Standard Terminology Relating to Methods of Mechanical Testing[1]

This standard is issued under the fixed designation E6; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ε1 NOTE—Editorial corrections were made throughout in March 2011.

1. Scope

1.1 This terminology covers the principal terms relating to methods of mechanical testing of solids. The general definitions are restricted and interpreted, when necessary, to make them particularly applicable and practicable for use in standards requiring or relating to mechanical tests. These definitions are published to encourage uniformity of terminology in product specifications.

1.2 Terms relating to fatigue and fracture testing are defined in Terminology E1823.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E8/E8M Test Methods for Tension Testing of Metallic Materials

E796 Test Method for Ductility Testing of Metallic Foil[3]

E1823 Terminology Relating to Fatigue and Fracture Testing

2.2 *ISO Standard:*[4]

ISO/IEC Guide 99:2007 International Vocabulary of metrology—Basic and general concepts and terms (VIM)

3. Index of Cross-References and Associated Definitions

3.1 The terms listed below are associated with terminology that is fundamental or commonly used. The definition for the term of interest is related to or is given below the definition for the fundamental term cited.

Term	
angular strain	see **strain**
axial strain	see **strain**
bending strain	see **strain**
chord modulus	see **modulus of elasticity**
direct verification	see **verification**
compressive stress	see **stress**
elastic constants	see **modulus of elasticity** and **Poisson's ratio**
elastic modulus	see **modulus of elasticity**
engineering strain	see **strain**
engineering stress	see **stress**
fracture stress	see **stress**
indirect verification	see **verification**
linear (tensile or compressive) strain	see **strain**
macrostrain	see **strain**
malleability	see **ductility**
microstrain	see **strain**
modulus of rigidity	see **modulus of elasticity**
nominal stress	see **stress**
normal stress	see **stress**
physical properties	see **mechanical properties**
pin	see **mandrel (in bend testing)**
plunger	see **mandrel (in bend testing)**
principal stress	see **stress**
residual strain	see **strain**
residual stress	see **stress**
Rockwell superficial hardness number	see **Rockwell hardness number**
secant modulus	see **modulus of elasticity**
shear strain	see **strain**
shear stress	see **stress**
static fatigue strength	see **creep rupture strength**
strain gauge fatigue life	see **fatigue life**
stress-rupture strength	see **creep rupture strength**
tangent modulus	see **modulus of elasticity**
tensile stress	see **stress**
torsional modulus	see **modulus of elasticity**
torsional stress	see **stress**
transverse strain	see **strain**
true strain	see **strain**
true stress	see **stress**
ultimate tensile strength (UTS)	see **tensile strength**
yield strength	see also **upper yield strength** and **lower yield strength**

[1] This terminology is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.91 on Terminology except where designated otherwise. A subcommittee designation in parentheses following a definition indicates the subcommittee with responsibility for that definition.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.ch.

4. Terminology

4.1 *Terms and Definitions:*

accuracy, *n*—the permissible variation from the correct value. **(E28.01)**

alignment, *n*—the condition of a testing machine and load train (including the test specimen) that influences the introduction of bending moments into a specimen during tensile loading. **(E28.04)**

angle of bend, *n*—the change in the angle between the two legs of the specimen during a bend test, measured before release of the bending forces.

DISCUSSION—The angle of bend is measured before release of the bending force, unless otherwise specified. **(E28.02)**

angle of twist (torsion test), *n*—the angle of relative rotation measured in a plane normal to the torsion specimen's longitudinal axis over the gauge length. **(E28.04)**

bearing area [L^2], *n*—the product of the pin diameter and specimen thickness. **(E28.04)**

bearing force [F], *n*—a compressive force on an interface. **(E28.04)**

bearing strain, *n*—the ratio of the bearing deformation of the bearing hole, in the direction of the applied force, to the pin diameter. **(E28.04)**

bearing strength [FL^{-2}], *n*—the maximum bearing stress which a material is capable of sustaining. **(E28.04)**

bearing stress [FL^{-2}], *n*—the force per unit of bearing area. **(E28.04)**

bearing yield strength [FL^{-2}], *n*—the bearing stress at which a material exhibits a specified limiting deviation from the proportionality of bearing stress to bearing strain. **(E28.04)**

bend test, *n*—a test for ductility performed by bending or folding a specimen, usually by steadily applied forces but in some instances by blows. The bending may be interrupted to examine the bent surface for cracks.

DISCUSSION—The ductility is usually judged by whether or not the specimen cracks under the specified conditions of the test.

DISCUSSION—There are four general types of bend tests according to the manner in which the forces are applied to the specimen to make the bend. These are as follows:

1. Free Bend
2. Guided Bend
3. Semi-Guided Bend
4. Wrap-Around Bend

DISCUSSION—The specimen has a substantially uniform cross-section and a length several times as great as the largest dimension of the cross-section. **(E28.02)**

bias, statistical, *n*—a constant or systematic error in test results. **(E28.04)**

biaxial stretching, *v*—a mode of sheet metal forming in which positive strains are observed in all directions at a given location. **(E28.02)**

breaking force[F], *n*—the force at which fracture occurs.

DISCUSSION—When used in connection with tension tests of thin materials or materials of small diameter for which it is often difficult to distinguish between the breaking force and the maximum force developed, the latter is considered to be the breaking force. **(E28.04)**

Brinell hardness number, HB , *n*—result from indentation hardness test in which a number proportional to the quotient obtained by dividing the test force by the curved surface area of the indentation which is assumed to be sphereical and of the diameter of the ball.

$$\text{HBW} = 0.102 \times 2F/\pi D[D-(D^2-d^2)^{-1/2} \quad (1)$$

where:

F = test force, N,
D = diameter of ball, mm, and
d = mean diameter of the indentation, mm.

DISCUSSION—In former standards, a steel ball was allowed for hardness values below 450. In cases where a steel ball was used the Brinell hardness was denoted by HB or HBS.

DISCUSSION—The symbol HBW is preceded by the hardness value when the test is carried out under the following conditions:

Ball diameter	10 mm
Force	3000 kgf
Duration of loading	10 to 15 s

When other conditions are used, the hardness value and symbol are supplemented by numbers indicating the test conditions in the following order: diameter of ball, force, and duration of loading. **(E28.06)**

Brinell hardness test, *n*—test in which an indenter (tungsten carbide ball) is forced into the surface of a test piece and the diameter of the indentation left in the surface after removal of the test force is measured.

DISCUSSION—The tungsten carbide ball may be used for materials with Brinell hardness not exceeding 650. **(E28.06)**

calibration, *n*—a process that establishes, under specific conditions, the relationship between values indicated by a measuring system and the corresponding values indicated by one or more standards.

DISCUSSION—This definition is intended to meet the principles of the definition of **calibration** provided by the ISO/IEC Guide 99:2007 International Vocabulary of Basic and General Terms in Metrology (VIM). **(E28.91)**

calibration factor, *n*—the factor by which a change in extensometer reading must be multiplied to obtain the equivalent strain.

DISCUSSION—For any extensometer, the calibration factor is equal to the ratio of change in length to the product of the gauge length and the change in extensometer reading. For direct-reading extensometers the calibration factor is unity. **(E28.01)**

compressive strength [FL^{-2}], *n*—the maximum compressive stress that a material is capable of sustaining. Compressive strength is calculated by dividing the maximum force during a compression test by the original cross-sectional area of the specimen.

DISCUSSION—In the case of a material which fails in compression by a shattering fracture, the compressive strength has a very definite value. In the case of materials which do not fail in compression by a shattering fracture, the value obtained for compressive strength is an arbitrary value depending upon the degree of distortion which is regarded as indicating complete failure of the material. **(E28.04)**

compressometer, *n*—a specialized extensometer used for sensing negative or compressive strain. **(E28.01)**

constraint, *n*—any restriction to the deformation of a body. **(E28.11)**

creep, *n*—the time-dependent strain that occurs after the application of a force which is thereafter maintained constant.

DISCUSSION—Creep tests are usually made at constant force and temperature. For tests on plastics, the initial strain – however defined– is included; for tests on metals, the initial strain is not included. **(E28.04)**

creep recovery, *n*—the time-dependent decrease in strain in a solid, following the removal of force.

DISCUSSION—Recovery is usually determined at constant temperature.

DISCUSSION—In tests of plastics, the initial recovery is generally included; for metals, it is not. Thermal expansion is excluded. **(E28.04)**

creep rupture strength [FL^{-2}], *n*—the stress causing fracture in a creep test at a given time, in a specified constant environment.

DISCUSSION—This is sometimes referred to as the *stress-rupture strength* or, in glass technology, the *static fatigue strength*. **(E28.04)**

creep strength [FL^{-2}], *n*—the stress that causes a given creep in a creep test at a given time in a specified constant environment. **(E28.04)**

deep drawing, *v*—a metal sheet forming operation in which strains on the sheet surface are positive in the direction of the punch travel and negative at 90° to that direction. **(E28.02)**

deflectometer, *n*—a specialized extensometer used for sensing of extension or motion, usually without reference to a specific gauge length. **(E28.01)**

Demeri split-ring test, *n*—a test the measures the springback behavior of sheet metal by comparing the diameter of a ring extracted from the wall of a flat bottom cup to the diameter of the same ring, split to release residual stresses. **(E28.02)**

discontinuous yielding, *n*—a hesitation or fluctuation of force observed at the onset of plastic deformation, due to localized yielding.

DISCUSSION—The stress-strain curve need not appear to be discontinuous. **(E28.04)**

discontinuous yielding stress, *n*—the peak stress at the initiation of the first measurable serration on the curve of stress-versus strain. **(E28.04)**

ductility, *n*—the ability of a material to deform plastically before fracturing.

DISCUSSION—Ductility is usually evaluated by measuring (*1*) the elongation or reduction of area from a tension test, (*2*) the depth of cup from a cupping test, (*3*) the radius or angle of bend from the bend test, or (*4*) the fatigue ductility from the fatigue ductility test (see Test Method E796).

DISCUSSION—Malleability is the ability to deform plastically under repetitive compressive forces. **(E28.02)**

dynamic mechanical measurement, *n*—a technique in which either the modulus or damping, or both, of a substance under oscillatory applied force or displacement is measured as a function of temperature, frequency, or time, or a combination thereof. **(E28.04)**

eccentricity, *n*—the distance between the line of action of the applied force and the axis of symmetry of the specimen in a plane perpendicular to the longitudinal axis of the specimen. **(E28.04)**

edge distance [L], *n*—the distance from the edge of a bearing specimen to the center of the hole in the direction of applied force. **(E28.04)**

edge distance ratio, *n*—the ratio of the edge distance to the pin diameter. **(E28.04)**

elastic calibration device, *n*—a device used in verifying the force readings of a testing machine consisting of an elastic member(s) to which forces may be applied, combined with a mechanism or device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation of the member under an applied force. **(E28.01)**

elastic force measuring device, *n*—a device or system consisting of an elastic member combined with a device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation of the member under an applied force. **(E28.01)**

elastic limit [FL^{-2}], *n*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress.

DISCUSSION—Due to practical considerations in determining the elastic limit, measurements of strain using a small force, rather than zero force, are usually taken as the initial and final reference.

elongation, *El*, *n*—the increase in gauge length of a body subjected to a tension force, referenced to a gauge length on the body. Usually elongation is expressed as a percentage of the original gauge length.

DISCUSSION—The increase in gauge length may be determined either *at* or *after* fracture, as specified for the material under test.

DISCUSSION—The term elongation, when applied to metals, generally means measurement after fracture; when applied to plastics and elastomers, measurement at fracture. Such interpretation is usually applicable to values of elongation reported in the literature when no further qualification is given.

DISCUSSION—In reporting values of elongation, the gauge length shall be stated.

DISCUSSION—Elongation is affected by specimen geometry (area and shape of cross section, parallel length, parallelism, fillet radii, etc.), preparation (degree to which surfaces within the reduced section are smooth and free of cold work), and test procedure (alignment and test speed, for example). **(E28.04)**

error, *n*—for a measurement or reading, the amount it deviates from a known or reference value represented by a measurement standard. Mathematically, the error is calculated by subtracting the accepted value from the measurement or reading. (See also **percent error**.) **(E28.91)**

extensometer, *n*—a device for sensing strain. **(E28.01)**

extensometer system, *n*—a system for sensing and indicating strain.

DISCUSSION—The system will normally include an extensometer, conditioning electronics, and auxiliary device (recorder, digital readout, computer, etc.). However, completely self-contained mechanical devices are permitted. An extensometer system may be one of three types. **(E28.01)**

Type 1 extensometer system, n— an extensometer system that both defines gauge length and senses extension; for example, a clip-on strain gauge type with conditioning electronics. **(E28.01)**

Type 2 extensometer system, n—an extensometer system that senses extension of a gauge length that is defined by specimen features such as ridges, notches, or overall height (in case of a compression test piece). **(E28.01)**

DISCUSSION—The precision associated with gauge length setting for a Type 2 extensometer should be specified in relevant test method or product standard. The position readout on a testing machine is not recommended for use in a Type 2 extensometer system.

Type 3 extensometer system, n—an extensometer system that intrinsically senses strain (ratiometric principle); for example, video camera system. **(E28.01)**

fatigue ductility, D_f, *n*—the ability of a material to deform plastically before fracturing, determined from a constant-strain amplitude, low-cycle fatigue test.

DISCUSSION—Fatigue ductility is usually expressed in percent, in direct analogy with elongation and reduction of area ductility measures.

DISCUSSION—The fatigue ductility corresponds to the fracture ductility, the true tensile strain at fracture. Elongation and reduction of area represent the engineering tensile strain after fracture.

DISCUSSION—The fatigue ductility is used for metallic foil for which the tension test does not give useful elongation and reduction of area measures. **(E28.02)**

fatigue life, N_f, *n*—the numbers of cycles of stress or strain of a specified character that a given specimen sustains before failure of a specified nature occurs. **(E28.01)**

forming limit curve, *n*—an empirically derived curve showing the biaxial strain levels beyond which localized through-thickness thinning (necking) and subsequent failure occur during the forming of a metallic sheet. **(E28.02)**

forming limit diagram, *n*—a graph on which the measured major and associated minor strain combinations are plotted to develop a forming limit curve. **(E28.02)**

fracture ductility, ε_f, *n*—the true plastic strain at fracture.

fracture strength, S_f **[FL^{-2}],** *n*—the normal stress at the beginning of fracture. Fracture strength is calculated by dividing the force at the beginning of fracture during a tension test by the original cross-sectional area of the specimen. **(E28.04)**

free bend, *n*—the bend obtained by applying forces to the ends of a specimen without the application of force at the point of maximum bending.

DISCUSSION—In making a free bend, lateral forces first are applied to produce a small amount of bending at two points. The two bends, each a suitable distance from the center, are both in the same direction. **(E28.02)**

force [F], *n*—in mechanical testing, a vector quantity of fundamental nature characterized by a magnitude, a direction, a sense, and a discrete point of application, that acts externally upon a test object and creates stresses in it.

DISCUSSION—Force is a derived unit of the SI system. Units of force in the SI system are newtons (N).

DISCUSSION—Where applicable, the noun **force** is preferred to **load** in terminology for mechanical testing. **(E28.91)**

gauge length, *n*—the original length of that portion of the specimen over which strain, elongation, or change of length are determined. Typically, this length is also the distance between gauge marks, if gauge marking is used to facilitate measurement of the elongation after fracture.

DISCUSSION—When sensing extension or motion with a gauge length that is predetermined by the specimen geometry or specific test method, then only resolution and strain error for the specified gauge length should determine the class of the extensometer system. **(E28.91)**

guided bend, *n*—the bend obtained by using a mandrel to guide and force the portion of the specimen being bent between two faces of a die. **(E28.02)**

hardness, *n*—the resistance of a material to deformation, particularly permanent deformation, indentation, or scratching.

DISCUSSION—Different methods of evaluating hardness give different ratings because they are measuring somewhat different quantities and characteristics of the material. There is no absolute scale for hardness; therefore, to express hardness quantitatively, each type of test has its own scale of arbitrarily defined hardness. **(E28.06)**

indentation hardness, *n*—the hardness as evaluated from measurements of area or depth of the indentation made by pressing a specified indenter into the surface of a material under specified static loading conditions. **(E28.06)**

initial recovery, *n*—the decrease in strain in a specimen resulting from the removal of force, before creep recovery takes place.

DISCUSSION—This is sometimes referred to as instantaneous recovery.

DISCUSSION—Recovery is usually determined at constant temperature. Thermal expansion is excluded.

DISCUSSION—For tests on plastics, the initial recovery is generally included as part of creep recovery.

DISCUSSION—This definition describes a quantity which is difficult to measure accurately. The values obtained may vary greatly with the sensitivity and accuracy of the test equipment. When determining this quantity, the procedure and characteristics of the test equipment should be reported. **(E28.04)**

initial strain, *n*—the strain introduced into a specimen by the given loading conditions, before creep takes place.

DISCUSSION—This is sometimes referred to as instantaneous strain. **(E28.04)**

initial stress, *n*—the stress introduced into a specimen by imposing the given constraint conditions before stress relaxation begins.

DISCUSSION—This is sometimes referred to as instantaneous stress. **(E28.11)**

Knoop hardness number, HK, *n*—a number related to the applied force and to the projected area of the permanent impression made by a rhombic-based pyramidal diamond indenter having included edge angles of 172° 30 min and 130° 0 min computed from the equation:

$$HK = P/0.07028d^2 \quad (2)$$

where:
P = applied force, kgf, and
d = long diagonal of the impression, mm.

In reporting Knoop hardness numbers, the test force is stated. **(E28.06)**

Knoop hardness test, *n*—an indentation hardness test using calibrated machines to force a rhombic-based pyramidal diamond indenter having specified edge angles, under specified conditions, into the surface of the material under test and to measure the long diagonal after removal of the force. **(E28.06)**

least count, *n*—the smallest change in indication that can customarily be determined and reported.

DISCUSSION—In machines with close graduations the least count may be the value of a graduation interval; with open graduations or with magnifiers for reading, it may be an estimated fraction, rarely as fine as one tenth, of a graduated interval; and with verniers it is customarily the difference between the scale and vernier graduation measured in terms of scale units. If the indicating mechanism includes a stepped detent, the detent action may determine the least count.

limiting dome height (LDH)—an evaluative test for metal sheet forming capability employing a 200 mm (4in.) hemisphereical punch and circumferential clamping force sufficient to prevent metal from the surrounding flange being pulled into the cavity. **(E28.02)**

load [F] **,** *n*—in mechanical testing, an external force or system of forces or pressures, acting upon the test specimen or sample.

DISCUSSION—**Load** is a deprecated term and, where practical, should be replaced by **force**, particularly when used as a noun. For reasons of editorial simplicity or traditional usage, replacement of **load** by **force** may not always be desirable when used as a verb, adjective, or other part of speech. For example, it is appropriate to refer to **loading** a specimen, a **loading** rate, a **load** cell, or a **load**–line displacement. **(E28.91)**

lower yield strength, *LYS* [FL^{-2}], *n*—the minimum stress recorded during discontinuous yielding, ignoring transient effects. See Figs. 1 and 2. **(E28.04)**

mandrel (in bend testing), *n*—the tool used to control the strain on the concave side of a bend in a wrap-around bend test and also to apply the bending force in a semi-guided or guided bend test.

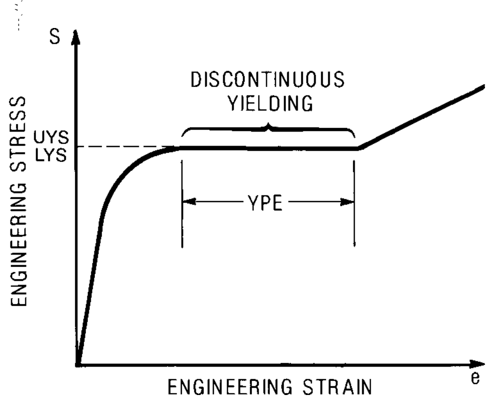

FIG. 1 Stress-Strain Diagram for Determination of Upper and Lower Yield Strengths and Yield Point Elongation in a Material Exhibiting Discontinuous Yielding

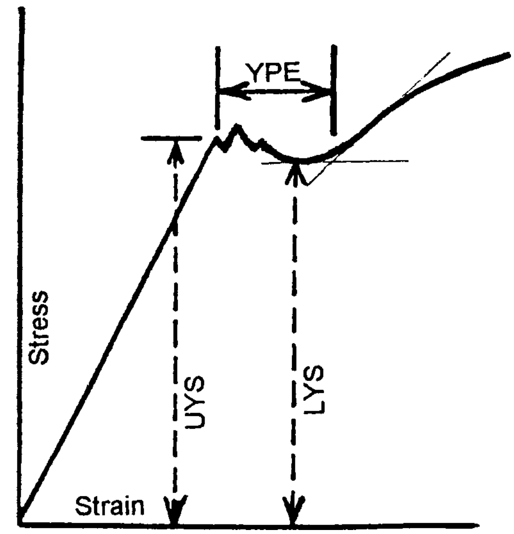

FIG. 2 Stress Strain Diagram Showing Yield Point Elongation and Upper and Lower Yield Strengths

DISCUSSION—The terms "pin" and "plunger" have been used in place of mandrel.

DISCUSSION—In free bends or semi-guided bends to an angle of 180° a shim or block of the proper thickness may be placed between the legs of the specimen as bending is completed. This shim or block is also referred to as a pin or mandrel. **(E28.02)**

mechanical hysteresis, *n*—the energy absorbed in a complete cycle of loading and unloading.

DISCUSSION—A complete cycle of loading and unloading includes any stress cycle regardless of the mean stress or range of stress. **(E28.04)**

mechanical properties, *n*—those properties of a material that are associated with elastic and inelastic reaction when force is applied, or that involve the relationship between stress and strain.

DISCUSSION—These properties have often been referred to as "physical properties," but the term "mechanical properties" is preferred. **(E28.91)**

mechanical testing, *n*—determination of the properties or the mechanical states of a material that are associated with elastic and inelastic reactions to force or that involve relationships between stress and strain. **(E28.91)**

modulus of elasticity [FL^{-2}], *n*—the ratio of stress to corresponding strain below the proportional limit.

DISCUSSION—The stress-strain relationships of many materials do not conform to Hooke's law throughout the elastic range, but deviate therefrom even at stresses well below the elastic limit. For such materials, the slope of either the tangent to the stress-strain curve at the origin or at a low stress, the secant drawn from the origin to any specified point on the stress-strain curve, or the chord connecting any two specified points on the stress-strain curve is usually taken to be the "modulus of elasticity." In these cases, the modulus should be designated as the "tangent modulus," the "secant modulus," or the "chord modulus," and the point or points on the stress-strain curve described. Thus, for materials where the stress-strain relationship is curvilinear rather than linear, one of the four following terms may be used:

(*a*) *initial tangent modulus* [FL^{-2}], *n*—the slope of the stress-strain curve at the origin.

(*b*) *tangent modulus* [FL^{-2}], *n*—the slope of the stress-strain curve at any specified stress or strain.

(*c*) *secant modulus* [FL^{-2}], *n*—the slope of the secant drawn from the origin to any specified point on the stress-strain curve.

(*d*) *chord modulus* [FL^{-2}], *n*—the slope of the chord drawn between any two specified points on the stress-strain curve below the elastic limit of the material.

DISCUSSION—Modulus of elasticity, like stress, is expressed in force per unit of area (pounds per square inch, etc.). **(E28.04)**

modulus of rupture in bending [FL^{-2}], *n*—the value of maximum tensile or compressive stress (whichever causes failure) in the extreme fiber of a beam loaded to failure in bending, computed from the flexure equation:

$$S_b = Mc/I \quad (3)$$

where:
M = maximum bending moment, computed from the maximum force and the original moment arm,
c = initial distance from the neutral axis to the extreme fiber where failure occurs, and
I = initial moment of inertia of the cross section about the neutral axis.

DISCUSSION—When the proportional limit in either tension or compression is exceeded, the modulus of rupture in bending is greater than the actual maximum tensile or compressive stress in the extreme fiber, exclusive of the effect of stress concentration near points of force application.

DISCUSSION—If the criterion for failure is other than rupture or attaining the first maximum force, it should be so stated. **(E28.02)**

modulus of rupture in torsion [FL^{-2}], *n*—the value of maximum shear stress in the extreme fiber of a member of circular cross section loaded to failure in torsion, computed from the equation:

$$S_s = Tr/J \quad (4)$$

where:
T = maximum twisting moment,
r = original outer radius, and
J = polar moment of inertia of the original cross section.

DISCUSSION—When the proportional limit in shear is exceeded, the modulus of rupture in torsion is greater than the actual maximum shear stress in the extreme fiber, exclusive of the effect of stress concentration near points of application of torque.

DISCUSSION—If the criterion for failure is other than fracture or attaining the first maximum of twisting moment, it should be so stated. **(E28.04)**

necking, *n*—the onset of nonuniform or localized plastic deformation, resulting in a localized reduction of cross-sectional area. **(E28.02)**

percent error, *n*—the ratio, expressed as a percent, of an error to the known accepted value represented by a measurement standard. (See also, **error**.) **(E28.91)**

precision, *n*—the degree of mutual agreement among individual measurements made under prescribed like conditions. **(E28.04)**

primary force standard, *n*—a deadweight force applied directly without intervening mechanisms (such as levers, hydraulic multipliers, or the like) whose mass has been determined by comparison with reference standards traceable to national standards of mass. **(E28.01)**

Poisson's ratio, μ, *n*—the negative of the ratio of transverse strain to the corresponding axial strain resulting from an axial stress below the proportional limit of the material.

DISCUSSION—Poisson's ratio may be negative for some materials, for example, a tensile transverse strain will result from a tensile axial strain.

DISCUSSION—Poisson's ratio will have more than one value if the material is not isotropic. **(E28.04)**

proportional limit [FL^{-2}], *n*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law).

DISCUSSION—Many experiments have shown that values observed for the proportional limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. When determination of proportional limit is required, the procedure and the sensitivity of the test equipment should be specified.

radius of bend, *n*—the radius of the cylindrical surface of the pin or mandrel that comes in contact with the inside surface of the bend during bending. In the case of free or semi-guided bends to 180° in which a shim or block is used, the radius of bend is one half the thickness of the shim or block. **(E28.02)**

rapid indentation hardness test, *n*—an indentation hardness test using calibrated machines to force a hard steel or carbide ball, under specified conditions, into the surface of the material under test and to measure the depth of the indentation. The depth measured can be from the surface of the test specimen or from a reference position established by the application of a preliminary test force. **(E28.06)**

rate of creep, *n*—the slope of the creep-time curve at a given time. **(E28.04)**

reading, *n*—a quantity (typically a measurement or test result) indicated by a piece of equipment, such that it can be read by a user. **(E28.91)**

reduced section, *n*—the part of the specimen length between the fillets. **(E28.04)**

reduced section, *n*—section in the central portion of the specimen, which has a cross section smaller than the gripped ends. **(E28.04)**

reduction of area, *n*—the difference between the original cross-sectional area of a tension test specimen and the area of its smallest cross section. The reduction of area is usually expressed as a percentage of the original cross-sectional area of the specimen.

DISCUSSION—The smallest cross section may be measured at or after fracture as specified for the material under test.

DISCUSSION—The term reduction of area when applied to metals generally means measurement after fracture; when applied to plastics and elastomers, measurement at fracture. Such interpretation is usually applicable to values for reduction of area reported in the literature when no further qualification is given. **(E28.04)**

reference standard, *n*—an item, typically a material or an instrument, that has been characterized by recognized standards or testing laboratories, for some of its physical or mechanical properties, and that is generally used for calibration or verification, or both, of a measurement system or for evaluating a test method.

DISCUSSION—Typically reference standards are accompanied by certificates stating the accepted value and the associated uncertainty. Information may also be provided demonstrating how the values were determined and how the traceability to national standards was established, if applicable. **(E28.91)**

relaxation rate, *n*—the absolute value of the slope of the relaxation curve at a given time.

DISCUSSION—A relaxation curve is a plot of either the remaining or relaxed stress as a function of time. **(E28.11)**

relaxed stress, *n*—the initial stress minus the remaining stress at a given time during a stress-relaxation test. **(E28.11)**

remaining stress, *n*—the stress remaining at a given time during a stress-relaxation test. **(E28.11)**

resolution—for a particular measurement device, the smallest change in the quantity being measured that causes a perceptible change in the corresponding indication.

DISCUSSION—Resolution may depend on the value (magnitude) of the quantity being measured.

DISCUSSION—For paper charts or analog indicators, the resolution should not be assumed to be better (smaller) than 1⁄10 of the spacing between graduations. For digital devices, the best resolution potentially achievable is the smallest difference between two different readings given by the display.

DISCUSSION—For both analog and digital devices, the actual resolution can be significantly poorer than described above, due to factors such as noise, friction, etc. **(E28.91)**

Rockwell hardness number, HR, *n*—a number derived from the net increase in the depth of indentation as the force on an indenter is increased from a specified preliminary test force to a specified total test force and then returned to the preliminary test force.

DISCUSSION—Rockwell hardness numbers are always quoted with a scale symbol representing the indenter and forces used. The hardness number is followed by the symbol HR and the scale designation. When a ball indentor is used, the scale designation is followed by the letter "S" to indicate the use of a steel ball or the letter "W" to indicate the use of a tungsten carbide ball. Examples:
64 HRC = Rockwell hardness number of 64 on Rockwell C Scale.
81 HR 30N = Rockwell superficial hardness number of 81 on Rockwell 30N scale.
72 HRBW = Rockwell hardness number of 72 on the Rockwell B scale measured using a tungsten carbide ball indenter. **(E28.06)**

Rockwell hardness test, *n*—an indentation hardness test using a verified machine to force a diamond sphero-conical indenter (diamond indenter) or a ball indenter under specified conditions into the surface of the material under test in two operations, and to measure the difference in depth of the indentation under the specified conditions of preliminary and total test forces (minor and major loads, respectively). **(E28.06)**

Rockwell superficial hardness test, *n*—same as the Rockwell hardness test except that smaller preliminary and total test forces are used. **(E28.06)**

Scleroscope hardness number, HSc or HSd, *n*—a number related to the height of rebound of a diamond-tipped hammer dropped on the material being tested.

DISCUSSION—Scleroscope hardness number is measured on a scale determined by dividing into 100 units the average rebound of the hammer from a quenched (to maximum hardness) and untempered high carbon water-hardening tool steel test block of AISI W-5. **(E28.06)**

Scleroscope hardness test, *n*—a dynamic indentation hardness test using a calibrated instrument that drops a diamond-tipped hammer from a fixed height onto the surface of the material under test.

DISCUSSION—The height of rebound of the hammer is a measure of the hardness of the material. **(E28.06)**

secondary force standard, *n*—an instrument or mechanism, the calibration of which has been established by comparison with primary force standards. **(E28.01)**

semi-guided bend, *n*—the bend obtained by applying a force directly to the specimen in the portion that is to be bent.

DISCUSSION—The specimen is either held at one end or forced around a pin or rounded edge, or is supported near the ends and bent by a force applied on the side of the specimen opposite the supports and midway between them. In some instances, the bend is started in this manner and finished in the manner of the free bend. **(E28.02)**

set, *n*—strain remaining after complete release of the force producing the deformation.

DISCUSSION—Due to practical considerations, such as distortion in the specimen and slack in the strain indicating system, measurements of strain at a small force rather than zero force are often taken.

DISCUSSION—Set is often referred to as permanent set if it shows no further change with time. Time elapsing between removal of force and final reading of set should be stated.

shear fracture, *n*—a mode of fracture in crystalline materials resulting from translation along slip planes which are preferentially oriented in the direction of the shearing stress. **(E28.04)**

shear modulus, *G* [FL^{-2}], *n*—the ratio of shear stress to corresponding shear strain below the proportional limit, also called *torsional modulus* and *modulus of rigidity*.

DISCUSSION—The value of the shear modulus may depend on the direction in which it is measured if the material is not isotropic. Wood, many plastics and certain metals are markedly anisotropic. Deviations from isotropy should be suspected if the shear modulus differs from that determined by substituting independently measured values of Young's modulus, *E*, and Poisson's ratio, μ, in the relation:

$$G = E/[2(1 + \mu)]$$

DISCUSSION—In general, it is advisable in reporting values of shear modulus to state the range of stress over which it is measured. **(E28.04)**

shear strength [FL^{-2}], *n*—the maximum shear stress which a material is capable of sustaining. Shear strength is calculated from the maximum force during a shear or torsion test and is based on the original dimensions of the cross section of the specimen. **(E28.04)**

slenderness ratio, *n*—the effective unsupported length of a uniform column divided by the least radius of gyration of the cross-sectional area. **(E28.04)**

springback, *n*—the difference between the final shape of a part and the shape of the forming die.

Discussion—The shape and dimensions of a deformed metal object generally change upon release of the force(s) applied during forming, due to elastic recovery. **(E28.02)**

strain, e, *n*—the per unit change in the size or shape of a body referred to its original size or shape. Strain is a nondimensional quantity, but it is frequently expressed in inches per inch, metres per metre, or percent.

Discussion—As used in the context of mechanical testing, the term **strain** refers to changes in size or shape associated with application of force, although strain can also be introduced due to other conditions, such as temperature changes or gradients.

Discussion—In this standard, "original" refers to dimensions or shape of cross section of specimens at the beginning of testing.

Discussion—Strain at a point is defined by six components of strain: three linear components and three shear components referred to a set of coordinate axes.

Discussion—In the usual tension, compression, or torsion test it is customary to measure only one component of strain and to refer to this as "the strain." In a tension or a compression test this is usually the axial component.

Discussion—Strain has an elastic and a plastic component. For small amounts of total strain or deformation, the plastic component can be imperceptibly small.

Discussion—Linear thermal expansion, sometimes called "thermal strain," and changes due to the effect of moisture are not normally specifically measured in mechanical testing, except to the extent that they may affect the measurements of strain due to force. **(E28.91)**

angular strain, *n*—use *shear strain.*

axial strain, *n*—linear strain in a plane parallel to the longitudinal axis of the specimen. **(E28.04)**

bending strain, *n*—the difference between the strain at the surface of the specimen and the axial strain. **(E28.04)**

elastic true strain, ε_e, *n*—elastic component of the true strain. **(E28.91)**

engineering strain, e, *n*—a dimensionless value that is the change in length (ΔL) per unit length of original linear dimension (L_0) along the loading axis of the specimen; that is, $e = (\Delta L)/L_0$. **(E28.02)**

linear (tensile or compressive) strain, *n*—the change per unit length due to force in an original linear dimension.

Discussion—An increase in length is considered positive. **(E28.04)**

macrostrain, *n*—the mean strain over any finite gauge length of measurement large in comparison with interatomic distances.

Discussion—Macrostrain can be measured by several methods, including electrical-resistance strain gages and mechanical or optical extensometers. Elastic macrostrain can be measured by X-ray diffraction.

Discussion—When either of the terms *macrostrain* or *microstrain* is first used in a document, it is recommended that the physical dimension or the gauge length, which indicate the size of the reference strain volume involved, be stated. **(E28.13)**

microstrain, *n*—the strain over a gauge length comparable to interatomic distances.

Discussion—These are the strains being averaged by the macrostrain measurement. Microstrain is not measurable by existing techniques. Variance of the microstrain distribution can, however, be measured by X-ray diffraction.

Discussion—When either of the terms *macrostrain* or *microstrain* is first used in a document, it is recommended that the physical dimension or the gauge length, which indicate the size of the reference strain volume involved, be stated. **(E28.13)**

microstrain, *n*—strain expressed in micro-units per unit, such as micrometres/metre or microinches/in. **(E28.04)**

plastic true strain, ε_p, *n*—the inelastic component of true strain. **(E28.91)**

residual strain, *n*—strain associated with internal residual stresses.

Discussion—A body may have internal residual stresses which are balanced in its current form, such that removal of some material may result in a measurable change in shape– due to a change in stresses and the body reacting to rebalance the stresses within it.

Discussion—Residual strains are elastic. **(E28.13)**

resistance strain gauge bridge, *n*—a common Wheatstone bridge made up of strain gages used for the measurement of small changes of resistance produced by a strain gauge. **(E28.14)**

shear strain, *n*—the tangent of the angular change, due to force, between two lines originally perpendicular to each other through a point in a body. **(E28.04)**

transverse strain, *n*—linear strain in a plane perpendicular to the axis of the specimen.

Discussion—Transverse strain may differ with direction in anisotropic materials. **(E28.91)**

true strain, ε, *n*—the natural logarithm of the ratio of instantaneous gauge length, *L*, to the original gauge length, L_0; that is, $\varepsilon = 1n\ (L / L_0)$ or $\varepsilon = 1n\ (1+e)$. **(E28.02)**

strain gauge fatigue life, *n*—the number of fully reversed strain cycles corresponding to the onset of degraded gauge performance, whether due to excessive zero shift or other detectable failure mode. **(E28.01)**

strain hardening, *n*—an increase in hardness and strength caused by plastic deformation. **(E28.02)**

stress [FL^{-2}], *n*—the intensity at a point in a body of the forces or components of force that act on a given plane through the point. Stress is expressed in force per unit of area (for example, pounds-force per square inch, megapascals).

Discussion—As used in tension, compression, or shear tests prescribed in product specifications, stress is calculated on the basis of the original dimensions of the cross section of the specimen. This stress is sometimes called "engineering stress," to emphasize the difference from true stress. **(E28.91)**

compressive stress [FL^{-2}], *n*—normal stress due to forces directed toward the plane on which they act. **(E28.04)**

engineering stress, S [FL^{-2}], *n*—the normal stress, expressed in units of applied force, *F*, per unit of original cross-sectional area, A_0; that is, $S = F/A_0$. **(E28.02)**

fracture stress [FL^{-2}], *n*—the true normal stress on the minimum cross-sectional area at the beginning of fracture.

Discussion—This term usually applies to tension tests of unnotched specimens. **(E28.91)**

nominal stress [FL^{-2}], *n*—the stress at a point calculated on the net cross section by simple elastic theory without taking into account the effect on the stress produced by geometric discontinuities such as holes, grooves, fillets, and so forth. **(E28.91)**

normal stress [FL^{-2}], *n*—the stress component perpendicular to a plane on which the forces act. **(E28.91)**

principal stress (normal) [FL^{-2}], *n*—the maximum or minimum value of the normal stress at a point in a plane considered with respect to all possible orientations of the considered plane. On such principal planes the shear stress is zero.

DISCUSSION—There are three principal stresses on three mutually perpendicular planes. The states of stress at a point may be:

(*1*) *uniaxial* [FL^{-2}], *n*—a state of stress in which two of the three principal stresses are zero,

(*2*) *biaxial* [FL^{-2}], *n*—a state of stress in which only one of the three principal stresses is zero, or

(*3*) *triaxial* [FL^{-2}], *n*—a state of stress in which none of the principal stresses is zero.

(*4*) *multiaxial* [FL^{-2}], *n*—biaxial or triaxial. **(E28.91)**

residual stress [FL^{-2}], *n*—stress in a body which is at rest and in equilibrium and at uniform temperature in the absence of external and mass forces. **(E28.13)**

shear stress [FL^{-2}], *n*—the stress component tangential to the plane on which the forces act. **(E28.04)**

tensile stress [FL^{-2}], *n*—normal stress due to forces directed away from the plane on which they act. **(E28.04)**

torsional stress [FL^{-2}], *n*—the shear stress in a body, in a plane normal to the axis of rotation, resulting from the application of torque. **(E28.04)**

true stress, σ [FL^{-2}], *n*—the instantaneous normal stress, calculated on the basis of the instantaneous cross-sectional area, *A*; that is, $\sigma = F/A$; if no necking has occurred, $\sigma = S(1+e)$. **(E28.02)**

stress relaxation, *n*—the time-dependent decrease in stress in a solid under given constraint conditions.

DISCUSSION—The general stress relaxation test is performed by isothermally applying a force to a specimen with fixed value of constraint. The constraint is maintained constant and the constraining force is determined as a function of time. **(E28.11)**

stress-strain diagram, *n*—a diagram in which corresponding values of stress and strain are plotted against each other. Values of stress are usually plotted as ordinates (vertically) and values of strain as abscissas (horizontally). **(E28.04)**

tensile strength, S_u [FL^{-2}], *n*—the maximum tensile stress which a material is capable of sustaining. Tensile strength is calculated from the maximum force during a tension test carried to rupture and the original cross-sectional area of the specimen.

DISCUSSION—The **tensile strength** of a material is also commonly referred to as the **ultimate tensile strength** or **UTS**. **(E28.04)**

testing machine (force-measuring type), *n*—a mechanical device for applying a force to a specimen. **(E28.01)**

torque [FL] , *n*—a moment (of forces) that produces or tends to produce rotation or torsion. **(E28.04)**

total elongation, El_t, *n*—the elongation determined after fracture by realigning and fitting together the broken ends of the specimen.

DISCUSSION—This definition is usually used for metallic materials. **(E28.04)**

uniform elongation, El_u[%], *n*—the elongation determined at the maximum force sustained by the test piece just prior to necking, or fracture, or both.

DISCUSSION—Uniform elongation includes both elastic and plastic elongation. **(E28.04)**

upper yield strength, *UYS* [FL^{-2}], *n*—in a uniaxial test, the first stress maximum (stress at first zero slope) associated with discontinuous yielding at or near the onset of plastic deformation. See Fig. 1, Fig. 2, and Fig. 3 **(E28.04)**

verification, *n*—an evaluation generating evidence to indicate whether an instrument, material, reference standard or procedure conforms to applicable requirements. (See also **direct verification** and **indirect verification.**)

DISCUSSION—Outside of mechanical testing, "verification" may refer to any check done to determine conformance. Within mechanical testing, the checking involves comparison to values indicated by a reference instrument or standard(s), and the applicable requirements generally address the accuracy and precision of data determined through use of the item verified.

direct verification—verification that assesses fundamental parameters of the test or equipment, such as force, time, or dimensions.

indirect verification—verification that does not assess fundamental parameters of the test or equipment but that instead uses reference standards to determine whether the instrument generates results meeting applicable requirements.

Vickers hardness number, HV , *n*—a number related to the applied force and the surface area of the permanent impression made by a square-based pyramidal diamond indenter having included face angles of 136°, computed from the equation:

$$HV = 2P \sin(\alpha/2)/d^2 = 1.8544P/d^2 \quad (5)$$

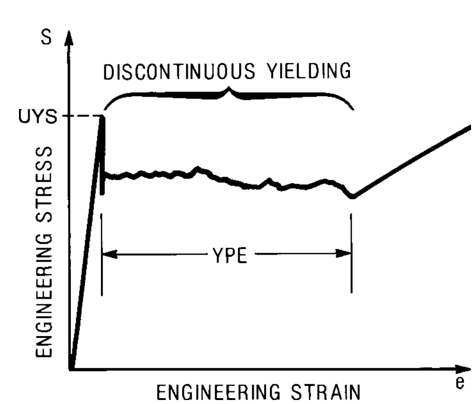

FIG. 3 Stress-Strain Diagram for Determination of Upper Yield Strength and Yield Point Elongation in a Material Exhibiting Discontinuous Yielding

where:
P = applied force, kgf,
d = mean diagonal of the impression, mm, and
α = face angle of diamond = 136°.

Discussion—The Vickers pyramid hardness number is followed by the symbol HV with a suffix number denoting the force and a second suffix number indicating the duration of loading when the latter differs from the normal loading time, which is 10 to 15 s. **(E28.06)**

Vickers hardness test, *n*—an indentation hardness test using calibrated machines to force a square-based pyramidal diamond indenter having specified face angles, under a predetermined force, into the surface of the material under test and to measure the diagonals of the resulting impression after removal of the force. **(E28.06)**

wrap-around bend, *n*—the bend obtained when a specimen is wrapped in a closed helix around a cylindrical mandrel.

Discussion—This term is sometimes applied to a semi-guided bend of 180° or less. **(E28.02)**

yield point, *YP* [FL^{-2}], *n*—term previously used, by E8 and E8M, for the property which is now referred to as **upper yield strength**. **(E28.04)**

yield point elongation, *YPE*, *n*—the strain (expressed in percent) separating the stress-strain curve's first point of zero slope from the point of transition from discontinuous yielding to uniform strain hardening.

Discussion—If the transition occurs over a range of strain, the *YPE* end point is the intersection between *(a)* a horizontal line tangent to the curve at the last zero slope and *(b)* a line drawn tangent to the strain hardening portion of the stress-strain curve at the point of inflection. (Fig. 2) If there is no point at or near the onset of yielding at which the slope reaches zero, the material has 0% *YPE*. **(E28.04)**

yield strength, *YS* or S_y [FL^{-2}], *n*—the engineering stress at which, by convention, it is considered that plastic elongation of the material has commenced. This stress may be specified in terms of (*a*) a specified deviation from a linear stress-strain relationship, (*b*) a specified total extension attained, or (*c*) maximum or minimum engineering stresses measured during discontinuous yielding.

Discussion—The following types of yield strengths, which correspond to the approaches listed above may be specified:
(*a*) *specified offset yield strength, n* (usually an offset strain of 0.2 % is specified)—the engineering stress at which the material has been plastically strained by an amount equal to the specified offset strain. This stress is reached at the point where the stress-strain curve intersects a line having a slope equal to the modulus of elasticity and constructed such that it is offset from the linear portion of the stress-strain curve by an amount equal to the specified strain (see Fig. 4).
(*b*) *specified extension under load yield strength, n* (usually a strain of 0.5 % is specified, although higher strains may need to be used in testing of elastomers, polymers, and high-strength materials, to ensure that the yield strength determined will exceed the material's elastic limit)—the engineering stress at which the material has elongated (including both elastic and plastic deformation) an amount corresponding to the specified strain. This stress is attained at the point where the stress-strain curve intersects a line drawn parallel to the stress axis at the specified strain on the strain axis (see Fig. 5).
(*c*) *upper or lower yield strengths, n*—the upper (first maximum) or the lower (minimum, ignoring transient effects) engineering stress measured during discontinuous yielding occurring at or near the onset of plastic deformation (see Fig. 1, Fig. 2 and Fig. 3).

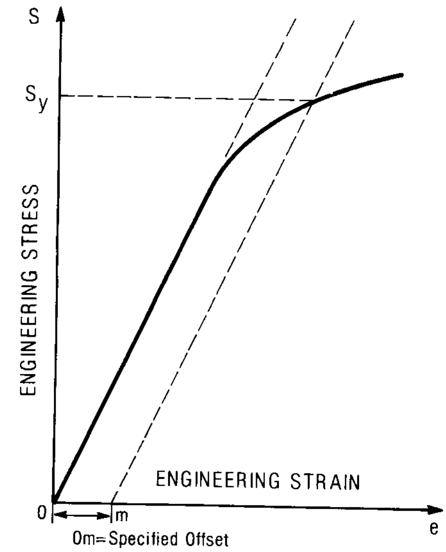

FIG. 4 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method

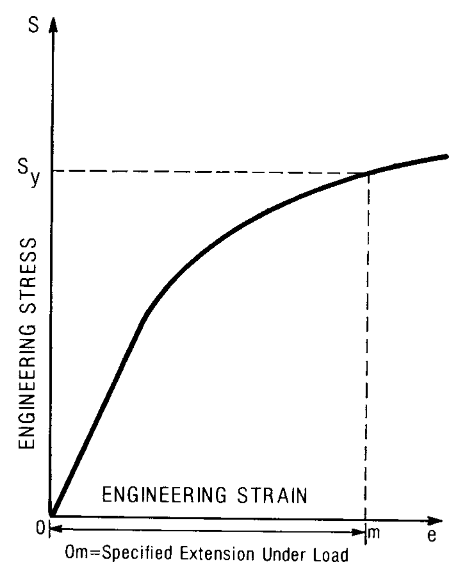

FIG. 5 Stress-Strain Diagram for Determination of Yield Strength by the Extension-Under-Load Method

Discussion—When yield strength is specified, the type of yield strength must be stated, along with the specified offset or extension under load, when applicable. The following are examples: *YS* (0.2 % offset), *YS* (0.5 % *EUL*), *UYS, LYS.*

Discussion—Offset or extension under load yield strengths should be specified for continuously yielding materials, because upper and lower yield strengths are not defined for such materials. Determination of upper or lower yield strengths, or both, is often favored for discontinuously yielding materials, because offsets or extensions constructed would generally intersect the portion of the stress-strain curve reflecting the stress oscillations which are characteristic of discontinuous yielding.

Discussion—The values obtained by the methods described above may differ. However, when discontinuous yielding causes the stress-strain curve to show a stress hesitation with no pronounced increases or decreases (see Fig. 1), the offset, *EUL* and upper and lower yield strengths generally approach or attain a common value.

DISCUSSION—Yield strength, however determined, is generally affected by speed of testing. However, upper and lower yield strengths can also be dramatically influenced by test equipment parameters such as stiffness and alignment. (For more information, consult Appendix 1 of E8/E8M.) **(E28.04)**

Young's modulus, E [FL^{-2}]**,** *n*—the ratio of tensile or compressive stress to corresponding strain below the proportional limit of the material. **(E28.04)**

zero time, *n*—the time when the given stress or constraint conditions are initially obtained in a stress relaxation test. **(E28.04)**

5. Keywords

5.1 abbreviations; bearing; bend; calibration; compression; creep; ductility; foil; elongation; hardness; impact; mechanical; pin; relaxation; shear; specifications; strain; strength; stress; symbols; tensile; tension; terms; testing; torsion; verification; yield

APPENDIX

(Nonmandatory Information)

X1. SYMBOLS AND ABBREVIATIONS

X1.1 The following symbols and abbreviations are frequently used instead of or along with the terms covered by these definitions. For stress, the use of S with appropriate lower case subscripts is preferred for general purposes; for mathematical analysis the use of Greek symbols is generally preferred.[5]

A	area of cross section
c	distance from centroid to outermost fiber
D	diameter
d	diameter or diagonal
DPH	diamond pyramid hardness (use HV, Vickers hardness number)
E	modulus of elasticity in tension or compression
F	force
G	modulus of elasticity in shear
HB	Brinell hardness number
HK	Knoop hardness number
HR	Rockwell hardness number (requires scale designation)
HV	Vickers hardness number
I	moment of inertia
J	polar moment of inertia
L	length
M	bending moment
P	concentrated load
r	radius
S	nominal engineering stress, or
S	normal engineering stress
S_a	shear engineering stress
S_c	compressive engineering stress
S_{cy}	compressive yield strength
S_t	tensile engineering stress
S_u	tensile strength
S_y	yield strength
T	temperature, torque, or twisting moment
t	time
W	work or energy
w	force per unit distance or per unit area
wA	total distributed force for a given area
wL	total distributed force for a given length
YPE	yield point elongation
YS	yield strength
Z	section modulus[4]
Δ	increment
δ	deviation
ε	true strain
γ	shear strain
μ	Poisson's ratio[A]
σ	normal true stress, nominal true stress[B]
σ_c	compressive true stress
σ_t	tensile true stress
τ	shear true stress
θ	angle of twist per unit length

[A] ν (nu) is preferred in applied mechanics.
[B] Symbol confusion could result when statistical treatments are involved.

[5] Many handbooks use S for section modulus, but Z is preferred since S is so widely used for normal or nominal stress.