

## CHAPTER 1

# Introduction to Tensile Testing

---

TENSILE TESTS are performed for several reasons. The results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared. Finally, tensile properties often are used to predict the behavior of a material under forms of loading other than uniaxial tension.

The strength of a material often is the primary concern. The strength of interest may be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. These measures of strength are used, with appropriate caution (in the form of safety factors), in engineering design. Also of interest is the material's ductility, which is a measure of how much it can be deformed before it fractures. Rarely is ductility incorporated directly in design; rather, it is included in material specifications to ensure quality and toughness. Low ductility in a tensile test often is accompanied by low resistance to fracture under other forms of loading. Elastic properties also may be of interest, but special techniques must be used to measure these properties during tensile testing, and more accurate measurements can be made by ultrasonic techniques.

This chapter provides a brief overview of some of the more important topics associated with tensile testing. These include:

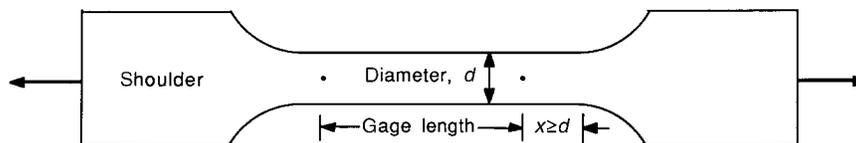
- Tensile specimens and test machines
- Stress-strain curves, including discussions of elastic versus plastic deformation, yield points, and ductility
- True stress and strain
- Test methodology and data analysis

It should be noted that subsequent chapters contain more detailed information on these topics. Most notably, the following chapters should be referred to:

- Chapter 2, "Mechanical Behavior of Materials Under Tensile Loads"
- Chapter 3, "Uniaxial Tensile Testing"
- Chapter 4, "Tensile Testing Equipment and Strain Sensors"

### Tensile Specimens and Testing Machines

**Tensile Specimens.** Consider the typical tensile specimen shown in Fig. 1. It has enlarged ends or shoulders for gripping. The important part of the specimen is the gage section. The cross-sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be



**Fig. 1** Typical tensile specimen, showing a reduced gage section and enlarged shoulders. To avoid end effects from the shoulders, the length of the transition region should be at least as great as the diameter, and the total length of the reduced section should be at least four times the diameter.

localized in this region. The gage length is the region over which measurements are made and is centered within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section, and the gage length should be great relative to its diameter. Otherwise, the stress state will be more complex than simple tension. Detailed descriptions of standard specimen shapes are given in Chapter 3 and in subsequent chapters on tensile testing of specific materials.

There are various ways of gripping the specimen, some of which are illustrated in Fig. 2. The end may be screwed into a threaded grip, or it may be pinned; butt ends may be used, or the grip section may be held between wedges. There are still other methods (see, for example, Fig. 24 in Chapter 3). The most important concern in the selection of a gripping method is to ensure that the specimen can be held at the maximum load without slippage or failure in the grip section. Bending should be minimized.

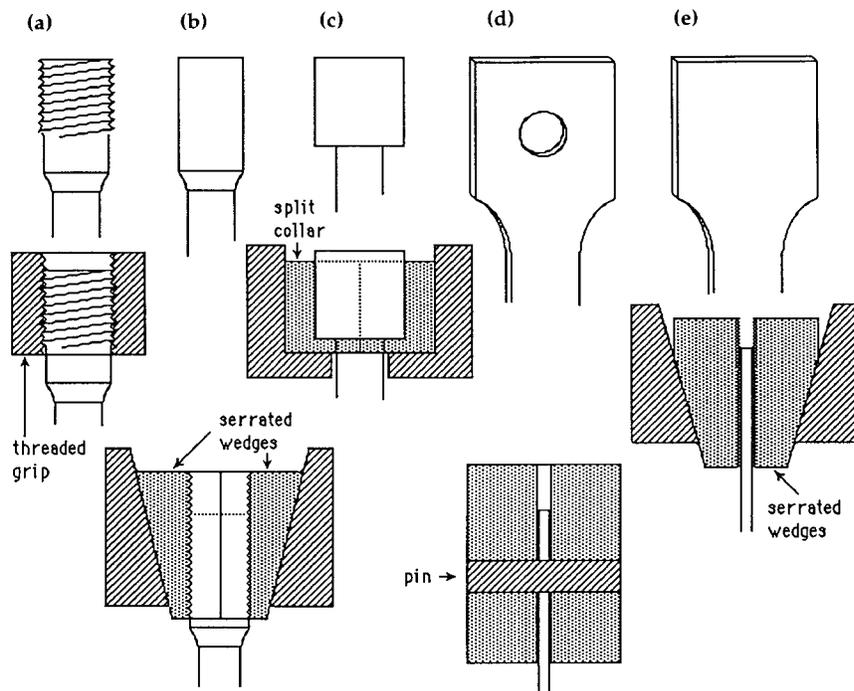
**Testing Machines.** The most common testing machines are universal testers, which test ma-

terials in tension, compression, or bending. Their primary function is to create the stress-strain curve described in the following section in this chapter.

Testing machines are either electromechanical or hydraulic. The principal difference is the method by which the load is applied.

Electromechanical machines are based on a variable-speed electric motor; a gear reduction system; and one, two, or four screws that move the crosshead up or down. This motion loads the specimen in tension or compression. Crosshead speeds can be changed 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.

Hydraulic testing machines (Fig. 3) are based on either a single or dual-acting piston that moves the crosshead up or down. However, most static hydraulic testing machines have a single acting piston or ram. In a manually operated machine, the operator adjusts the orifice of a pressure-compensated 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.



**Fig. 2** Systems for gripping tensile specimens. For round specimens, these include threaded grips (a), serrated wedges (b), and, for butt end specimens, split collars constrained by a solid collar (c). Sheet specimens may be gripped with pins (d) or serrated wedges (e).

In general, electromechanical machines are capable of a wider range of test speeds and longer crosshead displacements, whereas hydraulic machines are more cost-effective for generating higher forces.

### Stress-Strain Curves

A tensile test involves mounting the specimen in a machine, such as those described in the previous section, and subjecting it to tension. The tensile force is recorded as a function of the increase in gage length. Figure 4(a) shows a typical curve for a ductile material. Such plots of tensile force versus tensile elongation would be of little value if they were not normalized with respect to specimen dimensions.

Engineering stress, or nominal stress,  $s$ , is defined as

$$s = F/A_0 \quad (\text{Eq 1})$$

where  $F$  is the tensile force and  $A_0$  is the initial cross-sectional area of the gage section.

Engineering strain, or nominal strain,  $e$ , is defined as

$$e = \Delta L/L_0 \quad (\text{Eq 2})$$

where  $L_0$  is the initial gage length and  $\Delta L$  is the change in gage length ( $L - L_0$ ).

When force-elongation data are converted to engineering stress and strain, a stress-strain curve (Fig. 4b) that is identical in shape to the force-elongation curve can be plotted. The advantage of dealing with stress versus strain rather than load versus elongation is that the stress-strain curve is virtually independent of specimen dimensions.

**Elastic versus Plastic Deformation.** When a solid material is subjected to small stresses, the bonds between the atoms are stretched. When the stress is removed, the bonds relax and the material returns to its original shape. This re-

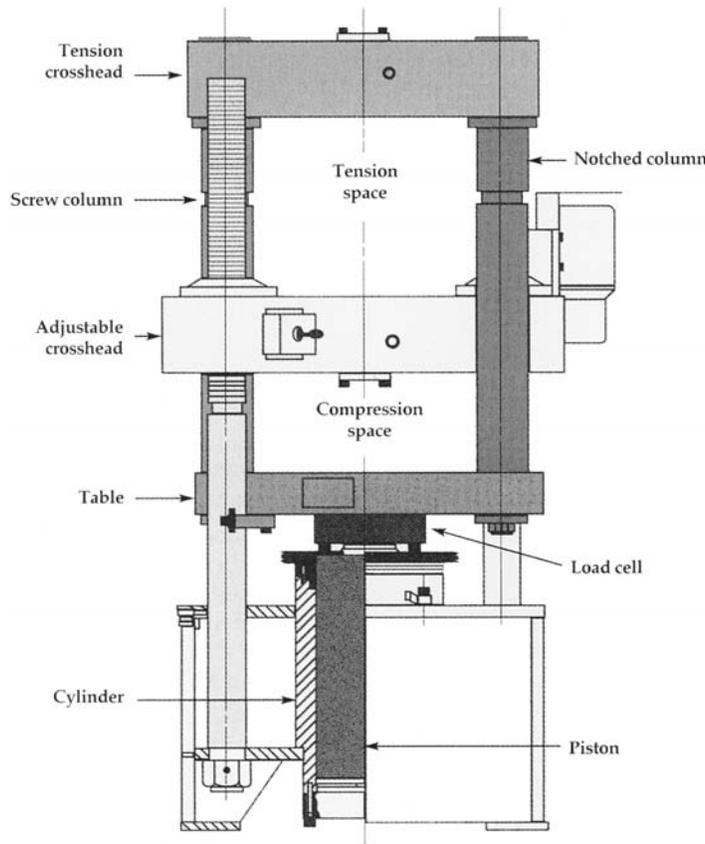
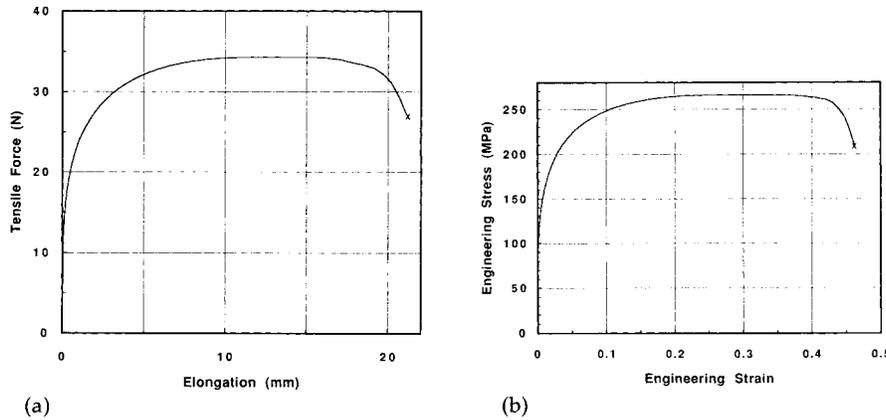


Fig. 3 Components of a hydraulic universal testing machine



**Fig. 4** (a) Load-elongation curve from a tensile test and (b) corresponding engineering stress-strain curve. Specimen diameter, 12.5 mm; gage length, 50 mm.

versible deformation is called *elastic deformation*. (The deformation of a rubber band is entirely elastic). At higher stresses, planes of atoms slide over one another. This deformation, which is not recovered when the stress is removed, is termed *plastic deformation*. Note that the term “plastic deformation” does not mean that the deformed material is a plastic (a polymeric material). Bending of a wire (such as paper-clip wire) with the fingers (Fig. 5) illustrates the difference. If the wire is bent a little bit, it will snap back when released (top). With larger bends, it will unbend elastically to some extent on release, but there will be a permanent bend because of the plastic deformation (bottom).

For most materials, the initial portion of the curve is linear. The slope of this linear region is called the *elastic modulus* or *Young’s modulus*:

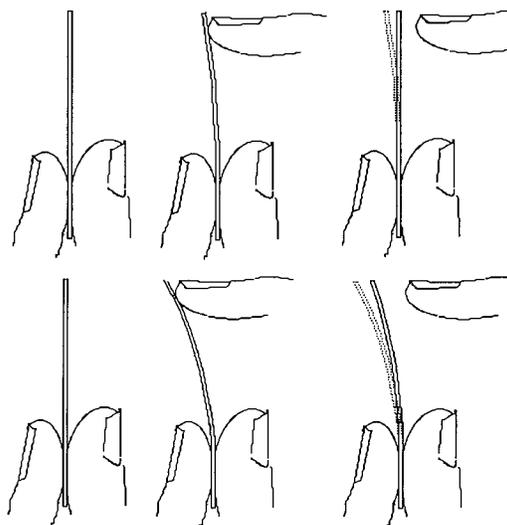
$$E = s/e \quad (\text{Eq 3})$$

In the elastic range, the ratio,  $\nu$ , of the magnitude of the lateral contraction strain to the axial strain is called *Poisson’s ratio*:

$$\nu = -e_y/e_x \text{ (in an } x\text{-direction tensile test)} \quad (\text{Eq 4})$$

Because elastic strains are usually very small, reasonably accurate measurement of Young’s modulus and Poisson’s ratio in a tensile test requires that strain be measured with a very sensitive extensometer. (Strain gages should be used for lateral strains.) Accurate results can also be obtained by velocity-of-sound measurements (unless the modulus is very low or the damping is high, as with polymers).

When the stress rises high enough, the stress-strain behavior will cease to be linear and the strain will not disappear completely on unloading. The strain that remains is called plastic strain. The first plastic strain usually corresponds to the first deviation from linearity. (For some materials, the elastic deformation may be nonlinear, and so there is not always this correspondence). Once plastic deformation has begun, there will be both elastic and plastic contributions to the total strain,  $e_T$ . This can be expressed as  $e_T = e_e + e_p$ , where  $e_p$  is the plas-



**Fig. 5** Elastic and plastic deformation of a wire with the fingers. With small forces (top), all of the bending is elastic and disappears when the force is released. With greater forces (below), some of the bending is recoverable (elastic), but most of the bending is not recovered (is plastic) when the force is removed.

tic contribution and  $e_e$  is the elastic contribution (and still related to the stress by Eq 3).

It is tempting to define an *elastic limit* as the stress at which plastic deformation first occurs and a *proportional limit* as the stress at which the stress-strain curve first deviates from linearity. However, neither definition is very useful, because measurement of the stress at which plastic deformation first occurs or the first deviation from linearity is observed depends on how accurately strain can be measured. The smaller the plastic strains that can be sensed and the smaller the deviations from linearity can be detected, the smaller the elastic and proportional limits.

To avoid this problem, the onset of the plasticity is usually described by an offset *yield strength*, which can be measured with greater reproducibility. It can be found by constructing a straight line parallel to the initial linear portion of the stress-strain curve, but offset by  $e = 0.002$  or 0.2%. The yield strength is the stress at which this line intersects the stress-strain curve (Fig. 6). The rationale is that if the material had been loaded to this stress and then unloaded, the unloading path would have been along this offset line and would have resulted in a plastic strain of  $e = 0.2\%$ . Other offset strains are

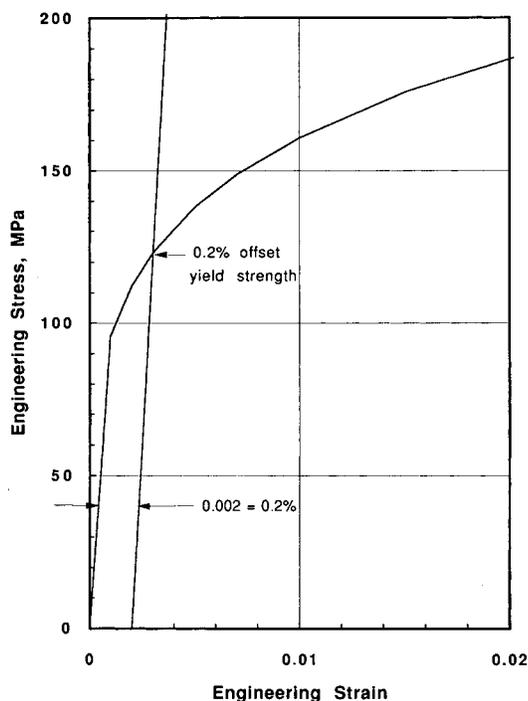


Fig. 6 The low-strain region of the stress-strain curve for a ductile material

sometimes used. The advantage of defining yield strength in this way is that such a parameter is easily reproduced and does not depend heavily on the sensitivity of measurement.

Sometimes, for convenience, yielding in metals is defined by the stress required to achieve a specified total strain (e.g.,  $e_T = 0.005$  or 0.5% elongation) instead of a specified offset strain. In any case, the criterion should be made clear to the user of the data.

**Yield Points.** For some materials (e.g., low-carbon steels and many linear polymers), the stress-strain curves have initial maxima followed by lower stresses, as shown in Fig. 7(a) and (b). After the initial maximum, all the deformation at any instant is occurring within a relatively small region of the specimen. Continued elongation of the specimen occurs by propagation of the deforming region (Lüders band in the case of steels) along the gage section rather than by increased strain within the deforming region. Only after the entire gage section has been traversed by the band does the stress rise again. In the case of linear polymers, a yield strength is often defined as the initial maximum stress. For steels, the subsequent *lower* yield strength is used to describe yielding. This is because measurements of the initial maximum or *upper* yield strength are extremely sensitive to how axially the load is applied during the tensile test. Some laboratories cite the minimum, whereas others cite a mean stress during this discontinuous yielding.

The tensile strength (ultimate strength) is defined as the highest value of engineering stress\* (Fig. 8). Up to the maximum load, the deformation should be uniform along the gage section. With ductile materials, the tensile strength corresponds to the point at which the deformation starts to localize, forming a neck (Fig. 8a). Less ductile materials fracture before they neck (Fig. 8b). In this case, the fracture strength is the tensile strength. Indeed, very brittle materials (e.g., glass at room temperature) do not yield before fracture (Fig. 8c). Such materials have tensile strengths but not yield strengths.

**Ductility.** There are two common measures used to describe the ductility of a material. One

\*Sometimes the upper yield strength of low-carbon steel is higher than the subsequent maximum. In such cases, some prefer to define the tensile strength as the subsequent maximum instead of the initial maximum, which is higher. In such cases, the definition of tensile strength should be made clear to the user.

is the percent elongation, which is defined simply as

$$\%El = [(L_f - L_0)/L_0] \times 100 \quad (\text{Eq 5})$$

where  $L_0$  is the initial gage length and  $L_f$  is the length of the gage section at fracture. Measurements may be made on the broken pieces or under load. For most materials, the amount of elastic elongation is so small that the two are equivalent. When this is not so (as with brittle metals or rubber), the results should state whether or not the elongation includes an elastic contribution. The other common measure of ductility is percent reduction of area, which is defined as

$$\%RA = [(A_0 - A_f)/A_0] \times 100 \quad (\text{Eq 6})$$

where  $A_0$  and  $A_f$  are the initial cross-sectional area and the cross-sectional area at fracture, respectively. If failure occurs without necking, one can be calculated from the other:

$$\%El = \%RA/(100 - \%RA) \quad (\text{Eq 7})$$

After a neck has developed, the two are no longer related. Percent elongation, as a measure of ductility, has the disadvantage that it is really composed of two parts: the uniform elongation that occurs before necking, and the localized elongation that occurs during necking. The second part is sensitive to the specimen shape. When a gage section that is very long (relative to its diameter), the necking elongation converted to percent is very small. In contrast, with a gage section that is short (relative to its di-

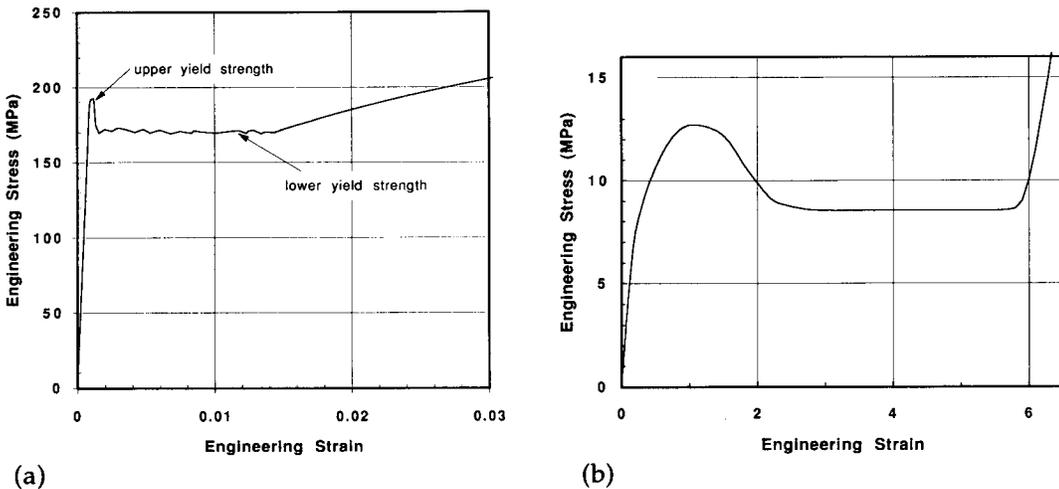


Fig. 7 Inhomogeneous yielding of a low-carbon steel (a) and a linear polymer (b). After the initial stress maxima, the deformation occurs within a narrow band, which propagates along the entire length of the gage section before the stress rises again.

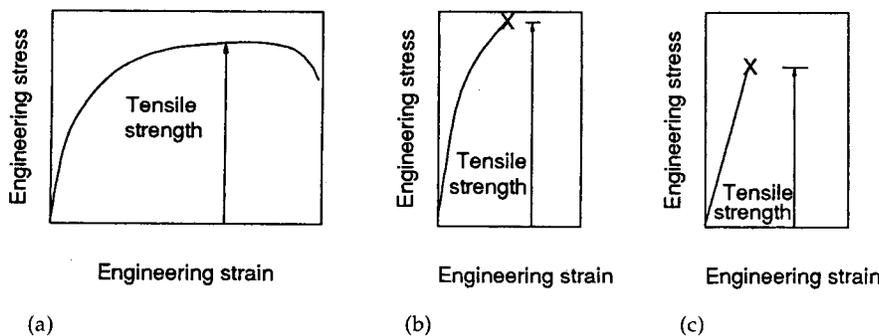


Fig. 8 Stress-strain curves showing that the tensile strength is the maximum engineering stress regardless of whether the specimen necks (a) or fractures before necking (b and c).

ameter), the necking elongation can account for most of the total elongation.

For round bars, this problem has been remedied by standardizing the ratio of gage length to diameter to 4:1. Within a series of bars, all with the same gage-length-to-diameter ratio, the necking elongation will be the same fraction of the total elongation. However, there is no simple way to make meaningful comparisons of percent elongation from such standardized bars with that measured on sheet tensile specimens or wire. With sheet tensile specimens, a portion of the elongation occurs during diffuse necking, and this could be standardized by maintaining the same ratio of width to gage length. However, a portion of the elongation also occurs during what is called localized necking, and this depends on the sheet thickness. For tensile testing of wire, it is impractical to have a reduced section, and so the ratio of gage length to diameter is necessarily very large. Necking elongation contributes very little to the total elongation.

Percent reduction of area, as a measure of ductility, has the disadvantage that with very ductile materials it is often difficult to measure the final cross-sectional area at fracture. This is particularly true of sheet specimens.

## True Stress and Strain

If the results of tensile testing are to be used to predict how a metal will behave under other forms of loading, it is desirable to plot the data in terms of true stress and true strain. True stress,  $\sigma$ , is defined as

$$\sigma = F/A \quad (\text{Eq 8})$$

where  $A$  is the cross-sectional area at the time that the applied force is  $F$ . Up to the point at which necking starts, true strain,  $\epsilon$ , is defined as

$$\epsilon = \ln(L/L_0) \quad (\text{Eq 9})$$

This definition arises from taking an increment of true strain,  $d\epsilon$ , as the incremental change in length,  $dL$ , divided by the length,  $L$ , at the time,  $d\epsilon = dL/L$ , and integrating. As long as the deformation is uniform along the gage section, the true stress and strain can be calculated from the engineering quantities. With constant volume and uniform deformation,  $LA = L_0A_0$ :

$$A_0/A = L/L_0 \quad (\text{Eq 10})$$

Thus, according to Eq 2,  $A_0/A = 1 + e$ . Equation 8 can be rewritten as

$$\sigma = (F/A_0)(A_0/A)$$

and, with substitution for  $A_0/A$  and  $F/A_0$ , as

$$\sigma = s(1 + e) \quad (\text{Eq 11})$$

Substitution of  $L/L_0 = 1 + e$  into the expression for true strain (Eq 9) gives

$$\epsilon = \ln(1 + e) \quad (\text{Eq 12})$$

At very low strains, the differences between true and engineering stress and strain are very small. It does not really matter whether Young's modulus is defined in terms of engineering or true stress strain.

It must be emphasized that these expressions are valid only as long as the deformation is uniform. Once necking starts, Eq 8 for true stress is still valid, but the cross-sectional area at the base of the neck must be measured directly rather than being inferred from the length measurements. Because the true stress, thus calculated, is the true stress at the base of the neck, the corresponding true strain should also be at the base of the neck. Equation 9 could still be used if the  $L$  and  $L_0$  values were known for an extremely short gage section centered on the middle of the neck (one so short that variations of area along it would be negligible). Of course, there will be no such gage section, but if there were, Eq 10 would be valid. Thus the true strain can be calculated as

$$\epsilon = \ln(A_0/A) \quad (\text{Eq 13})$$

Figure 9 shows a comparison of engineering and true stress-strain curves for the same material.

## Other Factors Influencing the Stress-Strain Curve

There are a number of factors not previously discussed in this chapter that have an effect on the shape of the stress-strain curve. These include strain rate, temperature, and anisotropy. For information on these subjects, the reader should refer to Chapters 2 and 3 listed in the introduction to this chapter as well as Chapter 12, "Hot Tensile Testing" and Chapter 15, "High Strain Rate Tensile Testing."

## Test Methodology and Data Analysis

This section reviews some of the more important considerations involved in tensile testing. These include:

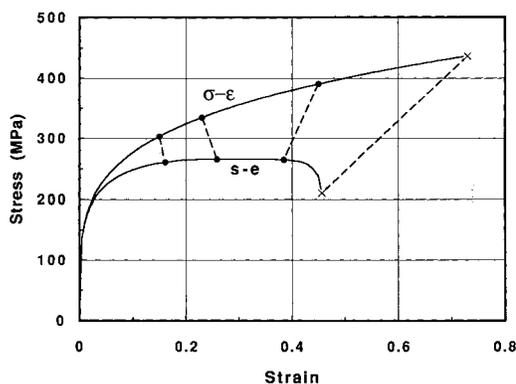
- Sample selection
- Sample preparation
- Test set-up
- Test procedure
- Data recording and analysis
- Reporting

**Sample Selection.** When a material is tested, the objective usually is to determine whether or not the material is suitable for its intended use.

The sample to be tested must fairly represent the body of material in question. In other words, it must be from the same source and have undergone the same processing steps.

It is often difficult to match exactly the test samples to the structure made from the material. A common practice for testing of large castings, forgings, and composite layups is to add extra material to the part for use as “built-in” test samples. This material is cut from the completed part after processing and is made into test specimens that have been subjected to the same processing steps as the bulk of the part.

In practice, these specimens may not exactly match the bulk of the part in certain important details, such as the grain patterns in critical areas of a forging. One or more complete parts may be sacrificed to obtain test samples from the most critical areas for comparison with the “built-in” samples. Thus, it may be determined



**Fig. 9** Comparison of engineering and true stress-strain curves. Prior to necking, a point on the  $\sigma$ - $\epsilon$  curve can be constructed from a point on the  $s$ - $e$  curve using Eq 11 and 12. Subsequently, the cross section must be measured to find true stress and strain.

how closely the “built-in” samples represent the material in question.

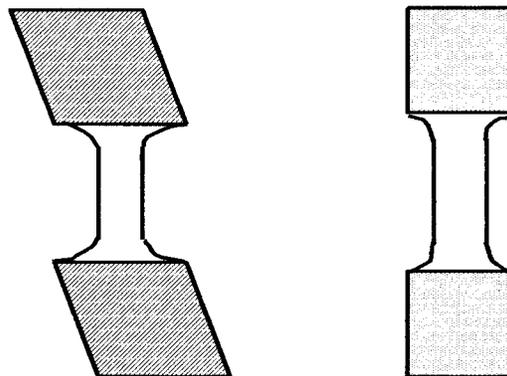
There is a special case in which the object of the test is to evaluate not the material, but the test itself. Here, the test specimens must be as nearly identical as possible so the differences in the test results represent, as far as possible, only the variability in the testing process.

**Sample Preparation.** It should be remembered that a “sample” is a quantity of material that represents a larger lot. The sample usually is made into multiple “specimens” for testing. Test samples must be prepared properly to achieve accurate results. The following rules are suggested for general guidance.

First, as each sample is obtained, it should be identified as to material description, source, location and orientation with respect to the body of material, processing status at the time of sampling, and the date and time of day that the sample was obtained.

Second, test specimens must be made carefully, with attention to several details. The specimen axis must be properly aligned with the material rolling direction, forging grain pattern, or composite layup. Cold working of the test section must be minimized. The dimensions of the specimen must be held within the allowable tolerances established by the test procedure. The attachment areas at each end of the specimen must be aligned with the axis of the bar (see Fig. 10). Each specimen must be identified as belonging to the original sample. If total elongation is to be measured after the specimen breaks, the gage length must be marked on the reduced section of the bar prior to testing.

**The test set-up** requires that equipment be properly matched to the test at hand. There are



**Fig. 10** Improper (left) and proper (right) alignment of specimen attachment areas with axis of specimen

three requirements of the testing machine: force capacity sufficient to break the specimens to be tested; control of test speed (or strain rate or load rate), as required by the test specification; and precision and accuracy sufficient to obtain and record properly the load and extension information generated by the test. This precision and accuracy should be ensured by current calibration certification.

For grips, of which many types are in common use in tensile testing, only two rules apply: the grips must properly fit the specimens (or vice versa), and they must have sufficient force capacity so that they are not damaged during testing.

As described earlier in the section “Tensile Specimens and Testing Machines,” there are several techniques for installing the specimen in the grips. With wedge grips, placement of the specimen in the grips is critical to proper alignment (see Fig. 11). Ideally, the grip faces should be of the same width as the tab ends of the test bar; otherwise, lateral alignment is dependent only on the skill of the technician. The wedge grip inserts should be contained within the grip body or crosshead, and the specimen tabs should be fully engaged by the grips (see Fig. 12).

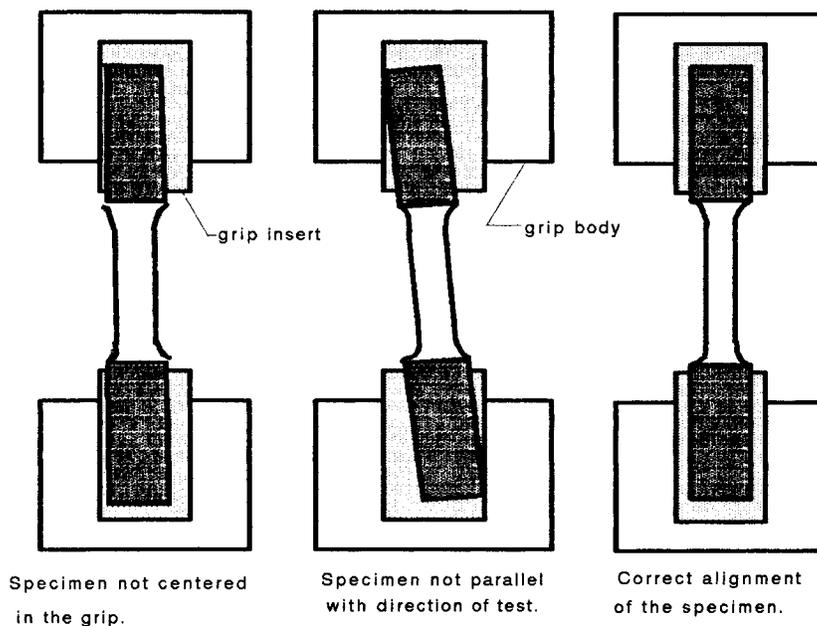
Other types of grips have perhaps fewer traps for the inexperienced technician, but an obvious one is that, with threaded grips, a length of

threads on the specimen equal to at least one diameter should be engaged in the threaded grips.

There are several potential problems that must be watched for during the test set-up, including specimen misalignment and worn grips. The physical alignment of the two points of attachment of the specimen is important, because any off-center loading will exert bending loads on the specimen. This is critical in testing of brittle materials, and may cause problems even for ductile materials. Alignment will be affected by the testing-machine loadframe, any grips and fixtures used, and the specimen itself. Misalignment may also induce load-measurement errors due to the passage of bending forces through the load-measuring apparatus. Such errors may be reduced by the use of spherical seats or “U-joints” in the set-up.

Worn grips may contribute to off-center loading. Uneven tooth marks across the width of the specimen tab are an indication of trouble in wedge grips. Split-collar grips may also cause off-center loading. Uneven wear of grips and mismatching of split-shell insert pairs are potential problem areas.

Strain measurements are required for many tests. They are commonly made with extensometers, but strain gages are frequently used—especially on small specimens or where Pois-



**Fig. 11** Improper (left, center) and proper (right) alignment of specimen in wedge grips

son's ratio is to be measured. If strain measurements are required, appropriate strain-measuring instruments must be properly installed. The technician should pay particular attention to setting of the extensometer gage length (mechanical zero). The zero of the strain readout should repeat consistently if the mechanical zero is set properly. In other words, once the extensometer has been installed and zeroed, subsequent installations should require minimal readjustment of the zero.

**Test Procedure.** The following general rules for test procedure may be applied to almost every tensile test.

Load and strain ranges should be selected so that the test will fit the range. The maximum values to be recorded should be as close to the top of the selected scale as convenient without running the risk of going past full scale. Ranges may be selected using past experience for a particular test, or specification data for the material (if available). Note that many computer-based testing systems have automatic range selection and will capture data even if the range initially selected is too small.

The identity of each specimen should be verified, and pertinent identification should be accurately recorded for the test records and report.

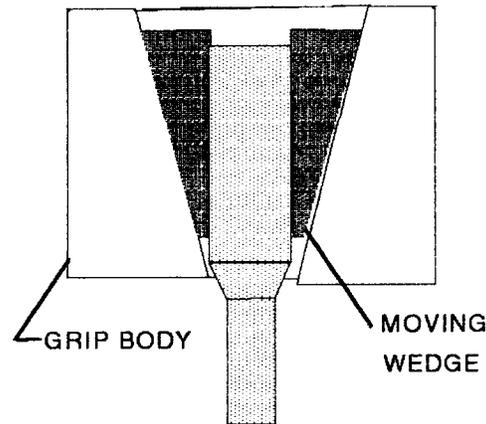
The dimensions needed to calculate the cross-sectional area of the reduced section should be measured and recorded. These measurements should be repeated for every specimen; it should not be assumed that sample preparation is perfectly consistent.

The load-indicator zero and the plot-load-axis zero, if applicable, should be set before the specimen is placed in the grips. Zeroes should never be reset after the specimen is in place.

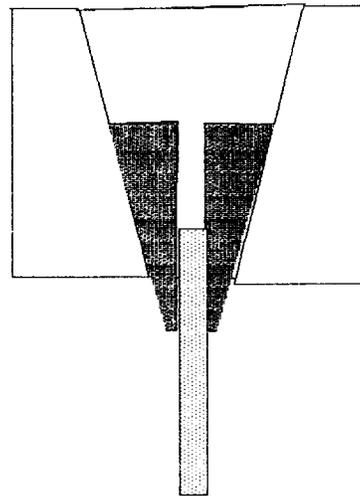
The specimen is placed in the grips and is secured by closing the grips. If preload is to be removed before the test is started, it should be physically unloaded by moving the loading mechanism. The zero adjustment should never be used for this purpose. Note that, in some cases, preload may be desirable and may be deliberately introduced. For materials for which the initial portion of the curve is linear, the strain zero may be corrected for preload by extending the initial straight portion of the stress-strain curve to zero load and measuring strain from that point. The strain value at the zero-load intercept is commonly called the "foot correction" and is subtracted from readings taken from strain scale (see Fig. 10 in Chapter 3, "Uniaxial Tensile Testing").

When the extensometer, if applicable, is installed, the technician should be sure to set the mechanical zero correctly. The strain-readout zero should be set after the extensometer is in place on the specimen.

The test procedure should be in conformance with the published test specification and should



**PROPER ENGAGEMENT OF A SPECIMEN IN WEDGE GRIPS.**



**POOR ENGAGEMENT. THIS SMALL 'BITE' IS LIKELY TO CAUSE DAMAGE TO THE GRIPS, AND RISK OF INJURY TO ANYONE NEAR THE MACHINE.**

**Fig. 12** Proper and improper engagement of a specimen in wedge grips

be repeated consistently for every test. It is important that the test specification be followed for speed of testing. Some materials are sensitive to test speed, and different speeds will give different results. Also, many testing machine load- and strain-measuring instruments are not capable of responding fast enough for accurate recording of test results if an excessive test speed is used.

The technician should monitor the test closely and be alert for problems. One common sign of trouble is a load-versus-strain plot in which the initial portion of the curve is not straight. This may indicate off-center loading of the specimen, improper installation of the extensometer, or the specimen was not straight to begin with.

Another potential trouble sign is a sharp drop in indicated load during the test. Such a drop may be characteristic of the material, but it also can indicate problems such as slippage between the specimen and the grips or stick-slip movement of the wedge grip inserts in the grip body. Slippage may be caused by worn inserts with dull teeth, particularly for hard, smooth specimens.

The stick-slip action in wedge grips is more common in testing of resilient materials, but it also can occur in testing of metals. Specimens cut from the wall of a pipe or tube may have curved tab ends that flatten with increasing force, allowing the inserts to move relative to the grip body. Short tab ends on round specimens also may be crushed by the wedge grips, with the same result. If the sliding faces are not lubricated, they may move in unpredictable steps accompanied by drops in the load reading. Dry-film molybdenum disulfide lubricants are effective in solving stick-slip problems in wedge grips, particularly when testing is done at elevated temperature.

When wedge grips are used, the specimen must be installed so that the clamping force is contained within the grip body. Placing the specimen too near the open end of the grip body results in excessive stress on the grip body and inserts and is a common cause of grip failure. **WARNING:** Grip failures are dangerous and may cause injury to personnel and damage to equipment.

**Data** generally may be grouped into “raw data,” meaning the observed readings of the measuring instruments, and “calculated data,” meaning the test results obtained after the first step of analysis.

In the most simple tensile test, the raw data comprise a single measurement of peak force

and the dimensional measurements taken to determine the cross-sectional area of the test specimen. The first analysis step is to calculate the “tensile strength,” defined as the force per unit area required to fracture the specimen. More complicated tests will require more information, which typically takes the form of a graph of force versus extension. Computer-based testing machines can display the graph without paper, and can save the measurements associated with the graph by electronic means.

A permanent record of the raw test data is important, because it allows additional analyses to be performed later, if desired, and because it allows errors in analysis to be found and corrected by reference to the original data.

**Data Recording.** Test records may be needed by many departments within an organization, including metallurgy, engineering, commercial, and legal departments.

Engineering and metallurgy departments typically are most interested in material properties, but may use raw data for error checking or additional analyses. The metallurgy department wants to know how variations in raw materials or processing change the properties of the product being produced and tested, and the engineering department wants to know the properties of the material for design purposes.

Shipping, receiving, and accounting departments need to know whether or not the material meets the specifications for shipping, acceptance, and payment. The sales department needs information for advertising and for advising prospective customers.

If a product incorporating the tested material later fails—particularly if persons are injured—the legal department may need test data as evidence in legal proceedings. In this case, a record of the raw data will be important for support of the original analysis and test report.

**Analysis of test data** is done at several levels. First, the technician observes the test in progress, and may see that a grip is slipping or that the specimen fractures outside the gage section. These observations may be sufficient to determine that a test is invalid.

Immediately after the test, a first-level analysis is performed according to the calculation requirements of the test procedure. ASTM test specifications typically show the necessary equations with an explanation and perhaps an example. This analysis may be as simple as dividing peak force by cross-sectional area, or it may require more complex calculations. The

outputs of this first level of analysis are the mechanical properties of the material being tested.

Upon completion of the group of tests performed on the sample, a statistical analysis may be made. The statistical analysis produces average (mean or median) values for representation of the sample in the subsequent database and also provides information about the uniformity of the material and the repeatability of the test.

The results of tests on each sample of material may be stored in a database for future use. The database allows a wide range of analyses to be performed using statistical methods to correlate the mechanical-properties data with other information about the material. For example, it may allow determination of whether or not there is a significant difference between the material tested and similar material obtained from a different supplier or through a different production path.

**Reporting.** The test report usually contains the results of tests performed on one sample composed of several specimens.

When ASTM specifications are used for testing, the requirements for reporting are defined by the specification. The needs of a particular user probably will determine the form for identification of the material, but the reported results will most likely be as given in the ASTM test specification.

The information contained in the test report generally should include identification of the testing equipment, the material tested, and the test procedure; the raw and calculated data for each specimen; and a brief statistical summary for the sample.

Each piece of test equipment used for the test should be identified, including serial numbers, capacity or range used, and date of certification or date due for certification.

Identification of the material tested should include the type of material (alloy, part number, etc.); the specific batch, lot, order, heat, or coil from which the sample was taken; the point in the processing sequence (condition, temper, etc.) at which the sample was taken; and any test or pretest conditions (test temperature, aging, etc.).

Identification of the test procedure usually will be reported by reference to a standard test procedure such as those published by ASTM or perhaps to a proprietary specification originating within the testing organization.

The raw data for each specimen are recorded, or a reference to the raw data is included so that

the data can be obtained from a file if and when they are needed. Frequently, only a portion of the raw data—dimensions, for example—is recorded, and information on the force-versus-extension graph is referenced.

A tabulation of the properties calculated for each specimen is recorded. The calculations at this stage are the first level of data analysis. The calculations required usually are defined in the test procedure or specification.

A brief statistical summary for the sample is a feature that is becoming more common with the proliferation of computerized testing systems, because the computations required can be done automatically without added operator workload. The statistical summary may include the average (mean) value, median value, standard deviation, highest value, lowest value, range, etc. The average or median value would be used to represent this sample at the next level of analysis, which is the material database.

Examination of this initial statistical information can tell a great deal about the test as well as the material. A low standard deviation or range indicates that the material in the sample has uniform properties (each of several specimens has nearly the same values for the measured properties) and that the test is producing consistent results. Conversely, a high standard deviation or range indicates that a problem of inconsistent material or testing exists and needs to be investigated.

A continuing record of the average properties and the associated standard deviation and range information is the basis for statistical process control, which systematically interprets this information so as to provide the maximum information about both the material and the test process.

## ACKNOWLEDGMENTS

This chapter was adapted from:

- W.F. Hosford, Overview of Tensile Testing, *Tensile Testing*, P. Han, Ed., ASM International, 1992, p 1–24
- P.M. Mumford, Test Methodology and Data Analysis, *Tensile Testing*, P. Han, Ed., ASM International, 1992, p 49–60
- R. Gedney, Guide To Testing Metals Under Tension, *Advanced Materials & Processes*, February, 2002, p 29–31



The Materials  
Information Society

**ASM International** is the society for materials engineers and scientists, a worldwide network dedicated to advancing industry, technology, and applications of metals and materials.

ASM International, Materials Park, Ohio, USA  
[www.asminternational.org](http://www.asminternational.org)

This publication is copyright © ASM International®. All rights reserved.

Publication title	Product code
<b>Tensile Testing</b>	<b>#05106G</b>

**To order products from ASM International:**

**Online** Visit [www.asminternational.org/bookstore](http://www.asminternational.org/bookstore)

**Telephone** 1-800-336-5152 (US) or 1-440-338-5151 (Outside US)

**Fax** 1-440-338-4634

**Mail** Customer Service, ASM International  
9639 Kinsman Rd, Materials Park, Ohio 44073-0002, USA

**Email** [CustomerService@asminternational.org](mailto:CustomerService@asminternational.org)

**In Europe** American Technical Publishers Ltd.  
27-29 Knowl Piece, Wilbury Way, Hitchin Hertfordshire SG4 0SX,  
United Kingdom  
Telephone: 01462 437933 (account holders), 01462 431525 (credit card)  
[www.ameritech.co.uk](http://www.ameritech.co.uk)

**In Japan** Neutrino Inc.  
Takahashi Bldg., 44-3 Fuda 1-chome, Chofu-Shi, Tokyo 182 Japan  
Telephone: 81 (0) 424 84 5550

**Terms of Use.** This publication is being made available in PDF format as a benefit to members and customers of ASM International. You may download and print a copy of this publication for your personal use only. Other use and distribution is prohibited without the express written permission of ASM International.

No warranties, express or implied, including, without limitation, warranties of merchantability or fitness for a particular purpose, are given in connection with this publication. Although this information is believed to be accurate by ASM, ASM cannot guarantee that favorable results will be obtained from the use of this publication alone. This publication is intended for use by persons having technical skill, at their sole discretion and risk. Since the conditions of product or material use are outside of ASM's control, ASM assumes no liability or obligation in connection with any use of this information. As with any material, evaluation of the material under end-use conditions prior to specification is essential. Therefore, specific testing under actual conditions is recommended.

Nothing contained in this publication shall be construed as a grant of any right of manufacture, sale, use, or reproduction, in connection with any method, process, apparatus, product, composition, or system, whether or not covered by letters patent, copyright, or trademark, and nothing contained in this publication shall be construed as a defense against any alleged infringement of letters patent, copyright, or trademark, or as a defense against liability for such infringement.