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Tensile Testing Basics, Tips and Trends

Mechanical properties are an important measure of product quality, and tensile testing is just one way to certify the product.

BY RICHARD GEDNEY

There are two classes of testing machines—electromechanical and hydraulic. *Photo: ADMET Inc.*

Success in today's marketplace requires improvements in efficiency, quality and accuracy of testing facilities and testing equipment. Testing machines are used to develop better information on known materials or to develop new materials and maintain the quality of the materials. For materials suppliers, the mechanical properties tested by these machines are an important measure of product quality, and testing is required for certification.

In a broad sense, strength refers to the ability of a structure to resist loads without failure. Failure may occur by rupture because of excessive stress or may take place owing to excessive deformation. Tensile properties include the resistance of materials to pulling or stretching forces. The amount of force required to break a material and the amount it extends before breaking are important properties. For most materials, the initial resistance to force, or modulus, and the point of permanent deformation, are obtained from plots of force against elongation. Analysis of force-elongation or stress-strain curves can convey much about the material being tested, and it can help in predicting its behavior.

Machine design

There are many types of testing machines. The most common are universal testing machines, which test materials in tension, compression or bending. The primary use of the testing machine is to create the stress-strain diagram. Once the diagram is generated, a pencil and straight edge or computer algorithm can be used to calculate yield strength, Young's Modulus, tensile strength or total elongation.

There are two classes of testing machines, electromechanical and hydraulic. The electromechanical machine uses an electric motor, gear reduction system and one, two or four screws to move the crosshead up or down. A range of crosshead speeds can be achieved by changing the speed of the motor. A microprocessor based closed-loop servo system can be implemented to accurately control the speed of the crosshead.

A hydraulic testing machine uses either a single- or dual-acting piston to move the crosshead up or down. In a manually operated machine, the operator adjusts a needle valve to control the rate of loading. In a closed-loop

hydraulic servo system, the needle valve is replaced by an electrically operated servo-valve for precise control.

In general, the electromechanical machine is capable of a wide range of test speeds and long crosshead displacements, whereas the hydraulic machine is a cost-effective solution for generating high forces.

Reporting results

In the laboratory, there are many things to consider. For those signing their name to the report, it's important to question the assumptions and methods used to obtain results. Check the ASTM International (American Society for Testing and Materials) test methods or other test specifications, and be sure the correct test speeds, loading profile and calculations are used.

The rate at which a test is performed can have a significant effect on tensile properties. Tensile properties for plastics, polymers and steels are very sensitive to testing rates, but aluminum alloys exhibit little sensitivity. Materials that are sensitive to strain rates exhibit higher tensile strengths and lower elongations at faster speeds.

Therefore, it is important that all testing rates are within the limits specified by the governing standard. If comparing results across lots or batches of similar materials, insist that the testing rates be identical.

ASTM requires that load and strain measuring devices be calibrated annually. If any device has been damaged or is subjected to excessive use, more frequent calibrations should be done. Calibration records should be kept to determine when it's time to replace or refurbish a device. Each device has its own certified range and, therefore, no

What is the strength of a material?

Strength refers to the ability of a structure to resist loads without failure because of excessive stress or deformation. Typical points of interest when testing a material include: ultimate tensile strength (UTS) or peak stress; offset yield strength (OYS) which represents a point just beyond the onset of permanent deformation; and the rupture (R) or fracture point where the specimen separates into pieces.

ENGINEERING STRESS-STRAIN CURVE
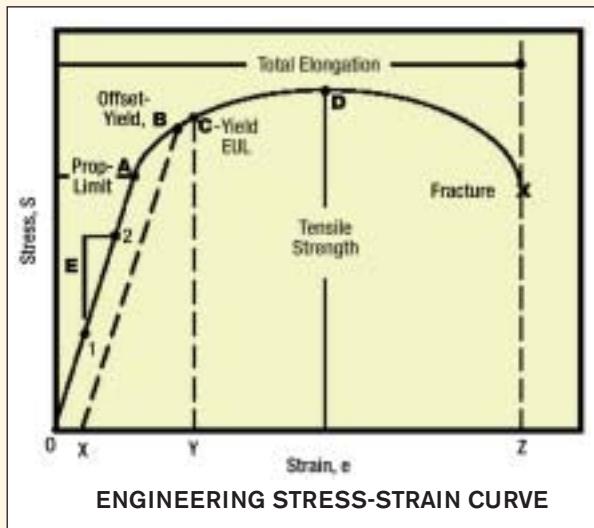
Theory

A graphical description of the amount of deflection under load for a given material is the stress-strain curve. Engineering stress (S) is obtained by dividing the load (P) at any given time by the original cross sectional area (A_O) of the specimen.

$$S = P/A_O \qquad \text{Eq. 1}$$

Engineering strain (e) is obtained by dividing the elongation of the gage length of the specimen (Δl) by the original gage length (lo).

$$e = \Delta l/l_O = (l - l_O)/l_O \qquad \text{Eq. 2}$$

The figure depicts a typical stress-strain curve. The shape and magnitude of the curve is dependent on the type of metal being tested. Point A represents the proportional limit of a material. A material loaded in tension beyond point A when unloaded will exhibit permanent deformation. The proportional limit is often difficult to calculate, therefore, two practical measurements, offset yield strength (OYS) and yield by extension under load (EUL), were developed to approximate the proportional limit. The initial portion of the curve below point A represents the elastic region and is approximated by a straight line. The slope (E) of the curve in the elastic region is defined as Young's Modulus of Elasticity and is a measure of material stiffness.

$$E = \Delta S /\Delta e = (S_2-S_1)/(e_2-e_1) \qquad \text{Eq. 3}$$

Point B represents the offset yield strength and is found by constructing a line X-B parallel to the curve in the elastic region. Line X-B is offset a strain amount O-X that is typically 0.2% of the gage length. Point C represents the yield strength by extension under load (EUL) and is found by constructing a vertical line Y-C. Line Y-C is offset a strain amount O-Y that is typically 0.5% of gage length. The ultimate tensile strength, or peak stress, is represented by point D. Total elongation, which includes both elastic and plastic deformation, is the amount of uniaxial strain at fracture and is depicted as strain at point Z. Percent elongation at break is determined by removing the fractured specimen from the grips; fitting the broken ends together and measuring the distance between gage marks. Percent elongation at break reports the amount of plastic deformation only. The gage length used for measurement is reported with the result.

$$\text{elongation at break(\%)} = e_z = 100*(l_z-l_O)/l_O \qquad \text{Eq. 4}$$

Reduction of area, like elongation at break, is a measure of ductility and is expressed in percent. Reduction of area is calculated by measuring the cross sectional area at the fracture point (Az).

$$\text{reduction of area(\%)} = (A_O-A_z)/A_O \qquad \text{Eq. 5}$$

results should be reported outside the certified ranges.

Changes made in 2001 to ASTM E4 Standard Practices for Force Verification of Testing Machines increased the minimum certifiable force for a given range from 100 to 200 times the force resolution. Resolution on dial gages and pen recorders depends on the distance between graduation marks and the width of the needle or pen. Often, with these devices, it is not clear what the resolution should be, and determining it is subject to much interpretation. Based on the new E4, tests formerly conducted at the low end of a given force range may no longer be valid.

Worn machine components can result in misalignment that creates bending stresses, lowering tensile stress readings. Check the test machine's alignment and play to ensure concentricity of the crosshead over the full travel range.

With the advent of microprocessor-based test systems, applied loads inadvertently can be "zeroed out," resulting in lower stress readings. To prevent this, clamp the specimen in the upper grip, then zero the load and close the lower grip.

Potential pitfalls

When testing most metals, strains are usually too small to be measured by using testing machine crosshead or piston displacement methods. Measuring small strains typical of a high-strength metals test—0.0001 inch or less—is the task of an extensometer.

If yield values are incorrect, review the stress-strain diagram; the extensometer may have slipped on the specimen during the test. To help prevent extensometer slippage, the clamping force and the zero point should be checked regularly and worn knife edges replaced.
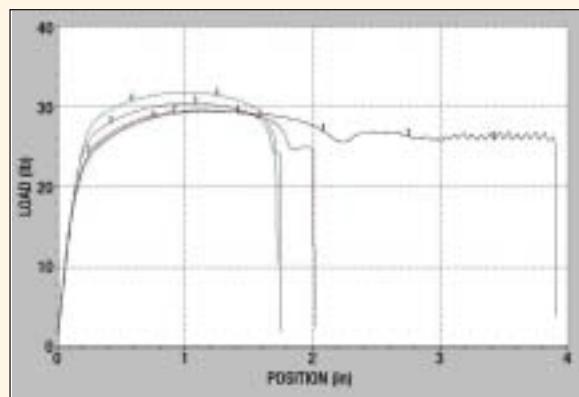
Wedge action grips are the most common style used in metals testing. As the axial load increases, the wedge acts to increase the squeezing pressure applied to the specimen. Wedge grips are manually, pneumatically or hydraulically actuated. For high-volume testing, it is recommended that pneumatic or hydraulic actuated grips be used. Worn or dirty grip faces can result in specimen slippage, which often renders the stress-strain diagram useless. The grip faces should be inspected periodically. Worn
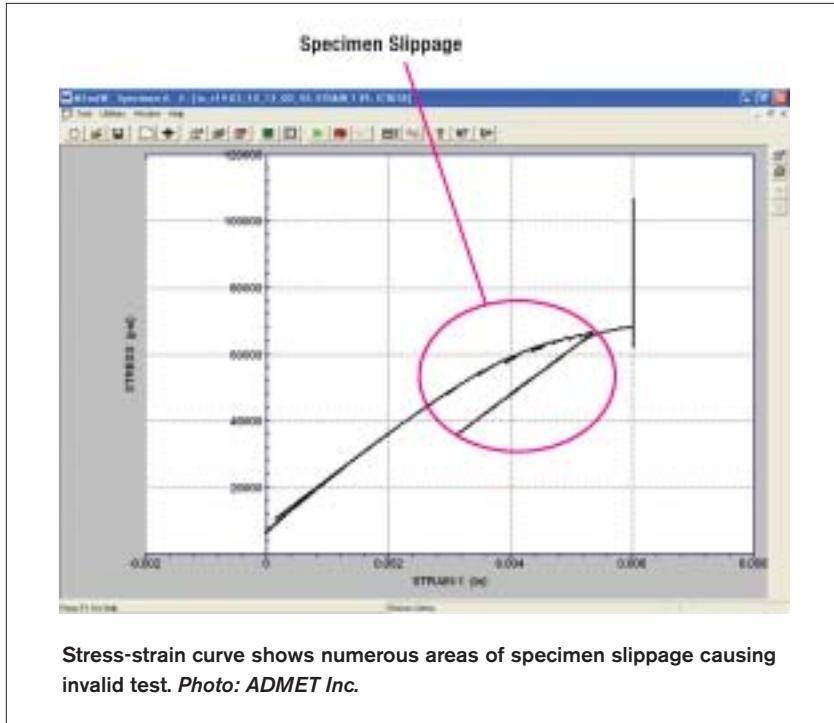

A stress-strain curve shows extensometer slippage. Inset: An extensometer is attached to a flat specimen. *Photo: ADMET Inc.*
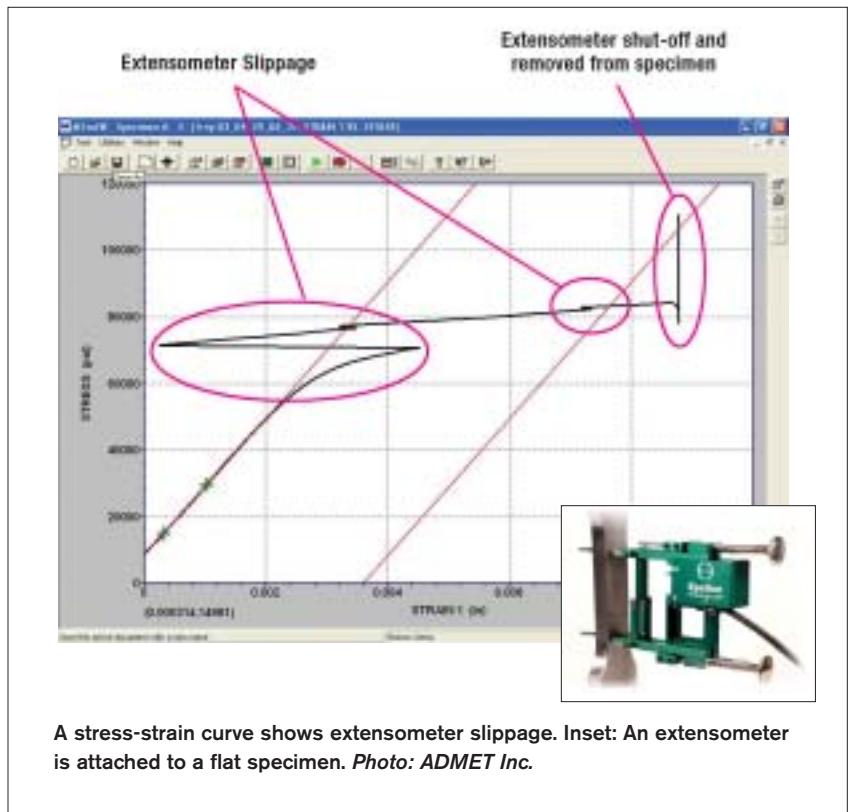
Strain rate sensitivity example - Wire tie test

Wire ties were pulled until fracture. Table and force-extension curves show how test speed affects peak load and maximum elongation. As the speed was doubled from 2 to 4 inches per minute, the maximum elongation was reduced by almost half. As the speed was increased from 2 to 16 inches per minute, the maximum force increased by 7.5%.

Curve#	Speed (in/min)	Peak Load (lb)	Elongation (in)
1	2	29.5	3.90
2	4	29.6	2.01
3	8	30.4	1.75
4	16	31.7	1.72

Specimen Slippage

Stress-strain curve shows numerous areas of specimen slippage causing invalid test. *Photo: ADMET Inc.*

1/2"

This diagram shows specimen fully engaged in grip faces and grip faces correctly supported inside grip pockets. Correct arrangement. *Photo: ADMET Inc.*

Potential area of damage

The diagram shows a specimen fully engaged in grip faces and grip faces not fully supported inside grip pockets. Arrangement can cause permanent damage to grip pockets and may lead to specimen slippage. *Photo: ADMET Inc.*

Potential area of damage

The diagram shows a specimen partially engaged in grip faces and grip faces correctly supported inside grip pockets. Arrangement can cause permanent damage to grip inserts and may lead to specimen slippage. *Photo: ADMET Inc.*

inserts should be replaced and dirty inserts cleaned.

Correct alignment of the grips and the specimen, when clamped in the grips, is important. Offsets in alignment will create bending stresses and lower tensile stress readings. It may even cause the specimen to fracture outside the gage length.

Most ASTM or similar test methods require a shaped specimen that will concentrate the stress within the gage length. If the specimen is incorrectly machined, fracture could occur outside the gage length and result in strain errors. Incorrect reading of specimen dimensions will create stress measurement errors. Worn micrometers or calipers should be replaced and care should be taken when recording specimen dimensions. Some computer-based test systems will read the micrometer or caliper directly, thus eliminating data entry errors.
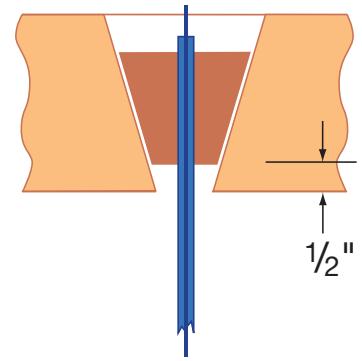
Can software do it all?

Today's software algorithms are good at calculating the correct results for a given stress vs. strain curve. It is usually the data fed into in the algorithm— such as the shape and magnitude of the stress vs. strain curve—that produces the bad results. That is why the test technician's job is important.

The technician must be responsible for doing the test according to specifications. He should be aware of the potential errors introduced by the machine, extensometer, grips and specimen irregularities, and also should alert the lab supervisor when problems arise. In short, the technician should be trained in correctly generating the stress vs. strain curve for a given test method.
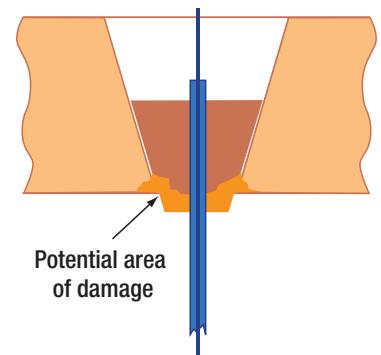
One indirect way of checking the results is to send specimens to at least two other testing laboratories so results can be compared.

The design and manufacture of new materials is broadening the scope of materials testing and complicating its practice. To remain competitive, reduce test times, eliminate data entry errors and speed the time of product shipments. Using testing systems that automatically perform the tests according to specification, automatically calculate results, and seamlessly communicate with other computers and programs running on the corporate network, will be paramount to success. **Q**
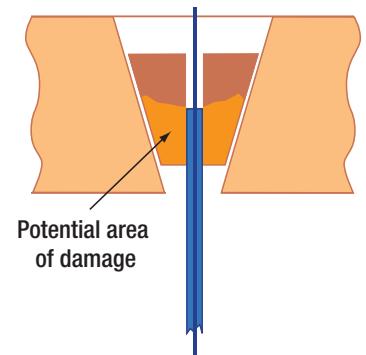
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