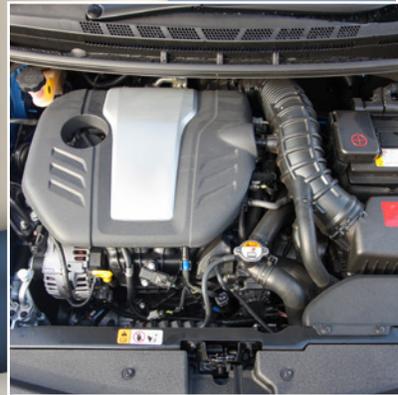
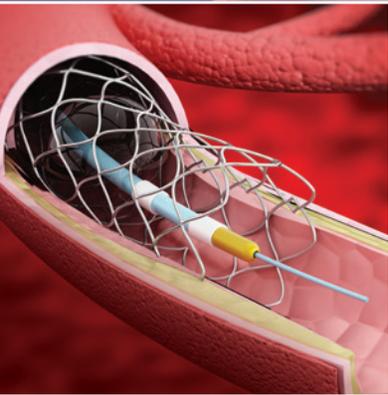


# From Lab to Application: How Mechanical Testing Ensures Strength and Reliability

A Selection Guide for Mechanical Testing



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# Why Mechanical Testing Matters

## From Lab to Application: How Mechanical Testing Ensures Strength and Reliability

**Mechanical testing** encompasses a variety of analysis techniques that measure how materials respond to different stresses and strains. Mechanical testing can be used to characterize materials in a variety of ways. For example:

- What is the structure of the material? For example, the miscibility of a blend
- Can a material perform a task? For example, is it stiff enough to support a load, or will it flex and allow the load to fall?
- Does a material fail in use due to the load applied? For example, will a bridge column withstand the weight of multiple trucks driving over it?

Testing samples under application-relevant conditions helps scientists, engineers, and technicians ensure the performance and longevity of their materials and products.

### Examples of Mechanical Testing Across Industries and Products

#### Radiator on a heavy-duty freight truck:

How will it withstand hours of driving vibration at high temperatures? Will the seals used in the design begin to leak due to stress relaxation or creep?



#### Medical device durability:

How will a new prosthesis withstand internal body conditions, including movement or exposure to blood?



#### Manufacturing artifacts' effects:

How do imperfections like knit lines, voids, and internal stresses influence mechanical strength and durability?



In all of these examples, mechanical testing answers key questions and demonstrates material properties in application-relevant conditions. Mechanical testing therefore informs successful material selection, product design, and performance predictions. Learn more about which kinds of mechanical testing are relevant to your materials and applications next.



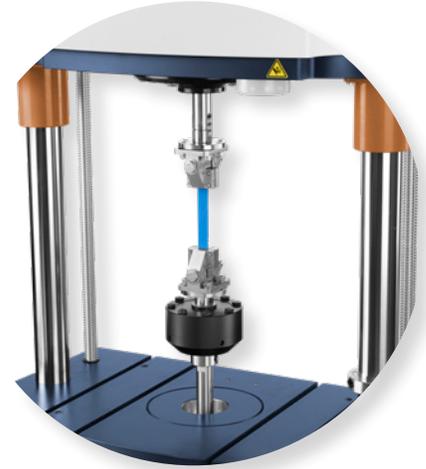
# Overview of Mechanical Test Techniques

## Types of mechanical test techniques include:

**Monotonic testing (AKA tensile tests):** Measure a material's response to an applied load. For example, how much stretching does it take to snap a rubber band? Or how far can a sheet of metal bend before it breaks? These tests measure the material's strength as well as how much it can deform before fracturing, also known as its elongation at break.

Common testing standards that use monotonic testing include:

- ASTM D638 - Test Method for Tensile Properties of Plastics
- ISO 527 - Plastics — Determination of tensile properties
- ISO 6892 - Metallic materials — Tensile testing
- ISO 178 - Plastics — Determination of flexural properties
- ASTM D3039 - Tensile Properties of Polymer Matrix Composite Materials
- ASTM D790 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

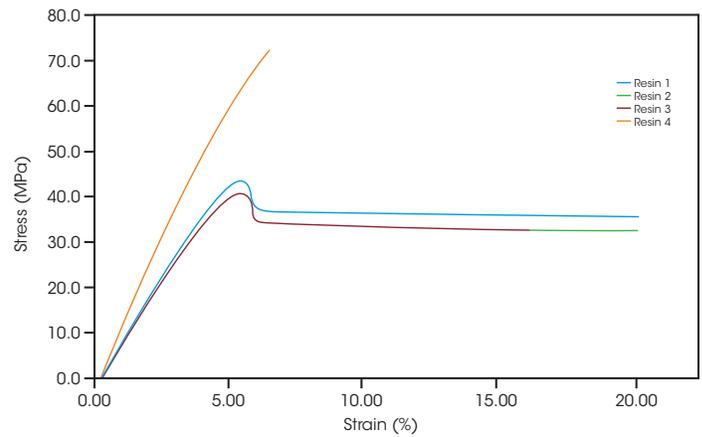


### Example Monotonic Test

Tensile testing was performed to evaluate the differences between three different ABS blends and the base SAN resin. Three tensile tests were completed for each sample according to ASTM D638-22 with a rate of 5 mm/min (0.083 mm/sec) on TA Instruments™ ElectroForce™ 3330 and ElectroForce APEX 1 Instruments.

Sample Grade	Thermoplastic	Average UTS (MPa)	Average Elongation at Break (%)	Average Stress at Break (MPa)	Average Modulus (MPa)
Resin 1	ABS	42.2 ± 0.1	21.1 ± 2.0	34.2 ± 1.0	872 ± 0.1
Resin 2	ABS	38.9 ± 0.1	20.2 ± 2.0	30.4 ± 0.7	770 ± 63.9
Resin 3	ABS	42.9 ± 0.0	16.29 ± 0.6	29.7 ± 1.5	921 ± 3.6
Resin 4	ABS	6.7 ± 0.4	6.7 ± 0.4	71.9 ± 0.1	1162 ± 21.1

Tensile testing reveals Resin 4 has the highest ultimate tensile strength (UTS), the maximum stress that a material can withstand without breaking. While it had a high strength, the material exhibited a brittle fracture which is shown by the material's lack of deformation or stretching after its maximum strength. The other three resins showed a more ductile behavior with a lot of stretch after their yield point. This ductile behavior is commonly associated with better performance and energy absorption under high speed and impact loading.



Tensile testing provides a quick and simple method to evaluate a material's short term mechanical properties and evaluate differences in materials.

**Fatigue testing:** Measures a material's response to repeated loading. For example, how many times can the spring in a pen be compressed before it snaps?

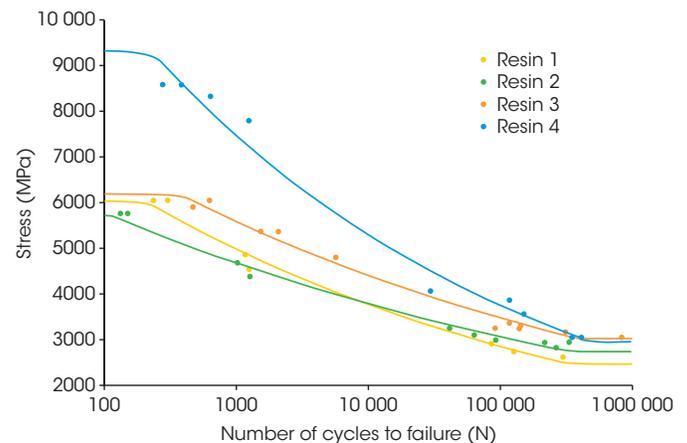
Common testing standards that use fatigue testing include:

- ISO 1099 - Metallic materials — Fatigue testing — Axial force-controlled method
- ASTM D623 - Test Methods for Rubber Property—Heat Generation and Flexing Fatigue In Compression
- ASTM D3479 - Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials
- ASTM D4482 - Test Method for Rubber Property—Extension Cycling Fatigue
- ASTM E466 - Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials

### Example Fatigue Test and Analysis

The same 4 materials that are shown in the tensile testing above were evaluated for their long-term fatigue properties. Fatigue tests were completed for each material at a range of maximum tensile stresses at 5 Hz in tension-tension from 10% to 100% of the fatigue loading for that test (R=0.1) on TA Instruments™ ElectroForce™ 3330 and ElectroForce APEX 1 Instruments. Compressed air was blown onto the sample to prevent self-heating and influence results. The sample temperatures were monitored throughout all fatigue tests.

The figure to the right shows the S-N Curve, stress (S) versus cycles (N) to failure, for Resins 1 through 4. Resin 4 (SAN) shows the highest fatigue strength at lower cycle counts but converges with Resin 3 and then becomes slightly weaker at higher cycle counts. Resin 1 and 2 trade positions from low to high cycle counts. Resin 3 displays a clear fatigue life advantage compared to the other two ABS resins.

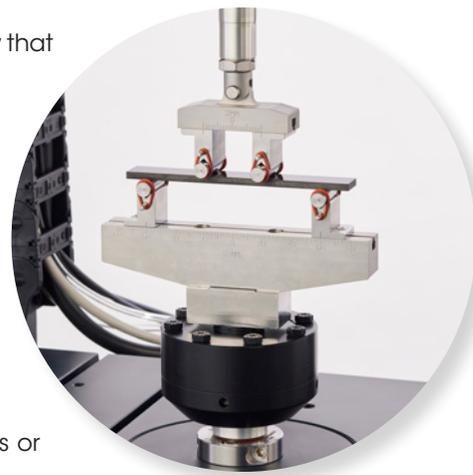


While tensile tests showed Resin 1's high ultimate tensile strength for the ABS materials, fatigue data reveals Resin 3's superior fatigue performance. While tensile strength can help to get a sense of a material's fatigue strength, this data clearly shows that it does not adequately predict which material will have the best fatigue performance, nor what kind of fatigue life can be expected from the material based only on tensile strength.

**Dynamic Mechanical Analysis (DMA):** measures the mechanical properties of materials as a function of time, temperature, and frequency, characterizing materials, products, and components to understand their performance and any processing effects.

DMA measures multiple material properties, including these most commonly measured ones:

- Storage modulus: The stored energy from the materials' elastic properties, and how that energy returns when it's stretched and returns back into shape
- Loss modulus: The energy lost to heat from the materials' viscous properties
- Tan Delta: The ratio of a materials' storage and loss modulus, commonly considered the indication of a materials' damping properties
- Multiple transitions: Including the glass transition (the temperature range in which a material changes from its rigid "glassy" state into a more rubbery, viscous state) and other secondary transitions that reveal material changes.



These measurements are helpful when comparing the stiffness of multiple samples or how a single sample changes across a temperature change.

### Example DMA Test and Analysis

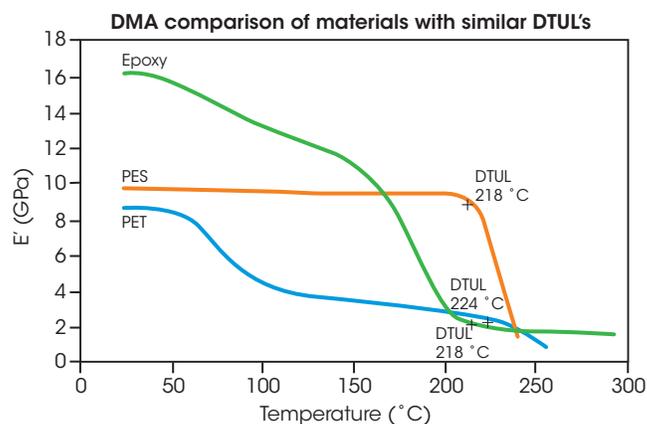
DMA was used to analyze three high performance materials: a polyethylene terephthalate (PET), a polyethersulfone (PES), and an epoxy. The property measured by DMA that was of greatest interest in determining load bearing capabilities is the flexural storage modulus ( $E'$ ) which agrees closely with the flexural modulus as measured by ASTM D-790. For dynamic heating scans,  $E'$  is reported as a function of temperature.

The modulus of the PET material begins to decrease rapidly at 60 °C as the material enters the glass transition. At the end of the glass transition, the modulus of the material has declined by about 50% from room temperature values. The modulus again drops rapidly as the crystalline structure approaches the melting point.

Polyethersulfone (PES) is a high-performance amorphous resin. Amorphous materials exhibit higher glass transition temperatures than their semi-crystalline counterparts and maintain a high percentage of their room temperature properties up to that point. However, with the onset of the glass transition the loss in properties is sudden and complete, even for highly reinforced grades.

The epoxy is a crosslinked system with a well-defined  $T_g$ . The temperature dependency of the modulus in such materials is related to the crosslink density. The epoxy experiences a steadily reducing modulus as the temperature increases to the  $T_g$ .

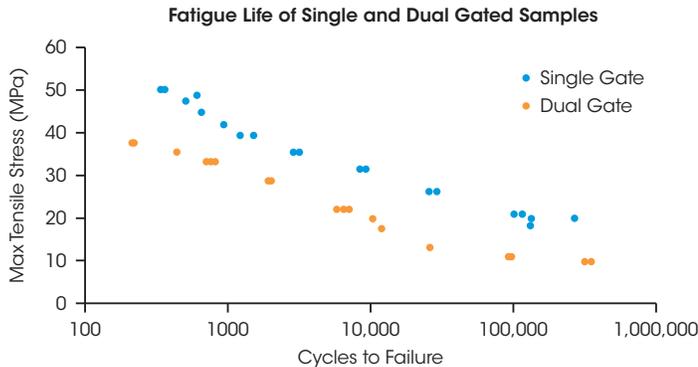
DMA provides a much more comprehensive picture of how these materials change and perform at elevated temperatures compared to other methods such as Deflection Temperature Under Load (DTUL). Read more in this [application note](#).



# Which technique is right for your application?

**Polymers** developers will find that **all three kinds of mechanical testing** mentioned earlier are highly beneficial: monotonic, fatigue, and DMA. The [material specification sheet](#) usually does not contain specific enough information to inform how your material or product will perform in application. Even if you know it will break under a specific force, what about 50% force applied 10,000 times? What about different temperatures?

**Example experiment:** How do production artifacts like knit lines impact polymer fatigue?



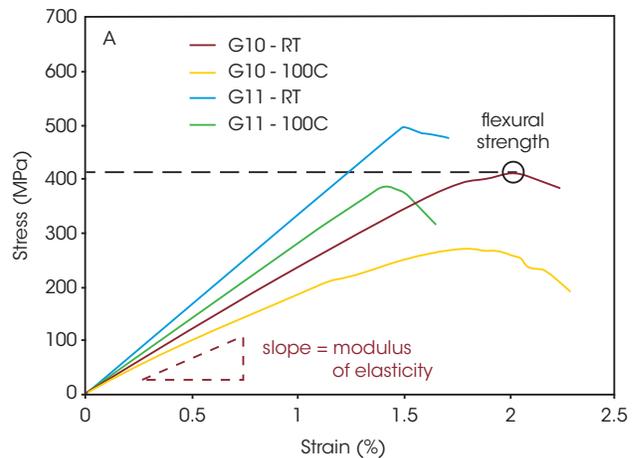
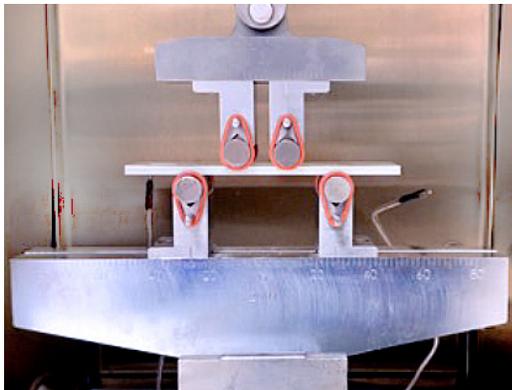
The dual gate, knitted samples have a fatigue life of just 6-18% of the life of their single gate counterparts. Read more in this [application note](#).

**Electronics** materials are usually chosen for their thermal stability. **DMA, fatigue, and monotonic testing**

reveal how electronic materials respond to force and loading under different temperatures. Temperature dependency of mechanical properties can influence electronics' performance under different operating temperatures and applications. Electronics manufacturers can test a variety of forces and conditions, simulating everything from dropping your phone to launching a rocket.



**Example experiment:** Garolite, a high-performance woven fiberglass composite, is used in electronics due to its electrical insulating properties, dimensional stability, durability, and resistance to humidity. Two grades of Garolite, G10 and G11 were tested; G11 has similar properties but with a higher temperature rating.



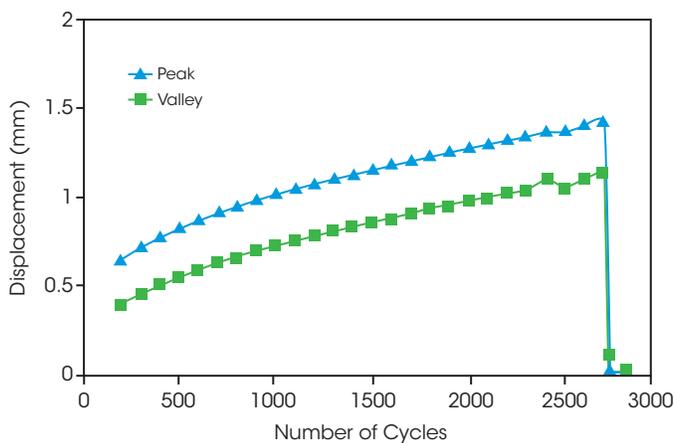
Four-point bending monotonic tests on G10 and G11 Garolite rectangular bars at both room temperature and 100 °C reveal a significant drop in flexural strength at a higher temperature of 100 °C. However, G11 performs significantly better with retaining ~80% of its structural strength, while G10 retains only 68% of its strength. While the 100C test temperature was well below the G10 and G11 ratings of 130C and 170C, the materials lost a staggering 91% and 46% of their fatigue life when tested at 100C – revealing a critical weakness within the operating temperature range. See the full experiment and analysis in this [application note](#).

**Automotive and Aerospace** materials require thermal and chemical resistance, as well as strength and durability. All three tests are important for specific aspects:

- Monotonic testing reveals how a single application of load, like a collision, will affect materials. How much force until they break?
- Fatigue testing reveals how repeated forces will affect materials. Will the suspension component break after repeatedly hitting a pothole? How will the engine isolators degrade after thousands of hours of operation in the hot environment under the hood?
- Dynamic Mechanical Analysis reveals how temperature and time affect materials. In addition to withstanding the regular heat of driving or flying, how will fuel system components behave during a crash or turbulence?



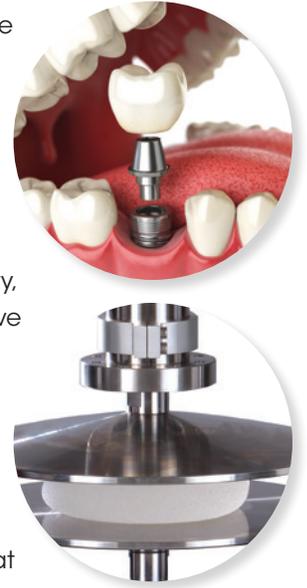
**Example experiment:** Advanced polymer and composite materials on the exteriors of modern vehicles need adequate strength and durability, plus the ability to withstand environmental extremes and sustain deformation safely.



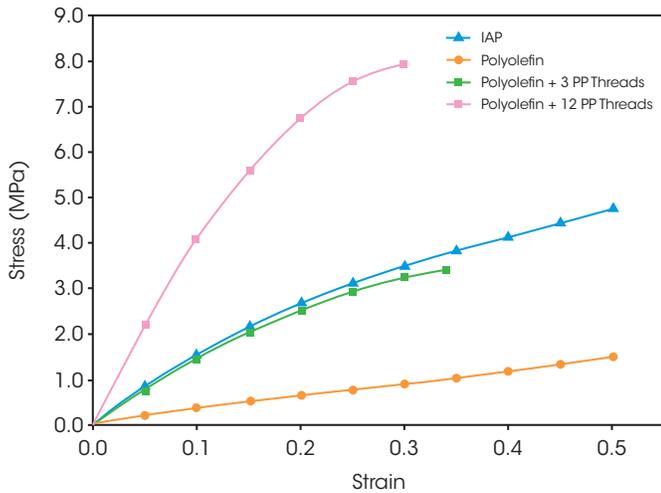
This polymer was assessed using force-controlled fatigue testing from 15 N to 145 N using a 5 Hz sinusoidal waveform. The accumulation of plastic strain is evident over the course of the test up to failure at 2700 cycles.



**Medical Devices and Implants** usually require enough strength, stiffness, and durability to replace body parts like bones or teeth, or support body parts such as implants or stents. These devices also must interact with the native tissue and are commonly required to have complementary mechanical properties to integrate with the body's functions while still accomplishing their goal. **Monotonic and fatigue testing** reveal how medical devices perform, simulating in-vivo environments and years of use within weeks or months.



**Example experiment:** Medical device technologies continue to evolve for improved durability, reliability, and patient outcomes. Researchers compared new composite polyolefin heart valve prosthesis with existing implant-approved polymer (IAP) material using monotonic and fatigue testing. A constant strain rate was applied to measure the tensile properties of the material and a 100 Hz sinusoidal cycling frequency was used to apply continuous cycles until the failure of each specimen.

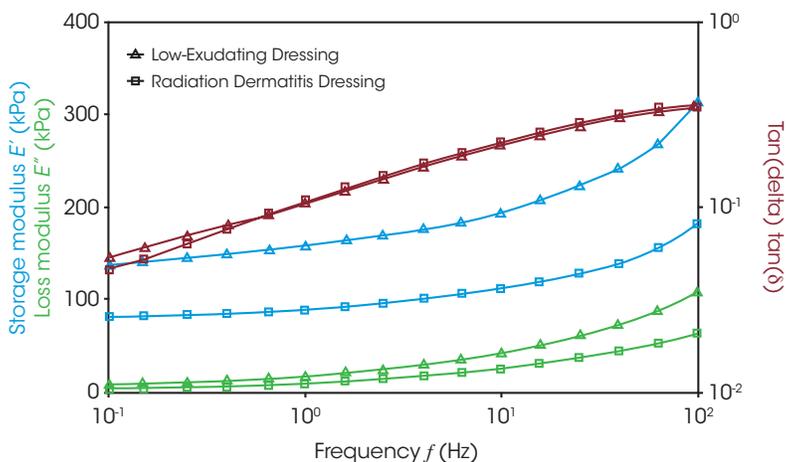


Tensile to failure tests indicated that the polyolefin fiber came closest to matching the IAP with a 3 thread count reinforcement (green line). The fatigue tests showed that the material with 3 thread count reinforcement had inferior fatigue properties but the 12 thread count material had superior fatigue properties. These results are helpful in narrowing down the best implant material to match or exceed the expected performance from existing materials. See the full experiment and analysis in this [application note](#).

**Biomaterials and Hydrogels** benefit from the same mechanical testing as medical devices above, but with the particular benefit of adding **Dynamic Mechanical Analysis** since these materials are used in close conjunction with native tissue.<sup>1</sup> Many native tissues and biomaterials are viscoelastic as well, requiring DMA for characterization of their dynamic properties under application conditions.



**Example experiment:** Dynamic Mechanical Analysis was used to characterize two types of topical wound dressing hydrogels, one specialized for radiation dermatitis, and another for low exuding wounds.



Frequency sweeps performed at 0.25% strain revealed that the storage moduli for the low-exuding dressing were approximately 50% higher, while tan delta measurements were similar. This indicates that the low-exuding dressing is stiffer and stores more energy elastically during deformation, meaning it will maintain its structure with less relaxation compared to the radiation dermatitis dressing. Their similar tan delta measurements indicate that both dressings showed a similar degree of damping across all tested frequencies. See the full experiment and analysis in this [application note](#).

# Choosing an Instrument

## The “Usability” Question

“Usability” is a buzzword in mechanical testing instrumentation, usually used to describe pretty software and nice symbols. But does it actually translate to your operators being able to easily obtain data without extensive training and years of experience?

True usability is about the operators being able to confidently execute experiments with a small amount of training and without fear of damaging the instrument. Your operators shouldn't have to worry about damaging the instrument when focused on their experimental goals.

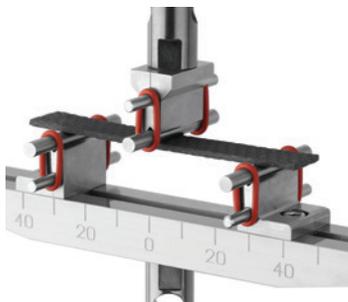
## Future-Proof Your Lab

When choosing a mechanical test instrument, scientists and engineers should consider their immediate needs, but also their future needs. Mechanical testing needs typically evolve over time, and buying an instrument that just meets the current needs might leave you with a capability shortfall as time goes on. Often this capability is thought about as specification sheet values, but the more important capabilities are commonly the types of measurements and experiments that a piece of equipment is capable of performing. Advanced mechanical testing instruments are large capital investments and you want to be confident that it can do more than just one or two types of testing.

## Testing Requirements to Consider

When deciding on a mechanical test instrument, scientists and engineers must consider a range of factors including test capability, force capacity and range, stroke, and required test frequency:

- **Test Types:** Different instruments have different capabilities to perform each experiment. Some instruments are more optimized for DMA, some for high frequency fatigue, and some are more balanced. It is important to know the current and future test needs when choosing an instrument to ensure the maximum value is available from your investment.
- **Force Capability:** The instrument's ability to accurately apply the desired force or stress to the sample. The instrument's force capability includes the maximum force capacity, but also the instrument's minimum force resolution.
  - Sometimes the sample geometry can be changed to achieve the same stress with less force.
- **Stroke Length:** The instrument's ability to apply the desired deformation/strain to the sample. The maximum deformation is the most common consideration, but the instrument's ability to apply and measure very small deformations must also be considered.
  - Additional benefit: More stroke length ensures the ability to test more samples and test types without tedious setup and fear of running out of stroke
- **Dynamic Performance:** enables execution of required stress and strain at maximum possible frequency for fastest test execution. Impactful for speed to market by completing tests at the fastest rate possible.
  - Max frequency can be limited by instrument's motor capability, sample limitations (e.g. self heating), or industry/regulatory limits

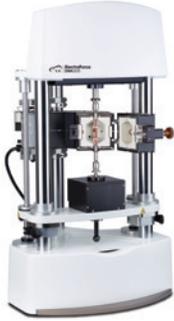


# Instrument Guide

## DMA

DMA 850	DMA 3200
 <p><b>Best overall DMA</b></p>	 <p><b>Best high-force DMA</b></p>
<p>Up to 18 N</p>	<p>Up to 500 N</p>

## Monotonic and Fatigue

ElectroForce 5500	ElectroForce 3200	ElectroForce 3500	ElectroForce Apex 1
<p>Affordable, precise fatigue, ideal for tissue and medical devices</p>	<p>Ideal for low-force testing plus DMA</p>	<p>Capable of testing the toughest samples with the highest force</p>	<p>Most versatile and easiest to use for monotonic and fatigue testing</p>
<p>200 N maximum force</p>	<p>225 N or 450 N maximum force</p>	<p>15,000 N maximum force</p>	<p>1,000 N maximum force</p>
			

## References

1. Jones, David S. Dynamic mechanical analysis of polymeric systems of pharmaceutical and biomedical significance. International Journal of Pharmaceutics, Volume 179, Issue 2. (1999): 167-178. [https://doi.org/10.1016/S0378-5173\(98\)00337-8](https://doi.org/10.1016/S0378-5173(98)00337-8).



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