplitude $/A^*$	$A'$	$A''$
Total sample amplitude $/As^*$	$As'$	$As''$
Total sample force $/Fs^*$	$Fs'$	$Fs''$
Stiffness $c^*$	Spring constant $c'$	Spring constant $c''$

## General Data

Static length change $dL$
Offset
Total dynamic force $F_{dyn}$
Static sample force $F_{stat}$
Loss factor $\tan\delta$

# Dynamic Mechanical Analysis – DMA 242 E Artemis

## Dynamic Mechanical Testing Supports Research and Quality Control of Polymers

### R&D

The DMA method is a very sensitive tool for generating data that can help define the mechanical properties of polymers and composites in order to support product development in industries such as automotive.

### Quality Control

$\alpha$ - and  $\beta$ - transitions can be used to compare production with standards and competitors' products. Our DMA experts support you by finding the right approach for specific applications and areas of interest.



DMA 242 E Artemis

### DMA Measurement Information

- Design data concerning stiffness and damping properties (modulus values and damping factor under a variety of conditions)
- Data on the composition and structure of polymer blends (compatibility)
- Glass transition temperature of highly cross-linked, amorphous or semi-crystalline polymers and composites
- Curing / post-curing
- Aging
- Creep and relaxation
- Stress and strain sweeps
- Multi-frequency tests
- Prediction of the material behavior using Time-Temperature-Superposition (TTS)
- Immersion tests

## Technical Key Data of the DMA 242 E Artemis

Temperature range	-170°C to 600°C
Heating rate	0.01 to 20 K/min
Frequency range	0.01 to 100 Hz
High force range	24 N (12 N static and 12 N dynamic)
High resolution force range	8 N (4 N static and 4 N dynamic)
Maximum controlled strain amplitude	± 240 µm
Static deformation	Up to 20 mm
Modulus range	10 <sup>-3</sup> to 10 <sup>6</sup> MPa
Damping range (tanδ)	0.005 to 100
Cooling device	<ul style="list-style-type: none"> <li>▪ Liquid nitrogen</li> <li>▪ Compressed air with vortex tube for cooling to 0°C</li> </ul>
Deformation modes	<ul style="list-style-type: none"> <li>▪ 3-point bending</li> <li>▪ Single / dual cantilever bending</li> <li>▪ Shearing</li> <li>▪ Tension</li> <li>▪ Compression / penetration</li> </ul>
Additional measurement modes	<ul style="list-style-type: none"> <li>▪ TMA mode</li> <li>▪ Creep / relaxation</li> <li>▪ Stress / strain sweep</li> </ul>
Sample geometries	Dependent on the deformation mode, e.g. for 3-point bending max. sample dimensions: length: 60 mm, width: 12 mm, thickness: 5 mm
Optional accessories	<ul style="list-style-type: none"> <li>▪ Immersion bath</li> <li>▪ Humidity generator</li> <li>▪ UV equipment</li> <li>▪ Dielectric Analyzer (DEA)</li> </ul>

# Sample Holders For Different Modes

## Sample Holders for Any Application

From liquids to highly-filled thermosets to metals and ceramics – all such materials can be measured with the DMA 242 E *Artemis*. Accurate results require optimal adaptation of the test conditions to the materials

and applications. That is why NETZSCH has developed a wide range of sample holders, accessories and measurement modes. All sample holders available are listed in the tables below and on the following pages.

Sample Holder		Sample Dimensions		Applications
SINGLE/DUAL CANTILEVER	Free Bending Length*	Width (max.)	Height (max.)	
Standard	(2x)1 mm	12 mm	5 mm	Thermoplastics, elastomers
	(2x)5 mm	12 mm	5 mm	
	(2x)16 mm	12 mm	5 mm	
	(2x)17 mm	12 mm	5 mm	
Standard, stiff clamp	17 mm	12 mm	5 mm	For determination of the glass transition (T <sub>g</sub> ) of reinforced polymers used in the aircraft industry
Free pushrod	20 mm	12 mm	5 mm	Very stiff samples; e.g., CFRP
3-POINT BENDING	Free Bending Length*	Width (max.)	Height (max.)	
Standard	10 mm	12 mm	5 mm	Fiber-reinforced or highly filled thermoplastics, metals, ceramics
	20 mm	12 mm	5 mm	
	40 mm	12 mm	5 mm	
	50 mm	12 mm	5 mm	
Knife-edged	20 mm	12 mm	5 mm	Stiff fiber-reinforced or highly filled polymers, metals
	40 mm	12 mm	5 mm	
TENSION	Free Tension Length* (max.)	Ø/Width/Thickness (max.)		
Standard	15 mm	6.8 mm		Films, fibers, thin rubber stripes

\* Remark: The samples must be greater in length than the free bending and free tension length values listed here.



Sample Holder	Sample Dimensions			Applications
COMPRESSION/ PENETRATION	Sample Ø (max.)	Pushrod Ø [mm]	Height (max.)	
Standard	15 mm	0.5, 1, 3, 5, 15	6 mm	Soft samples; e.g., rubber
	30 mm	0.5, 1, 3, 5, 15, 30	6 mm	
SHEARING	Ø/Width/Height (max.)	Thickness (max.)	Cross section	
With flat surfaces	15 mm	6 mm	225 mm <sup>2</sup>	Adhesives, elastomers
With grooved surfaces	15 mm	6 mm	225 mm <sup>2</sup>	Adhesives, pastes



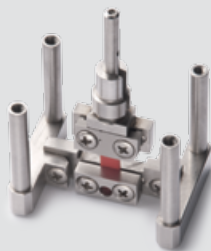
Sample holder for 3-point bending



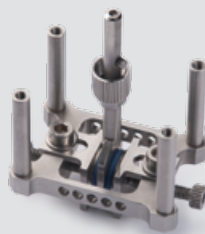
Sample holder for single/dual cantilever



A variety of sizes for frame and pushrods guarantee optimal adaptation of the compression/penetration sample holder to the test parameters.



Sample holder for tension



Sample holder for shearing

## Wide Choice of Special Sample Holders

Special Sample Holder for Compression/ Penetration	Sample Dimensions			Applications
	Sample Ø (max.)	Pushrod Ø	Height (max.)	
With pushrod made of fused silica and free alumina disk	15 mm	5 mm	6 mm	Insulation foams
With sample insert	7 mm	3 mm	2.5 mm	Curing of pasty samples with higher viscosity
With ball-shaped pushrod	Container: Ø 19 mm, height 15 mm Pushrod ball: Ø 8 mm			Curing of viscous samples
Fused silica window for UV light	15 mm	15 mm	6 mm	Curing of UV-sensitive materials
For simultaneous DMA- DEA measurements	15 mm	15 mm	6 mm	Curing of reactive resins



Sample holder for measurements on liquid or pasty samples in compression with insert



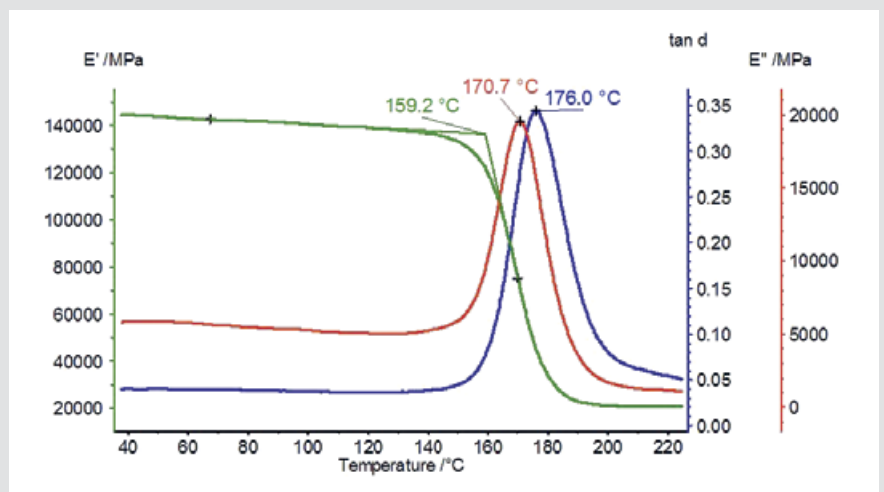
Sample holder for single cantilever bending with free pushrod, especially used for stiff materials



## Young's Modulus of a CFRP

The single cantilever sample holder with free pushrod was specially developed to accurately measure very stiff materials. The sample is tightly fixed at one end and a free pushrod oscillates at the other end.

The results of a DMA test on a carbon fiber-reinforced epoxy resin are presented in the plot to the right. The high storage modulus at 50°C (approx. 145,000 MPa) indicates that this material is even stiffer than metallic titanium. The drop in the curve at 159°C (onset temperature), related to the maxima in the loss modulus and loss factor curves at 171°C and 176°C, marks the glass transition of the epoxy matrix.

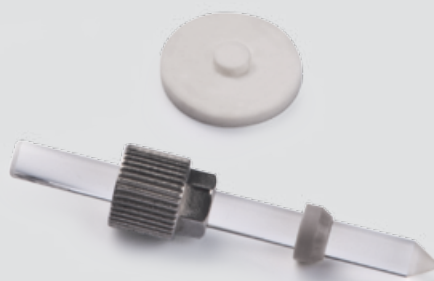


DMA measurement on a very stiff, carbon fiber-reinforced epoxy resin  
 Sample holder: single cantilever bending; 20-mm with free pushrod  
 Measurement parameters: heating rate 3 K/min, frequency: 10 Hz, amplitude:  $\pm 40 \mu\text{m}$

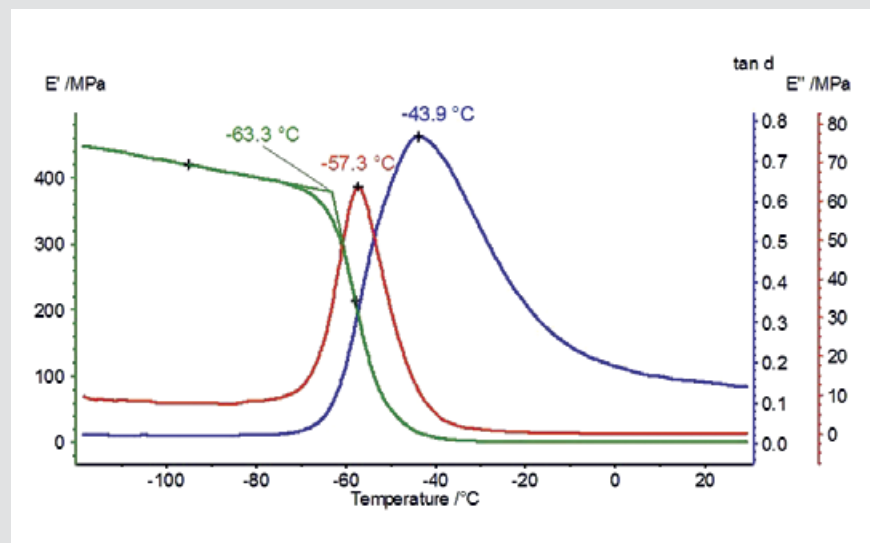
# Wide Choice of Special Sample Holders

## Sample Holder for Insulation Foams

Because of the very low heat conductivity of foams and insulation materials, heat can be lost if a standard metallic pushrod is used. It is thus advisable to work with the fused silica pushrod with free disk made of alumina especially developed for measurements in the compression mode.



Pushrod made of fused silica with free alumina disk



Compression measurement on an insulation foam (height 5 mm)  
Sample holder: compression with fused silica pushrod / alumina disk  
Measurement parameters: -120°C to 30°C at 2 K/min, frequency: 10 Hz, amplitude:  $\pm 30 \mu\text{m}$

## Visco-elastic Properties of a Foam

Insulation foams are increasingly important in the building industry for both new construction and building renovation. They help to lower energy consumption by preventing heat loss through the walls.

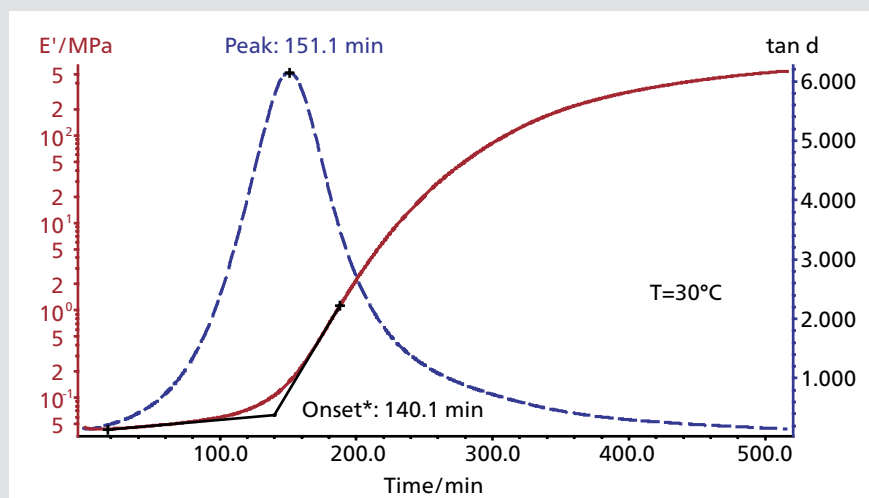
This plot shows a measurement on an insulation foam between -120°C and 30°C at a frequency of 10 Hz.

The decrease in the storage modulus curve beginning at -63°C is related to the peaks at -57°C (loss modulus) and at -44°C ( $\tan\delta$ ). It corresponds to the glass transition of this insulation material, thereby limiting the application range.

## Curing of a Liquid Epoxy Adhesive

The results of DMA measurements on a liquid epoxy adhesive are shown in the plot below. The sample holder with container and ball-shaped pushrod, which was developed for the curing of liquids, was used for the testing. The sharp increase in storage

modulus after 140 minutes (time onset) results from the curing reaction. It is related to a peak at 151 minutes in the  $\tan \delta$  curve. The further increase of the storage modulus value after approximately 500 minutes indicates that the curing has not been finished.



DMA measurement using the sample holder with ball-shaped pushrod  
 Sample: epoxy adhesive  
 Sample holder: compression sample holder with container and ball-shaped pushrod  
 Measurement parameters: isothermal 30°C, frequency: 1 Hz, amplitude:  $\pm 20 \mu\text{m}$



Special sample holder with ball-shaped pushrod for curing of high-viscous liquids

# Wide Selection of Accessories – Influence of Humidity and Immersion

## An Add-On for Each Special Application

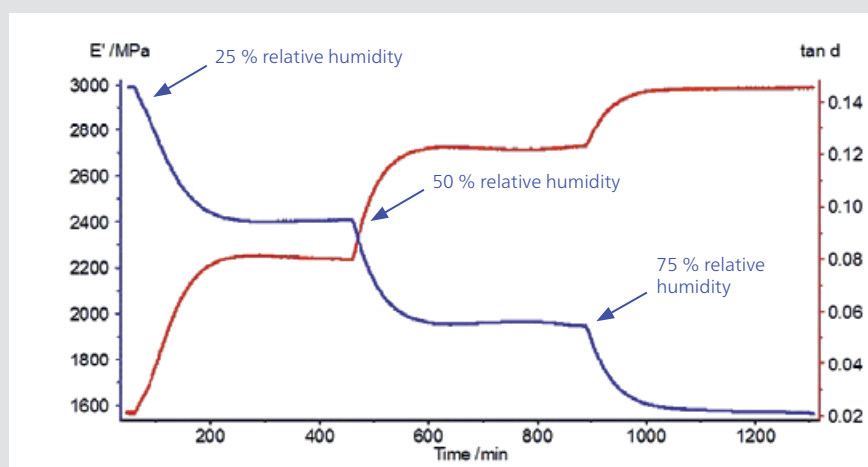
In addition to its broad selection of sample holders, the DMA 242 E *Artemis* offers a great deal of other optional accessories. A humidity generator, for example, can easily be

connected to the furnace. Measurements can then be carried out with a purge gas containing a defined amount of humidity. This add-on is useful for studying the influence of

humidity on the dynamic-mechanical properties of water-sensitive samples such as polyamides and polyesters.

### Influence of Humidity on the Mechanical Properties of a Polyamide Film\*

For this example, a polyamide film was dried and measured with the humidity generator in the tension mode. At the beginning of the test, the humidity generator was switched off and the storage modulus was constant at approx. 3000 MPa. As soon as humidity was introduced into the furnace, the storage modulus of the polymer decreased sharply; it reached a plateau at approx. 2400 MPa. Increasing the humidity content to 50% and 75% (after 7 hours and 14 hours) led to further decreases in the storage modulus. These results show that the humidity content has a great influence on the storage modulus of polyamide because water acts as a plasticizer on polymers.



#### DMA measurement with humidity generator

Sample: polyamide film (thickness: 50  $\mu\text{m}$ )

Sample holder: tension

Measurement parameters: isothermal 30°C, frequency: 1 Hz, amplitude:  $\pm 75 \mu\text{m}$

Humidity generator parameters: relative humidity: 25%, 50%, 75% at 30°C, purge gas: 10 ml/min  $\text{N}_2$

\*Our thanks go to Prof. Dr. T. Rödel and M. Wendt from the University of Applied Sciences in Merseburg for the measurement and discussions.

## Easy Measurement in Liquids: Immersion Bath

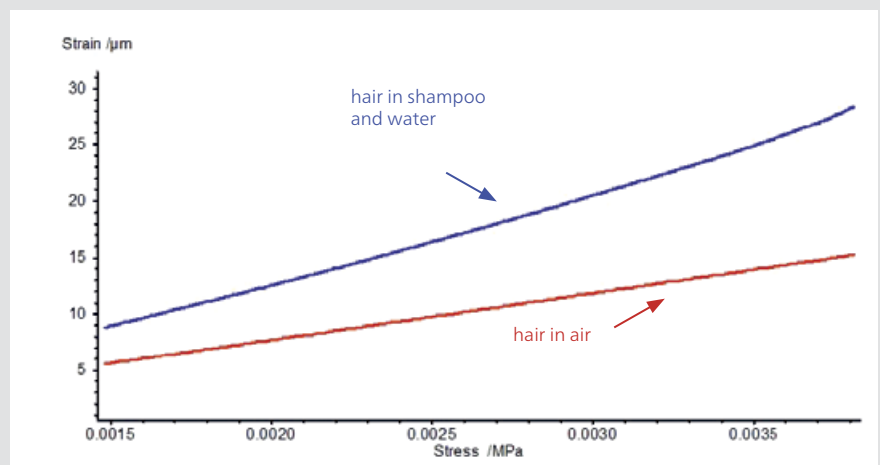
An immersion bath can be used in combination with any of the available sample holders to check the influence of a given liquid on the visco-elastic properties of a material. Because the immersion bath is inserted into the standard furnace, the temperature can be varied at will during the measurement. The only restriction is the evaporation/decomposition temperature of the solvent.



Container for immersion tests

## Influence of Shampoo on Human Hair

Stress-sweep tests were carried out on a human hair in an air atmosphere and in a mixture of water and shampoo. The same hair was used for both measurements. The force was varied from 0.1 N to 1 N and the strain was measured. The plot represents the stress-strain plot for both measurements. The curves differ in their slope: the hair has a lower storage modulus – i.e., is softer – when in contact with the mixture of water and shampoo than with air.



Influence of shampoo on the hair softness

Sample: Human hair (thickness between 70 μm and 80 μm)

Measurements parameter: tension mode, temperature: 25°C, frequency: 1 Hz, force varied between 0.1 and 1 N

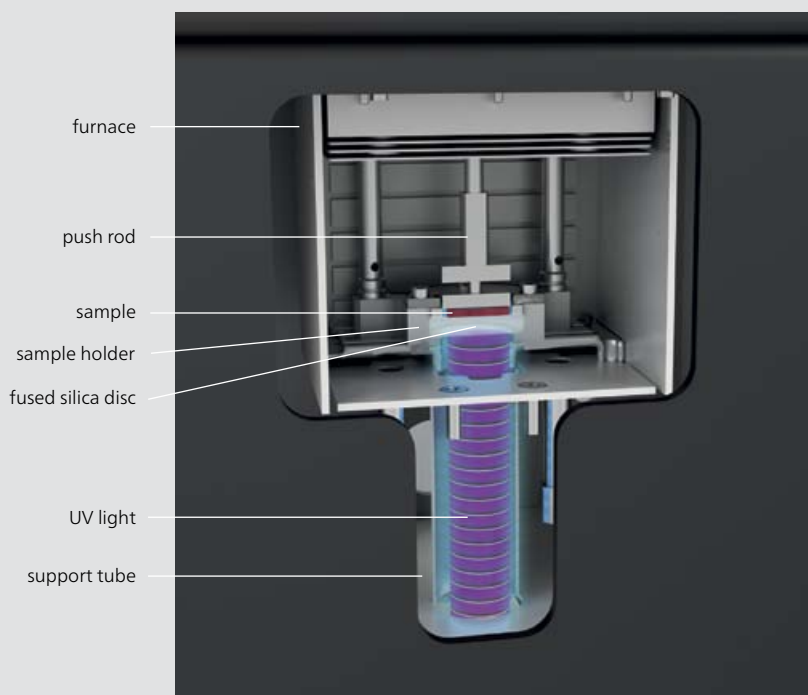
## Wide Choice of Accessories – UV Add-on and DMA-DEA

### Light-Curing: UV Add-On

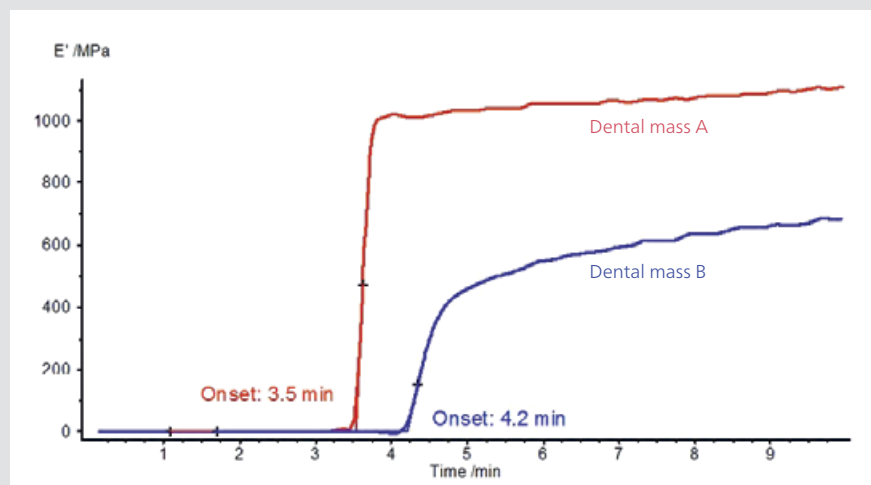
The furnace of the DMA 242 E *Artemis* can be connected to a light source in order to measure the curing of UV-reactive materials. A special compression sample holder allows the light to pass through a fused silica window.



Special sample holder with fused silica window for DMA measurements under the influence of UV light



Instrument set-up for connecting the DMA 242 E *Artemis* to a light source

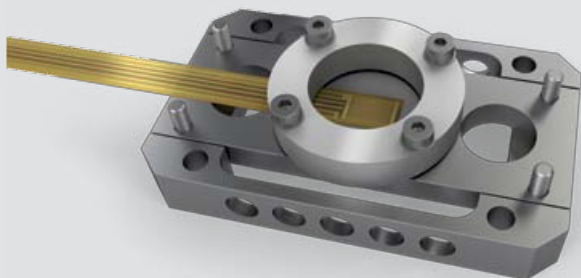


Comparison of the curing behavior of two dental masses  
Measurements parameter: compression mode, temperature: 30°C, frequency: 10 Hz, amplitude:  $\pm 15 \mu\text{m}$

### Light Curing of Two Dental Masses

The curing behavior of two dental masses under light were compared. The storage modulus of dental mass A (red) increased sharply after 3.5 minutes, which can be attributed to curing of the material. The reaction of dental mass B (blue) began nearly one minute later and ran more slowly, as can be seen by comparing the slopes of the two materials. The difference in the final storage moduli (1100 MPa for dental mass A and 700 MPa for dental mass B) is due to differences in the mechanical properties of the cured products.

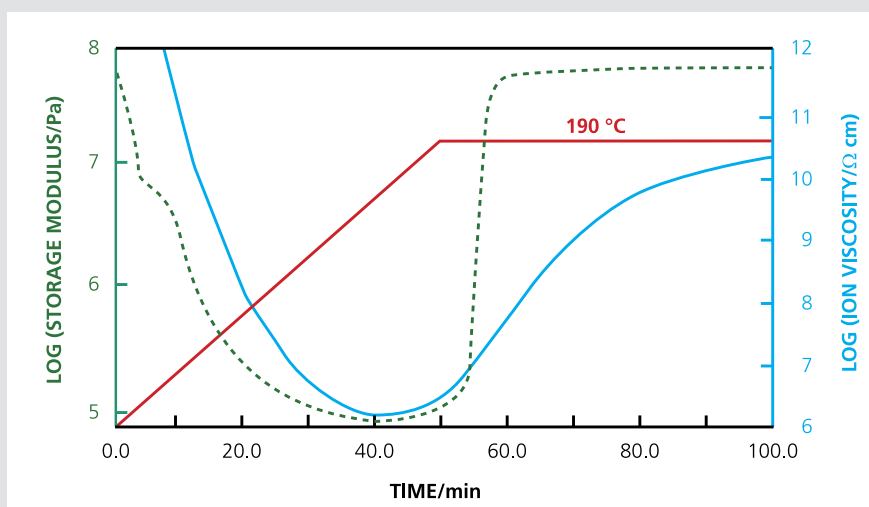




Sample holder for simultaneous DMA-DEA

## Simultaneous DMA-DEA: Two Measurements in One

DEA (Dielectric Analysis) is a method for determining the curing behavior of reactive resins by monitoring the ion viscosity. In the DMA-DEA coupling test, the DEA sensor is set on a special compression sample holder, and both DMA and DEA measurements run simultaneously during the same temperature program.



### Curing of an epoxy resin

Sample holder: special compression sample holder for DMA-DEA

Measurement parameters: room temperature to 190°C at 3 K/min and isothermal at 190°C, frequency: 10 Hz

## DMA-DEA Measurement on an Epoxy Resin

In this example, an uncured epoxy resin was heated to 190°C and the temperature was kept constant. The initial decrease in the storage modulus and ion viscosity during heating is due to softening of the sample. The increase in the storage modulus is related to the beginning of curing. The subsequent sharp increase in storage modulus demonstrates the sensitivity of DMA at the beginning of the curing reaction.

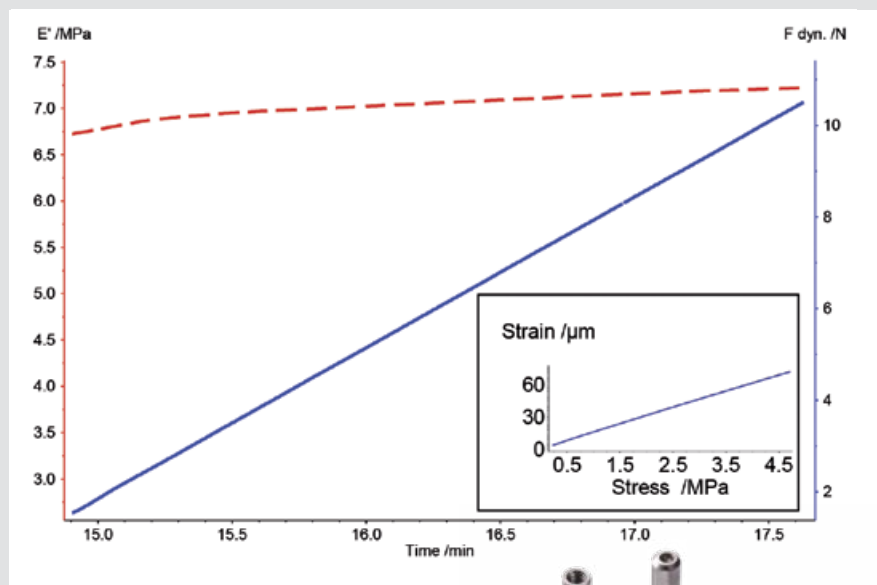
During the isothermal hold at 190°C, the storage modulus stabilizes in compression mode. However, the ion viscosity continues to increase; the more sensitive DEA method makes it possible to determine that curing has still not completely finished after 100 minutes.

## Different Measurement Modes – High Forces, TMA



### Higher Forces for More Information

The new DMA 242 E *Artemis* works with force levels up to 24 N (12 N dynamic and 12 N static). Thanks to this broad range, very thick and stiff samples can be investigated, especially in the compression and tension modes. Here, a natural rubber was measured in the compression mode. The maximum static force was set to 12 N. The dynamic force was varied between 0.5 N and 10.5 N, and the resulting strain was measured (stress-sweep test). The dynamic force which was applied and the resulting storage modulus are presented in the plot. Additionally, the strain curve is depicted as a function of the applied stress (inset) to check that the test was carried out in the Hooke's region (linearity of the curve).



Stress-sweep test of a natural rubber with a thickness of 2.01 mm  
Sample holder: compression, 15 mm diameter  
Measurement parameters: room temperature, frequency: 10 Hz



Sample holder for measurements in compression

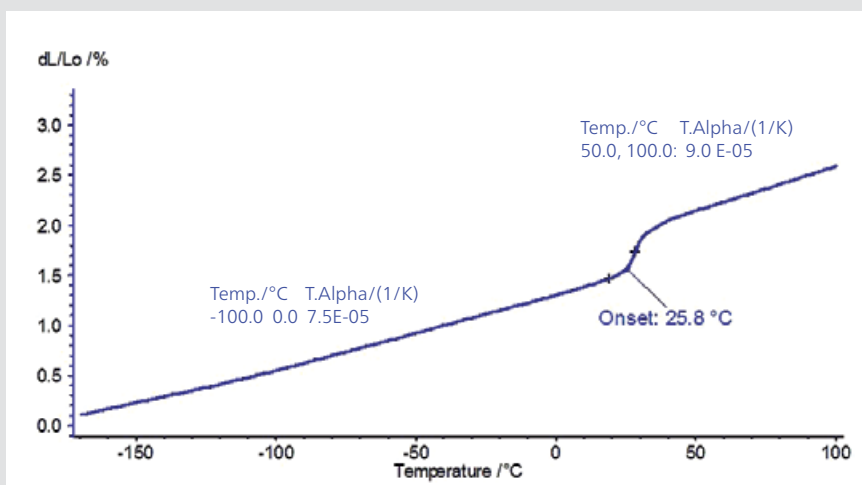
## Static Modes : Creep, Relaxation, TMA

Along with dynamic measurements, the DMA 242 E *Artemis* also allows for tests in the three static modes creep, relaxation and TMA.

In the creep mode, a constant static force is applied to the sample and the resulting deformation is measured.

The relaxation test determines the static force required to attain a defined constant deformation.

In the TMA mode, the thermal expansion of materials is determined. For this, a small static force is applied to the sample and the resulting length change is measured as a function of the increasing temperature.



TMA measurement of a PTFE

Sample holder: compression in the TMA mode

Measurement parameters: -170°C to 100°C at 2 K/min, static force: 0.1 N

## TMA Mode: Thermal Expansion of PTFE

In this example, the length change of PTFE was measured from -170°C to 100°C with the DMA 242 E *Artemis* in the TMA mode.

At the beginning of the test, the sample length increased linearly. The step in the sample expansion at 26°C is related to the transition from the well-ordered phase of PTFE to its disordered phase.

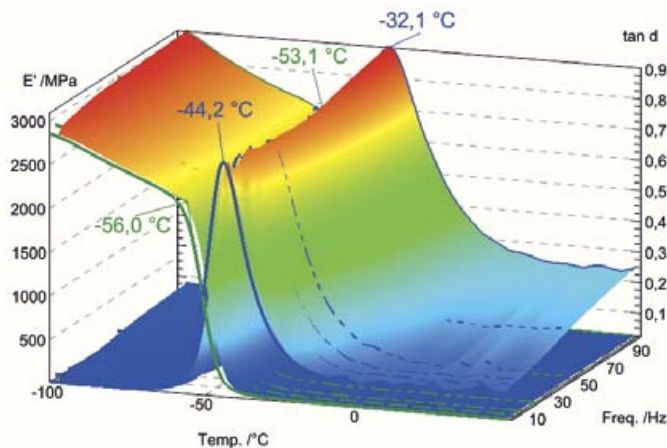
## Different Operation Modes – 3D-Plot, Multifrequency

### Multi-Frequency Measurement on an Elastomer

In addition to the ability to carry out multi-frequency measurements, the user also has the ability to present results in a three-dimensional plot: the visco-elastic properties of the tested material can be viewed as a function of both temperature and frequency at one glance.



Sample holder for dual cantilever bending



3D-plot of the visco-elastic properties of an elastomer (height: 2.66 mm, width: 7.77 mm)  
Sample holder: dual cantilever 2x16 mm  
Measurement parameters: heating from -100°C to 50°C at 2 K/min, frequencies: 1, 5, 10, 20, 50 and 100 Hz, amplitude:  $\pm 40 \mu\text{m}$

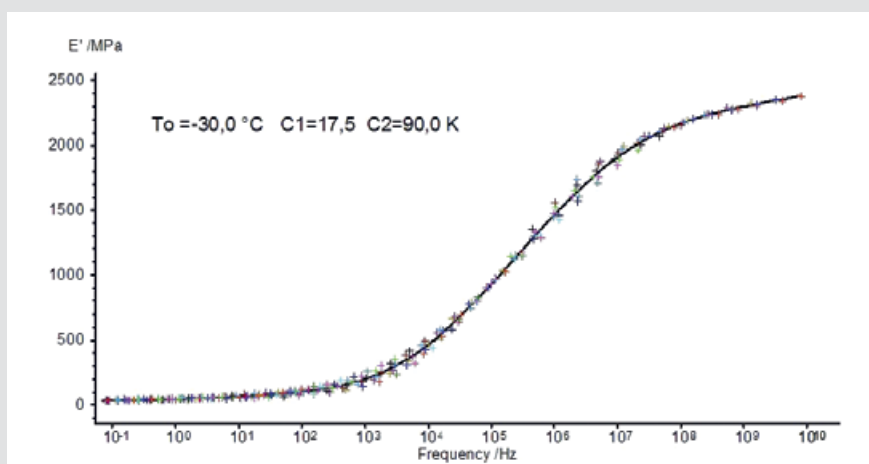
In this example, an elastomer was heated from -100°C to 50°C and its visco-elastic properties were determined for frequencies from 1 to 100 Hz.

The plot depicts the curves of the storage modulus and loss factor as a function of temperature and frequency. For each frequency, the decrease in the  $E'$  curve is associated with a peak in the  $\tan \delta$  curve. This effect is due to the glass transition of the sample. As expected, the glass transition is shifted to significantly higher temperatures with increasing frequency. The values given on the graph are the onset temperatures of the storage modulus curve and the peak temperatures of the loss factor curve for 1 Hz and 100 Hz.

## Master Curve and Arrhenius Plot of an Elastomer

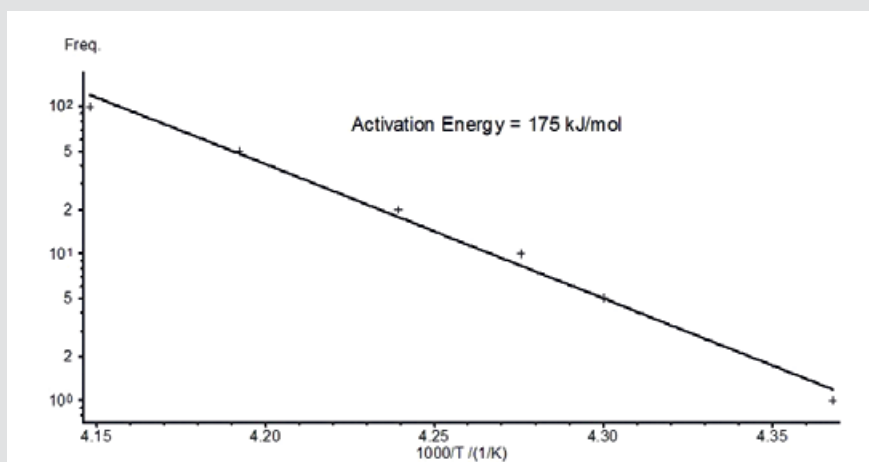
The visco-elastic behavior of a polymer as a function of frequency can easily and quickly be determined using the master curve calculated from a single multi-frequency measurement. To do this, the time-temperature superposition is used: the dependency relationship of  $E'$ ,  $E''$  and  $\tan\delta$  on frequency

can be extrapolated to frequencies exceeding the measuring range of the device. With the WLF (Williams-Landel-Ferry) equation, the shift factor can be calculated and a master curve can be established at a given reference temperature.



Master curve of an elastomer at a reference temperature of  $-30^{\circ}\text{C}$

In the example, the master curve of the storage modulus was calculated at a reference temperature of  $-30^{\circ}\text{C}$ . The DMA software evaluated the coefficients  $C1$  and  $C2$  of the shift factor according to the WLF equation. The measure of  $E'$  over the extrapolated frequency range up to  $10^{10}$  Hz can be demonstrated.



Arrhenius curve of an elastomer

Additionally, the *Proteus*® software allows for calculation of the activation energy for the glass transition. To do this, the logarithmic frequency dependence of the loss factor ( $\tan\delta$ ) is plotted over the inverse absolute temperature. The activation energy is given as the slope of the linear fit through the data points. An activation energy of 175 kJ/mol was found for the glass transition of the elastomer.

# DMA 242 E *Artemis* – *Proteus*® Software

The DMA 242 E *Artemis* runs under a 32- and 64-bit Windows® operating system and includes everything you need to carry out a measurement and evaluate the resulting data. User-friendly menus combined with automated routines make *Proteus*® very easy to use while still providing sophisticated analysis.

## Key Features of the General Software

- For Windows XP Professional®, Vista® (Enterprise, Business), Windows 7 (Professional®, Enterprise®, Ultimate®) operating systems
- Multi-tasking: simultaneous measurement and evaluation
- Multi-moduling: simultaneous operation on up to 4 different instruments with a single computer
- Combined analysis: comparison and/or evaluation of DSC, TGA, STA, DIL, TMA, DMA and DEA measurements in a single plot
- Comparative analysis of up to 64 curves/temperature segments from the same or different measurements (curve comparison)
- Storage of the analysis results and status with all analysis windows and preview-graphic in a file for later restoration and continuation with analysis
- Printout possible in 9 different languages
- Export graphics with evaluation results to clipboard or to common formats such as EMF, PNG, BMP, JPG, TIF or PDF
- ASCII-file export of the raw data and/or the corrected measurement data for data processing with more extensive analysis programs (e.g., peak separation)
- E-mail support: status messages or measurement files can be sent automatically following the measurement or in case of error
- Online evaluation of the measurement in progress (snapshot)

## Key Features of the Measurement Software

- Multiple programmable temperature segments (isothermal, dynamic) and temperature ramps with single or multiple frequencies; free selection of force values, deformation amplitudes and frequencies for each segment
- Online graphics with up to eight separate freely selectable axes, with online zoom, time- or temperature-scaled, single-segment or full-curve view
- Calibration routines: Dynamic mass, empty system, system stiffness, rotation tuning, temperature
- Oscillation control: Easy choice of stress control, strain control and special mixed mode (strain control with additional force limit) for materials with visco-elastic properties exhibiting considerable change

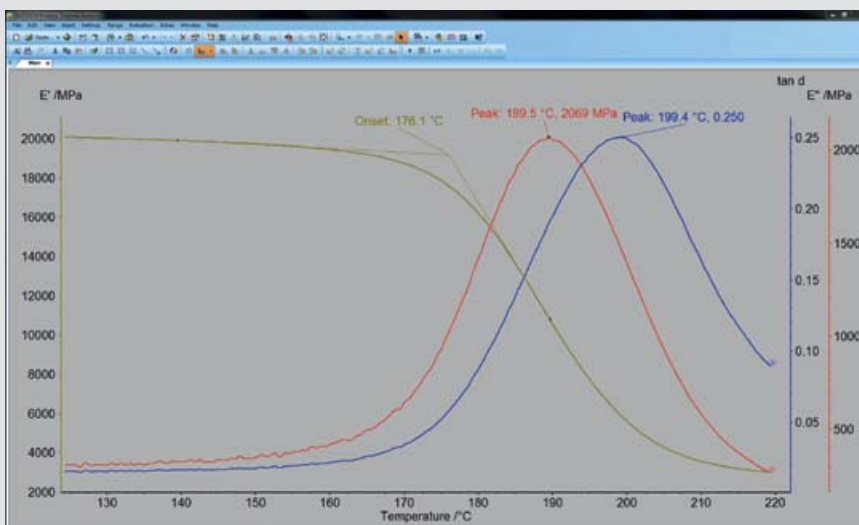
## Integrated Special Measurement Modes

- Creep mode
- Relaxation mode with deformation range up to 20 mm (depending on the sample size and chosen sample holder geometry)
- Stress-sweep mode
- Strain-sweep mode
- TMA mode
- Force modes:  
High force range (24 N),  
high-resolution force range (8 N)

## Key Features of the Analysis Software

- Determination of storage modulus  $E'$ , loss modulus  $E''$  and loss factor  $\tan\delta$
- 1<sup>st</sup> and 2<sup>nd</sup> derivative
- Superposition of the frequency-scaled curves (master curves)
- Graphical presentation of the measuring curves with up to 4 scalable Y-axes; e.g., storage modulus  $E'$ , loss modulus  $E''$ , loss factor,  $\tan\delta$ , amplitude.
- 3-D plot functionality for multi-frequency DMA data – to visualize, for example, the frequency-dependent shift of the glass transition temperature

- Determination of the activation energy (Arrhenius plot)
- Graphical presentation of  $\log(E'')$  or  $\log(\tan\delta)$  as a function of  $\log(E')$ , both for original data and for calculated master curves (Cole-Cole plot); also linear presentation
- Graphical presentation of the static length change, both in absolute units ( $dL/\mu m$ ) for all types of sample holders, and in relative units ( $dL/L_0$ ,  $dL/L_0/\%$ ) for all sample holders of the 'compression' or 'tension' type
- TMA Mode: Graphical presentation of the static length change, 'dL' (TMA mode), with the possibility for calibration correction and calculation of expansion coefficients (CTE) in dynamic segments
- Graphical presentation of creep and relaxation behavior
- Force-displacement diagram (evaluation of creep tests)
- Displacement-force diagram (evaluation of relaxation tests)
- Graphical presentation of stress- and strain-sweep behavior, stress-strain graph



Typical DMA-measurement with graphical presentation of  $E'$ ,  $E''$  and  $\tan\delta$ .



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