Designation: E1823 – 13

Standard Terminology
Relating to Fatigue and Fracture Testing[1]

This standard is issued under the fixed designation E1823; 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.

1. Scope

1.1 This terminology contains definitions, definitions of terms specific to certain standards, symbols, and abbreviations approved for use in standards on fatigue and fracture testing. The definitions are preceded by two lists. The first is an alphabetical listing of symbols used. (Greek symbols are listed in accordance with their spelling in English.) The second is an alphabetical listing of relevant abbreviations.

1.2 This terminology includes Annex A1 on Units and Annex A2 on Designation Codes for Specimen Configuration, Applied Loading, and Crack or Notch Orientation.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E6 Terminology Relating to Methods of Mechanical Testing
E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E28 Test Methods for Softening Point of Resins Derived from Pine Chemicals and Hydrocarbons, by Ring-and-Ball Apparatus
E208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels
E338 Test Method of Sharp-Notch Tension Testing of High-Strength Sheet Materials (Withdrawn 2010)[3]
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials
E436 Test Method for Drop-Weight Tear Tests of Ferritic Steels
E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
E468 Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials
E561 Test Method for ***K-R*** Curve Determination
E602 Test Method for Sharp-Notch Tension Testing with Cylindrical Specimens (Withdrawn 2010)[3]
E604 Test Method for Dynamic Tear Testing of Metallic Materials
E606 Test Method for Strain-Controlled Fatigue Testing
E647 Test Method for Measurement of Fatigue Crack Growth Rates
E739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (***S-N***) and Strain-Life (ε-***N***) Fatigue Data
E740 Practice for Fracture Testing with Surface-Crack Tension Specimens
E813 Test Method for JIc, A Measure of Fracture Toughness
E992 Practice for Determination of Fracture Toughness of Steels Using Equivalent Energy Methodology
E1049 Practices for Cycle Counting in Fatigue Analysis
E1152 Test Method for Determining-J-R-Curves
E1221 Test Method for Determining Plane-Strain Crack-Arrest Fracture Toughness, K_{Ia}, of Ferritic Steels
E1290 Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement (Withdrawn 2013)[3]
E1304 Test Method for Plane-Strain (Chevron-Notch) Fracture Toughness of Metallic Materials
E1450 Test Method for Tension Testing of Structural Alloys in Liquid Helium
E1457 Test Method for Measurement of Creep Crack Growth Times and Rates in Metals
E1681 Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials
E1737 Test Method for *J*-Integral Characterization of Fracture Toughness (Withdrawn 1998)[3]
E1820 Test Method for Measurement of Fracture Toughness
E1921 Test Method for Determination of Reference Temperature, T_o, for Ferritic Steels in the Transition Range
E1942 Guide for Evaluating Data Acquisition Systems Used in Cyclic Fatigue and Fracture Mechanics Testing
E2207 Practice for Strain-Controlled Axial-Torsional Fatigue Testing with Thin-Walled Tubular Specimens
E2208 Guide for Evaluating Non-Contacting Optical Strain Measurement Systems

[1] This terminology is under the jurisdiction of ASTM Committee E08 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.02 on Standards and Terminology.

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

E2298 Test Method for Instrumented Impact Testing of Metallic Materials
E2443 Guide for Verifying Computer-Generated Test Results Through The Use Of Standard Data Sets
E2472 Test Method for Determination of Resistance to Stable Crack Extension under Low-Constraint Conditions
E2714 Test Method for Creep-Fatigue Testing
E2760 Test Method for Creep-Fatigue Crack Growth Testing
G15 Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010)[3]

3. Terminology

3.1 *Alphabetical Listing of Principal Symbols Used in This Terminology:*

Symbol	Term
a	crack depth, crack length, crack size, estimated crack size
a_e	effective crack size
a_n	notch length
a_o	original crack size
a_p	physical crack size
a/W	normalized crack size
A	force ratio (P_a / P_m)
A_N	net-section area
b	remaining ligament
b_o	original uncracked ligament
B	specimen thickness
B_e	effective thickness
B_N	net thickness
$2c$	surface-crack length
C	normalized K-gradient
D	cycle ratio (n/N_f)
C*(t)	C*(t) – Integral
da/dN	fatigue-crack-growth rate
δ	crack-tip opening displacement (*CTOD*)
δd	specimen gage length
Δa	crack extension, estimated crack extension
ΔK	stress-intensity-factor range
ΔK_{th}	fatigue-crack-growth threshold
ΔP	force range
ε_a	strain amplitude
ε_{in}	inelastic strain
ε_m	mean force
G	crack-extension force
G_R	crack-extension resistance
H*	specimen center of pin hole distance
Γ	the path of the J-integral
J	J-integral
J_{Ic}	plane-strain fracture toughness
J_R	crack-extension resistance
k_f	fatigue notch factor
k_t	theoretical stress concentration factor (sometimes abbreviated stress concentration factor)
K, K_1, K_2, K_3, K_I, K_{II}, K_{III}	stress-intensity factor (see mode)
K_a	crack-arrest fracture toughness
K_c	plane-stress fracture toughness
K_{EAC}	stress intensity factor threshold for environment-assisted cracking
K_{Ia}	plane-strain crack-arrest fracture toughness
K_{IEAC}	stress intensity factor threshold for plane strain environment-assisted cracking
K_{Ic}	plane-strain fracture toughness
K_{IvM}, K_{Iv}, K_{Ivj}	plane-strain (chevron-notch) fracture toughness
K_{max}	maximum stress-intensity factor
K_{min}	minimum stress-intensity factor
K_o	stress-intensity factor at crack initiation
K_R	crack-extension resistance
n	cycles endured
N_f	fatigue life
P	force
P_a	force amplitude
P_m	mean force
P_M	precrack force
P_{max}	maximum force
P_{min}	minimum force
q	fatigue notch sensitivity
r	effective unloading slope ratio
r_c	critical slope ratio
r_y	plastic-zone adjustment
R	force ratio (P_{min} / P_{max})
s	sample standard deviation
s^2	sample variance
S	specimen span
S_a	force amplitude
S_f	fatigue limit
S_m	mean force
S_N	fatigue strength at N cycles
σ_c	crack strength
σ_N	nominal (net-section) stress
σ_r	residual strength
σ_s	sharp-notch strength
σ_{TS}	tensile strength
σ_x, σ_y, σ_z	normal stresses (refer to)
σ_Y	effective yield strength
σ_{YS}	yield strength
T	specimen temperature
t_T	transition time
τ_t	total cycle period
τ_{xy}, τ_{yz}, τ_{zx}	shear stresses (refer to Fig. 1)
u	displacement in x direction
v	displacement in y direction
$2v_m$	crack-mouth opening displacement
V_c	force-line displacement due to creep
w	displacement in z direction
W	specimen width
Y^*	stress-intensity factor coefficient
Y^*_m	minimum stress-intensity factor coefficient

3.2 *Alphabetical Listing of Abbreviations Used:*

CMOD	crack-mouth opening displacement
COD	see *CTOD*
CTOD	crack-tip opening displacement
DT	dynamic tear
DWTT	drop-weight tear test
EAC	environment-assisted cracking
K-EE	equivalent-energy fracture toughness
NTS	notch tensile strength
PS	part-through surface
SCC	stress corrosion cracking
SZW	stretch zone width

3.3 *Definitions*—Each definition is followed by the designation(s) of the standard(s) of origin. The listing of definitions is alphabetical.

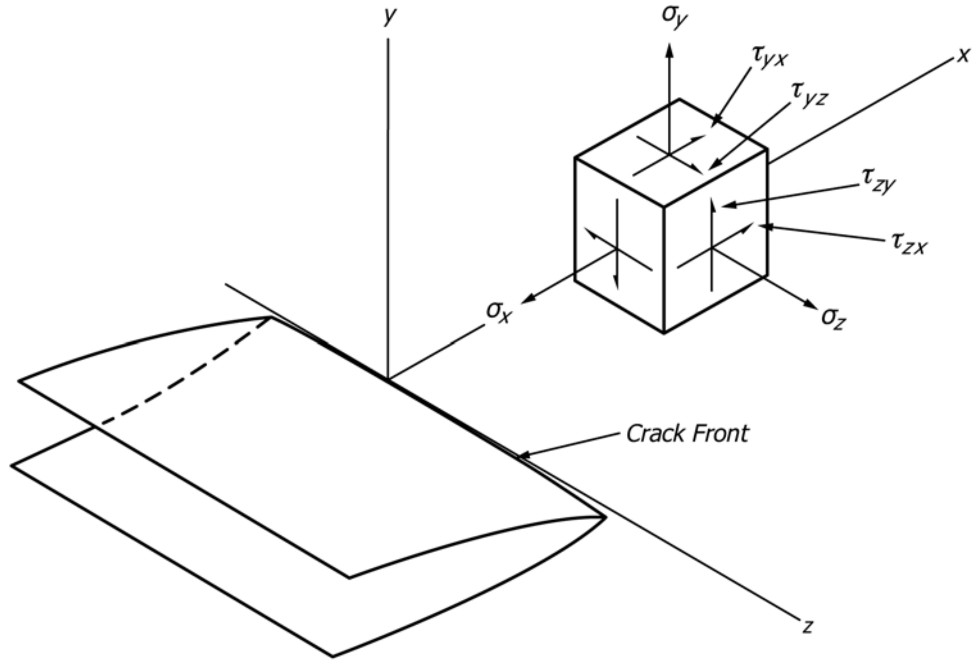
alternating force—See **loading amplitude**.

accuracy—The quantitative difference between a test measurement and a reference value. **E467, E2208**

applied-K curve—a curve (a fixed-force or fixed-displacement crack-extension-force curve) obtained from a fracture mechanics analysis for a specific configuration. The curve relates the stress-intensity factor to crack size and either applied force or displacement.

DISCUSSION—The resulting analytical expression is sometimes called a K calibration and is frequently available in handbooks for stress-intensity factors. **E647**

block—*in fatigue loading*, a specified number of constant amplitude loading cycles applied consecutively, or a spectrum loading sequence of finite length that is repeated identically. **E1823**



NOTE 1—See definition of mode.

FIG. 1 Customary Coordinate System and Stress on a Small Volume Element Located on the *x* Axis Just Ahead of the Crack Front

C*(t) integral, C*(t)[FL^{-1} T^{-1}] —a mathematical expression, a line or surface integral that encloses the crack front from one crack surface to the other, used to characterize the local stress-strain rate fields at any instant around the crack front in a body subjected to extensive creep conditions. **E1457, E2760**

DISCUSSION—1 The C*(t) expression for a two-dimensional crack, in the *x-z* plane with the crack front parallel to the *z*-axis, is the line integral:

$$C^*(t) = \int_{\Gamma} \left(W^*(t)dy - T\frac{\partial \dot{u}}{\partial x}ds \right) \quad (1)$$

where:

W(t)*	=	instantaneous stress-power or energy rate per unit volume,
Γ	=	path of the integral, that encloses (that is, contains) the crack tip contour (see Fig. 2),
ds	=	increment in the contour path,
T	=	outward traction vector on ds,
$\dot{u}$	=	displacement rate vector at ds,
x, y, z	=	rectangular coordinate system, and
$T\frac{\partial \dot{u}}{\partial x}ds$	=	rate of stress-power input into the area enclosed by Γ across the elemental length, *ds*.

DISCUSSION—2 The value of C*(t) from this equation is path-independent for materials that deform according to a constitutive law that may be separated into single-value time and stress functions or strain and stress functions of the forms:

$$\dot{\varepsilon} = f_1(t)f_2(\sigma) \text{ or,}$$

$$\dot{\varepsilon} = f_3(\varepsilon)f_4(\sigma)$$

Where f_1–f_4 represent functions of elapsed time, *t*, strain, ε , and applied stress, σ, respectively; $\dot{\varepsilon}$ is the strain rate.

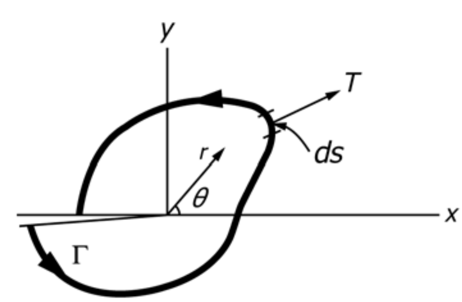


FIG. 2 Contour and Symbolism for Path-Independent Crack Tip Integrals

DISCUSSION—3 For materials exhibiting creep deformation for which the above equation is path independent, the *C*(t)*-integral is equal to the value obtained from two, stressed, identical bodies with infinitesimally differing crack areas. This value is the difference in the stress-power per unit difference in crack area at a fixed value of time and displacement rate or at a fixed value of time and applied force.

DISCUSSION—4 The value of C*(t) corresponding to the steady-state conditions is called C^*_s. Steady-state is said to have been achieved when a fully developed creep stress distribution has been produced around the crack tip. This occurs when secondary creep deformation characterized by the following equation dominates the behavior of the specimen.

$$\dot{\varepsilon}_{ss} = A\sigma^n$$

DISCUSSION—5 This steady state in C* does not necessarily mean steady state crack growth rate. The latter occurs when steady state damage develops at the crack tip. For Test Method E1457 this behavior is observed as "tails" at the early stages of crack growth. Test Method E1457 deals with this region as the initial crack extension period defined as time $t_{0.2}$, measured for an initial crack growth of 0.2 mm after first loading.

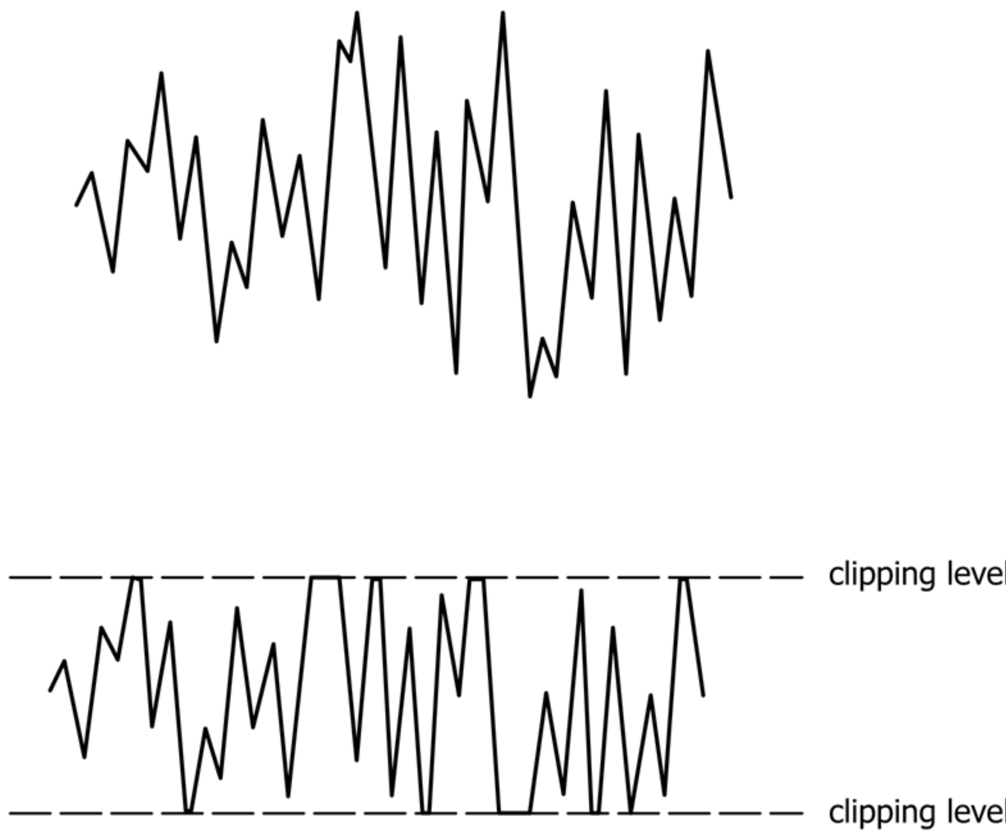


FIG. 3 Clipping of Fatigue Spectrum Loading

C_t parameter, C_t, [$FL^{-1}T^{-1}$]—parameter equal to the value obtained from two identical bodies with infinitesimally differing crack areas, each subjected to stress, as the difference in the stress-power per unit difference in crack area at a fixed value of time and displacement rate or at a fixed value of time and applied force for an arbitrary constitutive law. **E1457, E2760**

DISCUSSION—The value of C_t is path-independent and is identical to C*(t) for extensive creep conditions when the constitutive law described in Discussion 2 of *C*(t)-integral* definition applies.

DISCUSSION—Under small-scale creep conditions, *C*(t)* is not path-independent and is related to the crack tip stress and strain fields only for paths local to the crack tip and well within the creep zone boundary. Under these circumstances, C_t is related uniquely to the rate of expansion of the creep zone size . There is considerable experimental evidence that the C_t parameter which extends the *C*(t)-integral* concept into the small-scale creep and the transition creep regime correlates uniquely with creep crack growth rate in the entire regime ranging from small-scale to extensive creep regime.

DISCUSSION—for a specimen with a crack subject to constant force, *P*

$$C\,t = \frac{P\dot{V}_C}{BW}\,(f'/f)$$

and

$$f' = \frac{df}{d\,(a/W)}$$

circulation rate [$L^3\ T^{-1}$]—*in fatigue testing*, the volume rate of change of the environment chamber volume. **E1823**

clipping—*in fatigue spectrum loading*, the process of decreasing or increasing the magnitude of all loads (strains) that are, respectively, above or below a specified level, referred to as clipping level; the loads (strains) are decreased or increased to the clipping level (see Fig. 3). **E1823**

compliance (LF^{-1})— the ratio of displacement increment to force increment. **E1820**

confidence interval—an interval estimate of a population parameter computed so that the statement "the population parameter included in this interval" will be true, on the average, in a stated proportion of the times such computations are made based on different samples from the population. **E1823**

confidence level (or coefficient)—the stated proportion of the times the confidence interval is expected to include the population parameter. **E1823**

confidence limits—the two statistics that define a confidence interval. **E1823**

constant amplitude loading— *in fatigue loading*, a loading (straining) in which all of the peak forces (strains) are equal and all of the valley forces (strains) are equal. **E1049**

constant life diagram— *in fatigue*, a plot (usually on rectangular coordinates) of a family of curves each of which is for a single fatigue life, *N*, relating stress amplitude, S_a, to mean stress, S_m, or maximum stress, S_{max}, or both, to minimum stress, S_{min}. The constant life fatigue diagram is usually derived from a family of *S-N* curves each of which represents a different stress ratio (*A* or *R*) for a 50 % probability of survival. **E1820**

control force, Pm [F]—a calculated value of maximum force to stipulate allowable precracking limits. **E1820, E1921**

corrosion fatigue—the process by which fracture occurs prematurely under conditions of simultaneous corrosion and repeated cyclic loading at lower stress levels or fewer cycles than would be required in the absence of the corrosive environment. **G15**

counting method—*in fatigue spectrum loading*, a method of counting the occurrences and defining the magnitude of various loading parameters from a load-time history; (some of the counting methods are: level crossing count, peak count, mean crossing peak count, range count, range-pair count, rain-flow count, racetrack count). **E1049**

crack extension, Δ*a* [L]—an increase in crack size.

DISCUSSION—For example, in Practice E561, Δa_p or Δa_e is the difference between the crack size, either a_p (physical crack size) or a_e (effective crack size), and a_o (original crack size). **E561**

crack-extension force, *G* [FL^{-1} or FLL^{-2}]—the elastic energy per unit of new separation area that is made available at the front of an ideal crack in an elastic solid during a virtual increment of forward crack extension.

DISCUSSION—This force concept implies an analytical model for which the stress-strain relations are regarded as elastic. The preceding definition of *G* applies to either static cracks or running cracks. From past usage, *G* is commonly associated with linear-elastic methods of analysis, although the *J* (see ***J*-integral**) also may be used for such analyses. **E1823**

crack-extension resistance, K_R [FL$^{-3/2}$], G_R [FL^{-1}] or J_R [FL^{-1}]—a measure of the resistance of a material to crack extension expressed in terms of the stress-intensity factor, *K*; crack-extension force, *G*; or values of *J* derived using the *J*-integral concept.

DISCUSSION—See definition of *R*-curve. **E561**

crack initiation—the onset of crack propagation from a preexisting macroscopic crack created in the specimen by a stipulated procedure. **E1921**

crack-mouth opening displacement (CMOD), *Vm*, $2v_m$ [L]—crack opening displacement resulting from the total deformation (elastic plus plastic), measured under force at the location on a crack surface that has the largest displacement per unit force.

DISCUSSION—In part-through surface-crack (PS) specimens, *CMOD* is measured on the specimen surface at the midpoint of the crack length. **E399, E647, E740, E1221, E1457, E1681, E1820**

crack opening displacement (COD)[L]—force-induced separation vector between two points at a specified gage length. The direction of the vector is normal to the crack plane. **E399, E1221, E1290, E1820, E2472**

crack-plane orientation—an identification of the plane and direction of fracture or crack extension in relation to product configuration. This identification is designated by a hyphenated code with the first letter(s) representing the direction normal to the crack plane and the second letter(s) designating the expected direction of crack propagation.

DISCUSSION—See also E1823 Annex A2, (A2.4 on crack or notch orientation). **E399, E1457**

crack size, *a* [L]—principal lineal dimension used in the calculation of fracture mechanics parameters for through-thickness cracks as defined in the applicable standard. See Fig. A2.2 for schematic representations.

DISCUSSION—For example, in the C(T) specimen *a* is the average measurement from the line connecting the bearing points of force application; in the M(T) specimen, *a* is the average measurement from the perpendicular bisector of the central crack.

DISCUSSION—In practice, the value of *a* is obtained from procedures for measurement of physical crack size, a_p, original crack size, a_o, and effective crack size, a_e, as appropriate to the situation being considered.

DISCUSSION—For part-through cracks see crack depth *(a)* and surface crack length *(2c)* in *Definitions of Terms* (Specific to the indicated standards.)

DISCUSSION—In Test Method E1457, the physical crack size is represented as a_p . The subscript *p* is everywhere implied. **E1457**

crack strength, σ_c [FL^{-2}]—the maximum value of the nominal stress that a cracked structure is capable of sustaining.

DISCUSSION—1 Crack strength is calculated on the basis of the maximum force and the original minimum cross-sectional area (net cross section or ligament). Thus, it takes into account the original size of the crack but ignores any crack extension that may occur during the test.

DISCUSSION—2 Crack strength is analogous to the ultimate tensile strength, as it is based on the ratio of the maximum force to the minimum cross-sectional area at the start of the test. **E338, E602**

crack-tip opening displacement (CTOD),δ, [L]—the crack displacement resulting from the total deformation (elastic plus plastic) at variously defined locations near the original (prior to force application) crack tip.

DISCUSSION—In common practice, δ is estimated for Mode 1 by inference from observations of crack displacement nearby or away, or both, from the crack tip. **E1290**

crack-tip plane strain—a stress-strain field (near the crack tip) that approaches plane strain to the degree required by an empirical criterion.

DISCUSSION—For example, in Mode 1, the criterion for crack-tip plane strain given by Test Method E399 requires that plate thickness, *B*, must be equal to or greater than 2.5 $(K/\sigma_{YS})^2$. **E399**

crack-tip plane stress—a stress-strain field (near the crack tip) that is not in plane strain.

DISCUSSION—In such situations, a significant degree of plane strain may be present. **E1823**

creep crack growth (CCG) rate, da/dt or Δa/Δt [L/t]—the rate of crack extension caused by creep damage and expressed in terms of average crack extension per unit time. **E1457**

creep zone boundary—the locus of points ahead of the crack front where the equivalent strain caused by the creep deformation equals 0.002 (0.2%).

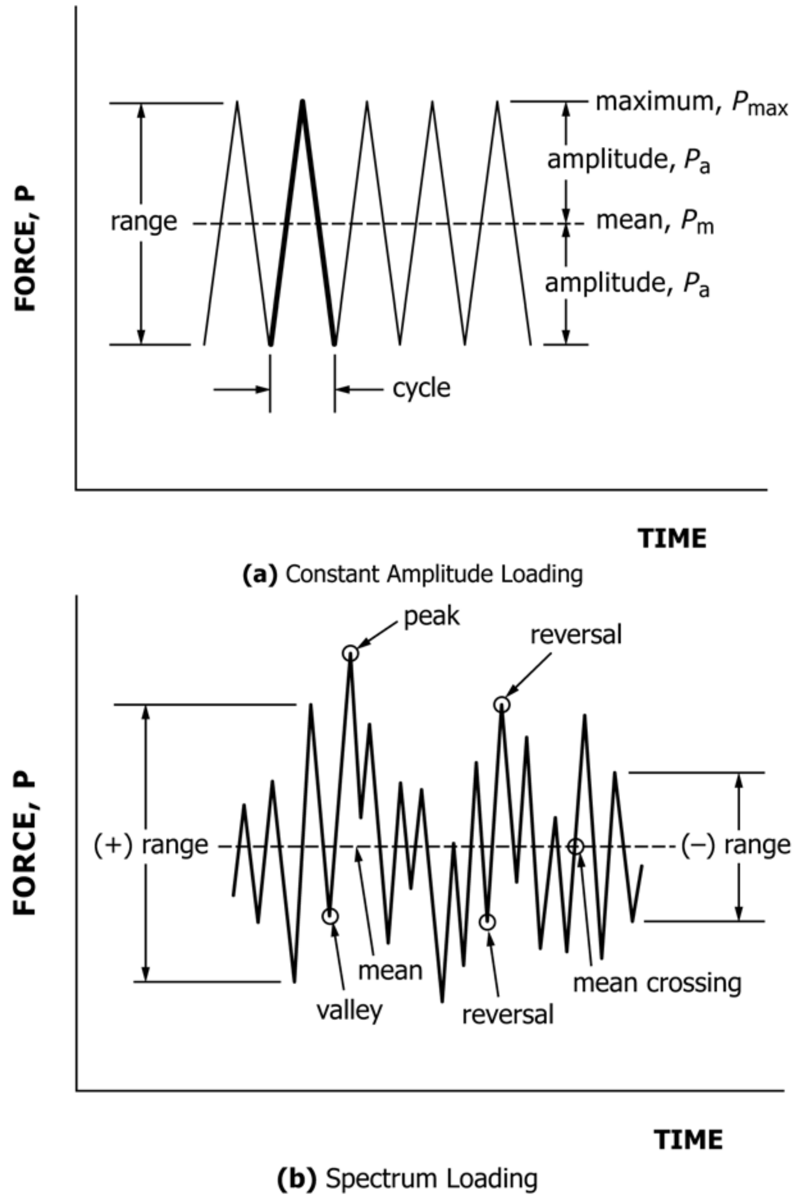


FIG. 4 Fatigue Loading Basic Terms

DISCUSSION—Under small-scale creep conditions, the creep zone expansion with time occurs in a self-similar manner for planar bodies, thus, the creep zone size, r_c, can be defined as the distance to the creep zone boundary from the crack tip at a fixed angle, θ, with respect to the crack plane. The rate of expansion of the creep zone size is designated as $\dot{r}_c$ (θ). **E1457, E2760**

criterion of failure—complete separation, or the presence of a crack of specified length visible at a specified magnification. Other criteria may be used but should be clearly defined. **E468**

crystallographic cleavage—the separation of a crystal along a plane of fixed orientation relative to the three-dimensional crystal structure within which the separation process occurs, with the separation process causing the newly formed surfaces to move away from one another in directions containing major components of motion perpendicular to the fixed plane. **E1823**

*cumulative frequency spectrum***—**See **exceedances spectrum**.

*cumulative occurrences spectrum***—**See **exceedances spectrum**.

cycle—*in fatigue*, one complete sequence of values of force (strain) that is repeated under constant amplitude loading (straining). (See Fig. 4.) The symbol *N* (see definition of **fatigue life**) is used to indicate the number of cycles.

DISCUSSION—In *spectrum loading*, definition of cycle varies with the counting method. **E1823**

cycle ratio, *D*— the ratio of cycles endured, *n*, to the estimated fatigue life, N_f, obtained from the stress versus fatigue life (*S-N*) or the strain versus fatigue life (ε-*N*) diagram for cycles of the same character, that is, $D = n/N_f$. **E1823**

cycles endured, *n*—*in fatigue*, the number of cycles of specified character (that produce fluctuating force) which a specimen has endured at any time in its force history. **E1823**

cyclic loading—See **fatigue loading.**

deaeration—*in environmentally affected fatigue testing*, the process of removal of air from the liquid environment before and during a test. **E1823**

derived data—data obtained through processing of the raw data. **E1942, E2208, E2443**

dynamometer—an elastic calibration device used to verify the indicated forces applied by a fatigue testing system. It shall consist of an instrumented member having mass, stiffness, and end displacements such that the inertial effects of the specimen and its attachments to the testing machine for which the verification of forces is desired are duplicated within 5 %. The instrumentation shall permit an accurate determination of the magnitude of the average strain in a region of the uniform transverse cross section when the dynamometer is subjected to a tensile or compressive force along its longitudinal axis, within 1 % of the true strains. A strain gaged specimen is often used as a dynamometer. **E467**

dynamometer dynamic forces [F]—the maximum and minimum forces (or the mean force and the force amplitude) that correspond to the readings obtained from the dynamometer output according to an existing static calibration. Such forces are considered true specimen dynamic forces for the purpose of this terminology. **E467**

dynamometer range [F]—the range of forces for which the dynamometer may be used for verification purposes. A dynamometer for use in tension and in compression will have two dynamometer ranges, one in tension and one in compression. **E467**

effective crack size, a_e [L]—the physical crack size augmented to account for crack-tip plastic deformation.

DISCUSSION—Sometimes the effective crack size, a_e, is calculated from a measured value of a physical crack size, a_p, plus a calculated value of a plastic-zone adjustment, r_Y. Another method for calculation of a_e involves comparing the compliance from the secant of a force-deflection trace with the elastic compliance from a calibration for the given specimen design. **E561**

effective modulus, E_{eff} [FL^{-2}]—an elastic modulus that allows a theoretical (modulus normalized) compliance to match an experimentally measured compliance for an actual initial crack size, a_o. **E561, E1450, E1921**

effective thickness B_e [L]—for compliance-based extension measurements: **E1823, E1820**

$$B_e = B - (B - B_N)^2/B \quad (2)$$

DISCUSSION—for Test Method E1820, for side-grooved specimens this is used for elastic unloading compliance measurement of crack size.

effective yield strength, σ_Y [FL^{-2}]—an assumed value of uniaxial yield strength, that represents the influences of plastic yielding upon fracture test parameters. **E1820, E1921**

DISCUSSION—1 It is calculated as the average of the 0.2 % offset yield strength, σ_{YS}, and the ultimate tensile strength, σ_{TS}, as follows:

$$\sigma_Y = (\sigma_{YS} + \sigma_{TS})/2 \quad (3)$$

DISCUSSION—2 In estimating σ_Y, influences of testing conditions, such as loading rate and temperature, should be considered.

elastic constraint modulus, E' [FL-2]—a linear-elastic factor relating stress to strain, the value of which is dependent on the degree of constraint. For plane stress, E' = E is used, and for plane strain, $E/(1 - \nu^2)$ is used, with ν being Poisson's ratio. **E399, E647, E1457, E1681, E1921**

elastic modulus—see **modulus of elasticity**.

environment—*in fatigue testing*, the aggregate of chemical species and energy that surrounds a test specimen. **E1823**

environment chamber— *in fatigue testing*, the container of the bulk volume surrounding a test specimen. **E1823**

environment chamber volume [L^3]—*in fatigue testing*, that bulk volume surrounding a test specimen. **E1823**

environment composition [ML^{-3}]—*in corrosion fatigue testing*, the concentration of the chemical components in the fluid environment surrounding a test specimen. **E1823**

environment hydrogen content [ML^{-3}]—*in corrosion fatigue testing*, the hydrogen gas concentration of the fluid environment surrounding a test specimen. **E1823**

environment monitoring— *in fatigue testing*, the periodic or continuous measurement of fluid concentrations of the environment. **E1823**

environment oxygen content [ML^{-3}]—*in corrosion fatigue testing*, the oxygen concentration of the fluid environment surrounding a test specimen. **E1823**

environment pressure [FL^{-2}]—*in fatigue testing*, the pressure of the bulk volume surrounding a test specimen. **E1823**

environment temperature— *in fatigue testing*, the temperature of the bulk volume surrounding a test specimen. **E1823**

environment volume [L^3]—*in fatigue testing*, the total volume immediately surrounding a test specimen plus that contained in a circulating reservoir if applicable. **E1823**

estimate—*in statistical analysis*, the particular value or values of a parameter computed by an estimation procedure for a given sample. **E1823**

estimated crack extension, Δ*a*[L]—an increase in estimated crack size ($\Delta a = a - a_{oq}$). **E1737**

estimated crack size *a*[L]—the distance from a reference plane to the observed crack front developed from measurements of elastic compliance or other methods. The reference plane depends on the specimen form, and it is normally taken to be either the boundary, or a plane containing either the force line or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation. **E1737**

estimation—*in statistical analysis*, a procedure for making a statistical inference about the numerical values of one or more unknown population parameters from the observed values in a sample. **E1823**

exceedances spectrum— *in fatigue loading*, representation of spectrum loading contents by the number of times specified values of a particular loading parameter (peak, range, and so forth) are equaled or exceeded (also known as *cumulative occurrences* or *cumulative frequency spectrum*). **E1823**

fatigue—the process of progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses and strains at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations.

DISCUSSION—1 In ceramic technology, static tests of considerable duration are called "static fatigue" tests, a type of test referred to as stress-rupture in metal testing.

DISCUSSION—2 Fluctuations may occur both in force and with time (frequency) as in the case of "random vibration." **E1823**

fatigue-crack-growth rate, *da/dN*, [L/cycle]—the rate of crack extension under fatigue loading, expressed in terms of crack extension per cycle. **E1823, E399, E647**

fatigue-crack-growth threshold, ΔK_{th} [$FL^{-3/2}$]—that asymptotic value of ΔK at which da/dN approaches zero. For most materials an *operational*, though arbitrary, definition of ΔK_{th} is given as that ΔK which corresponds to a fatigue crack growth rate of 10^{-10} m/cycle.

DISCUSSION—The intent of this Definition is not to define a true threshold, but rather to provide a practical means of characterizing a material's fatigue crack growth resistance in the near-threshold regime. Caution is required in extending this concept to design. **E647**

fatigue cycle—See **cycle**.

fatigue ductility coefficient, ε'f —the ability of a material to deform plastically before fracturing, determined from constant strain-amplitude, low-cycle fatigue tests. Intercept of the log-log plot of plastic strain amplitude and the fatigue life in reversals (1 cycle = 2 reversals). **E1823, E606, E2207**

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

fatigue ductility exponent, c—the slope of the log-log plot of plastic strain amplitude and the fatigue life in reversals (1 cycle = 2 reversals). Determined from constant strain amplitude, low-cycle fatigue tests. **E1823, E606, E2207**

DISCUSSION—The fatigue ductility exponent varies between -0.5 and -0.7 for many metallic alloys.

fatigue life, N_f —the number of cycles of a specified character that a given specimen sustains before failure of a specified nature occurs. Fatigue life, or the logarithm of fatigue life, is a dependent variable. **E1823**

fatigue life for *p* %survival —an estimate of the fatigue life that *p* % of the population would attain or exceed under a given loading. The observed value of the median fatigue life estimates the fatigue life for 50 % survival. Fatigue life for *p* % survival values, where *p* is any number, such as, 95, 90, and so forth, also may be estimated from the individual fatigue life values. **E1823**

fatigue limit, S_f [FL^{-2}]—the limiting value of the median fatigue strength as the fatigue life, N_f , becomes very large.

DISCUSSION—Certain materials and environments preclude the attainment of a fatigue limit. Values tabulated as "fatigue limits" in the literature are frequently (but not always) values of S_N for which 50 % of the specimens survive a predetermined number of cycles. These specimens are frequently tested at a mean stress of zero. **E1823**

fatigue limit for *p* %survival [FL^{-2}]—the limiting value of fatigue strength for *p* % survival as *N* becomes very large; *p* may be any number, such as 95, 90, and so forth. **E1823**

fatigue loading—periodic, or not periodic, fluctuating loading applied to a test specimen or experienced by a structure in service. (Also known as *cyclic loading*.) **E1823**

fatigue notch factor, k_f —the ratio of the fatigue strength of a specimen with no stress concentration to a specimen with a stress concentration for the same percent survival at *N* cycles and for the same conditions.

DISCUSSION—1 In specifying k_f, it is necessary to specify the geometry and the values of S_a, S_m, and *N* for which it is computed.

DISCUSSION—2 k_f was originally termed the fatigue limit (endurance limit) reduction factor. Early data pertained almost exclusively to mild steels, namely, to $S_a - N$ curves with knees. Later the term was generalized to fatigue strength reduction factor; but, nevertheless, the k_f values tabulated in the literature still pertain almost exclusively to very long ("infinite") fatigue lives where the notched and unnotched $S_a - N$ curves were almost parallel and almost horizontal. Otherwise, the k_f data are not consistent and are markedly dependent on the type of notch, the fatigue life of interest, and the value of the mean stress.

DISCUSSION—3 Virtually no k_f data exist for percentiles other than (approximately) 50 %. Nevertheless, k_f is highly dependent on the percentile of interest. **E1823**

fatigue notch sensitivity, *q*—a measure of the degree of agreement between fatigue notch factor, k_f, and theoretical stress concentration factor, k_t.

DISCUSSION—1 The definition of fatigue notch sensitivity is $q = (k_f - 1)/(k_t - 1)$.

DISCUSSION—2 *q* was originally termed the fatigue notch sensitivity index.

DISCUSSION—3 Virtually all *q* data and *q* curves found in the literature pertain to very long ("infinite") fatigue lives where the notched and unnotched $S_a - N$ curves are almost parallel and almost horizontal, as well as to tests in which $S_m = 0$. Thus, these values should not be extrapolated to $S_m \neq 0$ or "finite" life situations.

DISCUSSION—4 Fatigue notch sensitivity is not considered to be a material property. **E1823**

fatigue strength at *N* cycles, S_N [FL^{-2}]—a value of stress for failure at exactly *N* cycles as determined from an $S - N$ diagram. The value of S_N thus determined is subject to the same conditions as those which apply to the $S - N$ diagram.

DISCUSSION—The value of S_N that is commonly found in the literature is the value of S_{max} or S_a at which 50 % of the specimens of a given sample could survive *N* stress cycles in which $S_m = 0$. This is also known as the median fatigue strength for *N* cycles. **E1823**

fatigue strength for p % survival at N cycles [FL^{-2}]—an estimate of the stress level at which p % of the population would survive N cycles; p may be any percent, such as 95, 90, and so forth.

DISCUSSION—ASTM STP 588[4] and STP 744[5] include estimation methods for these values. **E1823**

fatigue testing system—a device for applying repeated force cycles to a specimen or component. **E467**

ferritic steels—typically carbon, low-alloy, and higher alloy grades. Typical microstructures are bainite, tempered bainite, tempered martensite, and ferrite and pearlite. All ferritic steels have body centered cubic crystal structures that display ductile-to-cleavage transition temperature fracture toughness characteristics. See also test methods E23, E208, and E436. **E1921**

DISCUSSION—This definition is not intended to imply that all of the many possible types of ferritic steels have been verified as being amenable to analysis by Test Method E1921.

force, P [F]—the force applied to a test specimen or to a component.

DISCUSSION—used in Practices E1049 to denote force, stress, strain, torque, acceleration, or other parameters of interest. **E1823**

force cycle—See **cycle**.

force-line displacement due to creep, elastic and plastic strain V [L]— the total displacement measured at the loading pins (V^{FLD}) due to the force placed on the specimen at any instant and due to subsequent crack extension that is associated with the accumulation of creep, elastic, and plastic strains in the specimen. **E1457, E2760**

DISCUSSION—1 in creeping bodies, the total displacement at the force-line V^{FLD} can be partitioned into an instantaneous elastic part V_e, a plastic part, V_p, and a time-dependent creep part V_c where $V \sim V_e + V_p + V_c$ The corresponding symbols for the rates of force-line displacement components shown in the equation above are given respectively as: $\dot{V}$, $\dot{V}_e$,$\dot{V}_p$,$\dot{V}_c$ This information is used to derive the parameter C^* and C_t.

DISCUSSION—2 for the set of specimens in Test Method E1457 for creep ductile material where creep strains dominate and in which test times are longer (usually >1000 hours), the elastic and plastic displacement rate components are small compared to the creep and therefore it is recommended to use the total displacement rate,$\dot{V}$ assuming that, $\dot{V}_c \approx \dot{V}$ to derive the steady state C^*. See Test Method E1457, Section 11 for detailed discussion.

DISCUSSION—3 the force-line displacement associated with just the creep strains is expressed as V_c.

force line displacement rate $d\Delta_{LL}/dt$ [LT^{-1}]—rate of increase of specimen force-line displacement. **E1921**

force range, ΔP [F]—*in fatigue loading*, the algebraic difference between successive valley and peak forces (positive range or increasing force range) or between successive peak and valley forces (negative range or decreasing force range). (See Fig. 4.) In constant amplitude loading, the range is given as follows:

$$\Delta P = P_{max} - P_{min} \tag{4}$$

DISCUSSION—In cycle counting by various methods, it is common to employ ranges between valley and peak forces, or between peak and valley forces, which are not necessarily successive events. The word "range" is used in this broader sense when dealing with cycle counting. **E1823**

force ratio (also stress ratio), R, A—*in fatigue*, the algebraic ratio of the two loading parameters of a cycle. The most widely used ratios are as follows

$$R = \frac{\text{minimum load}}{\text{maximum load}} = \frac{P_{min}}{P_{max}} = \frac{S_{min}}{S_{max}}, \text{ and} \tag{5}$$

$$A = \frac{\text{loading amplitude}}{\text{mean load}} = \frac{P_a}{P_m} = \frac{S_a}{S_m} \tag{6}$$

E647

force (strain) amplitude, P_a (S_a or ε_a) [F or FL^{-2}] —*in fatigue loading*, one half of the range of a cycle (see Fig. 4) (also known as *alternating force*). **E1823**

force transducer—a measuring device that can provide an output signal proportional to the force being applied. **E467**

fracture toughness—a generic term for measures of resistance to extension of a crack.

DISCUSSION—The term is sometimes restricted to results of fracture mechanics tests, which are directly applicable in fracture control. However, the term commonly includes results from tests of notched or precracked specimens which do not involve fracture mechanics analysis. Results from tests of the latter type are often useful for fracture control, based upon either service experience or empirical correlations with tests analyzed using fracture mechanics. **E740**

frequency distribution—the way in which the frequencies of occurrence of members of a population, or a sample, are distributed in accordance with the values of the variable under consideration. **E1823**

group—*in fatigue*, specimens of the same type tested at a specific time, or consecutively, at one stress level. A group may comprise one or more specimens. **E1823**

high point, High—the point on a force-displacement plot, at the start of an unloading-reloading cycle, at which the displacement reverses direction, that is, the point at which the specimen mouth begins closing due to unloading (see points labeled High in Fig. 5 and Fig. 6). **E1304**

hold time, t_h [T]—*in fatigue testing*, the amount of time in the cycle where the controlled test variable (for example, force, strain, displacement) remains constant with time. (See Fig. 7.) **E606**

hysteresis diagram—*in fatigue*, the stress-strain path during a cycle. **E1823**

ideal crack—a simplified model of a crack. In a stress-free body, the crack has two smooth surfaces that are coincident and join within the body along a smooth curve called the crack front; in two-dimensional representations the crack front is called the crack tip. **E1823**

ideal-crack-tip stress field—the singular stress field, infinitesimally close to the crack front, that results from loading

[4] *Manual on Statistical Planning and Analysis,* ASTM STP 588, ASTM, 1975.
[5] *Statistical Analysis of Fatigue Data*, ASTM STP744, ASTM, 1979.

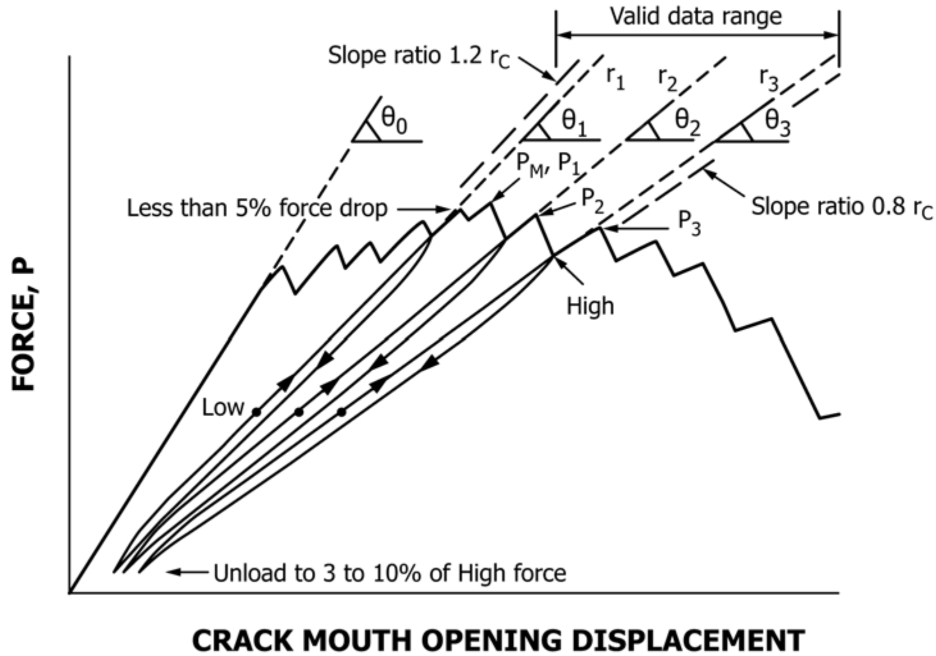


FIG. 5 Schematic of a Force-Displacement Test Record for Crack Jump Behavior, with Unloading/Reloading Cycles, Data Reduction Constructions, and Definitions of Terms

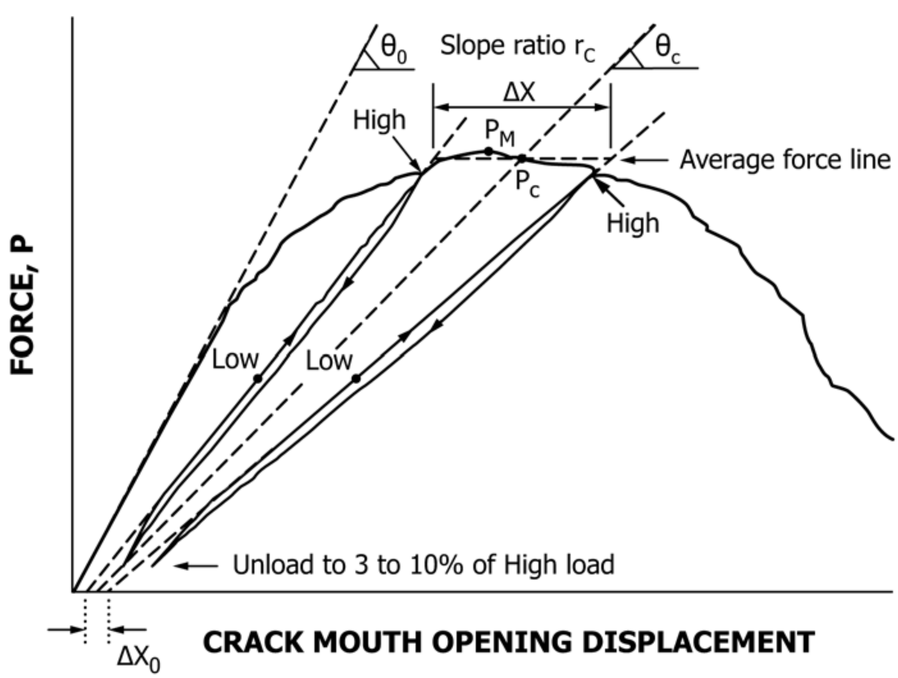


FIG. 6 Schematic of a Force-Displacement Test Record for Smooth Crack Growth Behavior, with Unloading/Reloading Cycles, Data Reduction Constructions, and Definitions of Terms

an ideal crack. In a linear-elastic homogeneous body, the significant stress components vary inversely as the square root of the distance from the crack tip.

DISCUSSION—In a linear-elastic body, the crack-tip stress field can be regarded as the superposition of three component stress fields called modes. **E1823**

independent variable—the selected and controlled variable (namely, stress or strain). It is denoted *X* when plotted on appropriate coordinates. **E739**

indicated dynamic forces [F]—the maximum and minimum forces (or the mean force and the force amplitude) that correspond to the readings obtained from the force transducer associated with the fatigue testing system, according to an existing static calibration. The force transducer calibration may have been furnished by the machine manufacturer or may have been developed by the user. **E467**

inelastic strain, ε_{in} — the strain that is not elastic.

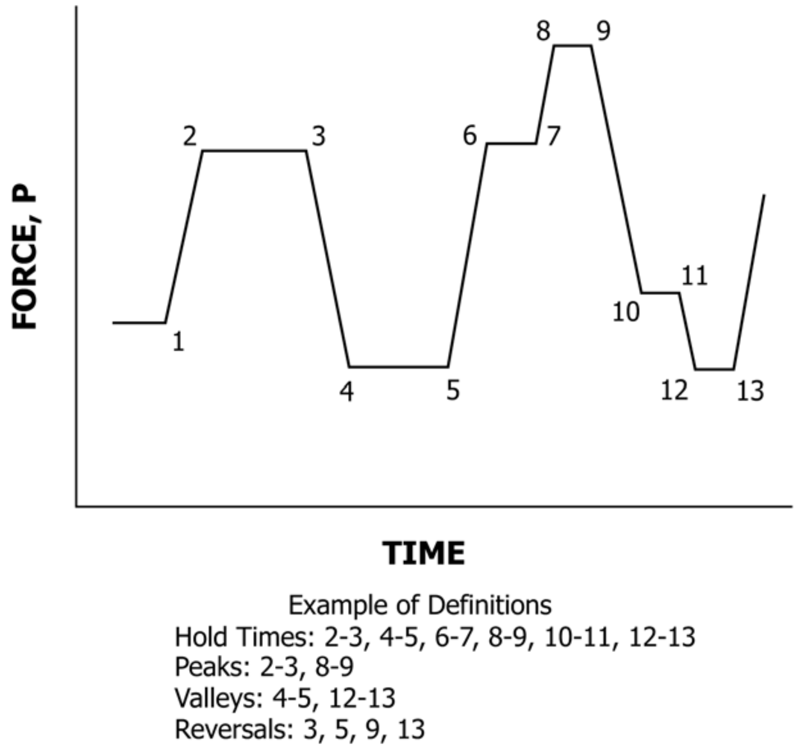


FIG. 7 Definitions of Terms for Force-Histories with Hold Times

Discussion—For isothermal conditions, ε_{in} is calculated by subtracting the elastic strain from the total strain. **E606**

interval estimate—the estimate of a parameter given by two statistics, defining the end points of an interval. **E1823**

irregularity factor— *in fatigue loading*, the ratio of the number of zero crossings with positive slope (or mean crossings) to the number of peaks or valleys in a given, force-time history. **E1823**

irregular loading— See **spectrum loading**.

***J*-integral, *J* [FL^{-1}]—**a mathematical expression, a line or surface integral that encloses the crack front from one crack surface to the other, used to characterize the local stress-strain field around the crack front. **E1457, E1820**

Discussion—1 The *J*-integral expression for a two-dimensional crack, in the *x-z* plane with the crack front parallel to the *z* axis, is the line integral,

$$J = \int_{\Gamma} \left(W dy - T \frac{\partial u}{\partial x} \, ds \right) \quad (7)$$

where:

W = loading work per unit volume or, for elastic bodies, strain energy density,
Γ = path of the integral, that encloses (that is, contains) the crack tip (see Fig. 2),
ds = increment of the contour path,
T = outward traction vector on ds,
u = displacement vector at ds,
x, y, z = rectangular coordinates (see Fig. 1), and
$T \frac{\partial u}{\partial x} ds$ = rate of work input from the stress field into the area enclosed by Γ.

Discussion—2 The value of *J* obtained from the preceding equation is taken to be path independent for commonly used specimen designs. However, in service components (and perhaps in test specimens), caution is needed to adequately consider loading interior to Γ such as from motion of the crack and from residual and thermal stress.

Discussion—3 In elastic (linear or nonlinear) solids, the *J*-integral equals the crack-extension force, *G*. (See **crack extension force**.)

Discussion—4 In Test Method E1820, in elastic (linear and nonlinear) solids for which the mathematical expression is path independent, the *J*-integral is equal to the value obtained from two identical bodies with infinitesimally differing crack areas each subject to stress. The parameter *J* is the difference in work per unit difference in crack area at a fixed value of displacement or, where appropriate, at a fixed value of force.[6]

***J-R* curve—**a plot of far-field *J*-integral versus the physical crack extension, Δa_p. It is recognized that the far-field value of *J* may not represent the stress-strain field local to a growing crack. **E1820**

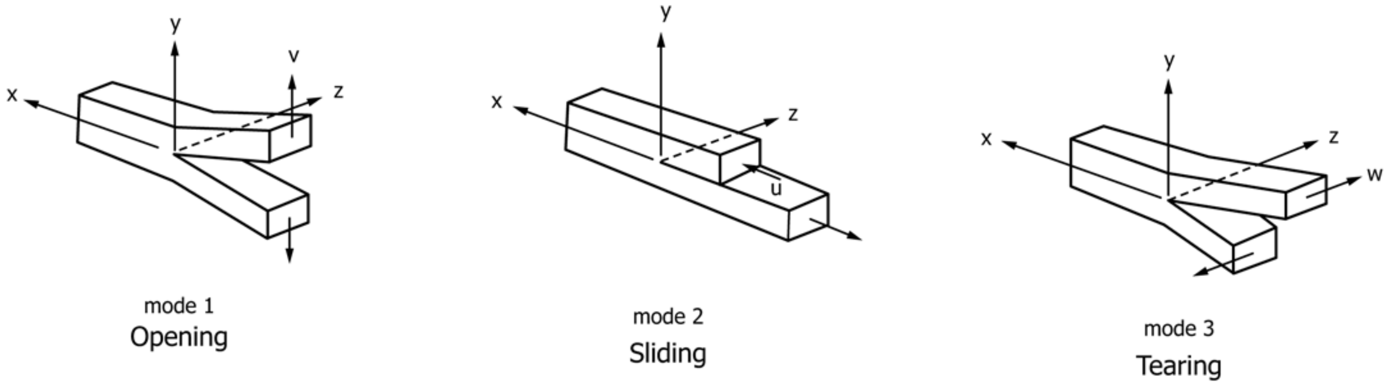
Discussion—In Test Method E1820, the *J-R* curve is a plot of the *J*-integral against physical crack extension Δa_p.

***K-R*-curve—**a plot of crack-extension resistance as a function of stable crack extension, Δa_p or Δa_e.

Discussion—For specimens discussed in Practice E561, the influence of in-plane geometry appears to be negligible, but *K-R*-curves normally depend upon specimen thickness and, for some materials, upon temperature and strain rate. **E561, E1820**

level crossings—*in fatigue loading*, the number of times that the load-time (strain-time) history crosses a given load

[6] For further discussion, see Rice , J. R., *Journal of Applied Mechanics*, Vol 35, 1968, p. 379.



NOTE 1—See definition of mode.

FIG. 8 Basic Modes of Crack (Surface) Displacements for Isotropic Materials

(strain) level with a positive slope or a negative slope, or both, as specified during a given period. **E1823**

load, [F] **—see force**

DISCUSSION—In practice E1049 load is used to denote force, stress, strain, torque, acceleration, or other parameters of interest. Units and symbols are dependent on the parameter of interest. **E1049**

load cell—see **force transducer** **E467**

loading (unloading) rate [F T^{-1}]—the time rate of change in the monotonic increasing (decreasing) portion of the force-time function. **E1823**

log-normal distribution—the distribution of *N* when log (*N*) is normally distributed. (Accordingly, it is convenient to analyze log (*N*) using methods based on the normal distribution.) **E739**

low point, Low—the point on the reloading portion of an unloading-reloading cycle where the force is one half the high point force (see points labeled Low in Fig. 5 and Fig. 6). **E1304**

maximum force, P_{max} [F]—*in instrumented impact testing*, maximum value of applied force during an instrumented impact test.

DISCUSSION—Test Method E1820 Annex A.17, F_m is also used for maximum force **E647, E1820**

maximum stress-intensity factor, K_{max} [$FL^{-3/2}$]—*in fatigue*, the maximum value of the stress-intensity factor in a cycle. This value corresponds to P_{max}. **E647**

mean crossings—*in fatigue loading*, the number of times that the force-time history crosses the mean force level with a positive slope or a negative slope, or both, as specified during a given period. (See Fig. 4.) **E1049**

mean force, P_m (or S_m or ε_m) [F or FL^2]— *in fatigue loading*, the algebraic average of the maximum and minimum forces in constant amplitude loading, or of individual cycles in spectrum loading,

$$P_m = \frac{P_{max} + P_{min}}{2} \tag{8}$$

or the integral average of the instantaneous force values of a spectrum loading history. **E1049**

median fatigue life—the middle value of the observed fatigue lives, arranged in order of magnitude, of the individual specimens in a group tested under essentially identical conditions. If the sample size is even, it is the average of the two middlemost values.

DISCUSSION—1 The use of the median instead of the arithmetic mean (that is, the average) is usually preferred.

DISCUSSION—2 In the literature, the abbreviated term "fatigue life" usually has meant the median fatigue life of the group. However, when applied to a collection of data without further qualification, the term " fatigue life" is ambiguous. **E1823**

median fatigue strength at *N* cycles [FL^{-2}]—an estimate of the stress level at which 50 % of the population would survive *N* cycles.

DISCUSSION—1 The estimate of the median fatigue strength is derived from a particular point of the fatigue life distribution, since there is no test procedure by which a frequency distribution of fatigue strengths at *n* cycles can be directly observed.

DISCUSSION—2 This is a special case of the more general definition of fatigue strength for *p* % survival at *N* cycles. **E1823**

minimum force, P_{min} [F]—*in fatigue*, the lowest algebraic value of applied force in a cycle. By convention, tensile forces are positive and compressive forces are negative. **E647**

minimum stress-intensity factor, K_{min} [$FL^{-3/2}$]—*in fatigue*, the minimum value of the stress-intensity factor in a cycle. This value corresponds to P_{min} when $R > 0$ and is taken to be zero when $R \leq 0$. **E647**

mode—one of the three classes of crack (surface) displacements adjacent to the crack tip. These displacement modes are associated with the stress-strain fields around the crack tip and are designated one, two, and three. Arabic numerals 1, 2, and 3 are used for the general case, and they represent opening, sliding, and tearing displacements, respectively. (See Fig. 8.) Roman numerals are used to specialize the mode to plane strain (I and II) or to antiplane-strain (III).

DISCUSSION—For isotropic materials, these three modes can be represented by the crack (surface) displacements presented in Table 1 and Fig. 8. For anisotropic materials, displacements can be more

TABLE 1 Stress and Displacement Components[A] for Plane-Strain and Anti-Plane-Strain Modes (see Definition of Mode). See Fig. 8.

NOTE 1—It is recommended that the arabic subscript 1 be omitted except where needed for clarity.

	Mode I	Mode II	Mode III
Crack (surface) displacements[B] just behind the crack front:			
u	0	*	0
v	*	0	0
w	0	0	*
Stresses on the $x-z$ plane just ahead of the crack front (see Fig. 1):			
σ_x	*	0	0
σ_y	*	0	0
σ_z	*	0	0
τ_{xy}	0	*	0
τ_{yz}	0	0	*
τ_{zx}	0	0	0

[A] * means non-zero. 0 means zero.
[B] Not applicable generally to anisotropic materials.

complex. Using the coordinates shown in Fig. 1 and assuming a homogeneous, isotropic elastic body, the singular stresses on an infinitesimal element just ahead of the crack front for Modes I, II, and III are zero or non-zero as indicated in Table 1. For linear-elastic bodies, the three stress-strain fields can be added to describe any crack-tip stress-strain field. **E1823**

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

DISCUSSION—The stress-strain relations of many materials do not conform to Hooke's law throughout the elastic range, but deviate 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}]*—the slope of the stress-strain curve at the origin.
(b) *tangent modulus [FL^{-2}]*—the slope of the stress-strain curve at any specified stress or strain.
(c) *secant modulus [FL^{-2}]*—the slope of the secant drawn from the origin to any specified point on the stress-strain curve.
(d) *chord modulus [FL^{-2}]*—the slope of the chord drawn between any two specified points on the stress-strain curve below the elastic limit of the material.

DISCUSSION—The term "Young's Modulus" is commonly used for materials that conform to Hooke's Law.

net-section area, A_N [L^2]—area of the net remaining ligament.

net thickness, B_N [L]—distance between the roots of the side grooves in side-grooved specimens. **E1457, E1820, E1921**

neutral solution—a fluid environment containing an equal amount of hydrogen and hydroxyl ions, that is, pH = 7.

nominal (net-section) stress, σ_N [FL^{-2}]—*in fracture testing*, a measure of the stress on the net cross section calculated in a simplified manner and without taking into account stress gradients produced by geometric discontinuities such as holes, grooves, fillets, and so forth.

DISCUSSION—1 In tension specimens (tension only), the average stress is used:

$$\sigma_N = P/A_N \tag{9}$$

where:

A_N = B(W – a) for rectangular sections, and
A_N = (π d^2)/4 for circular sections.

DISCUSSION—2 In bend specimens (bending only), a fiber stress is used:

$$\sigma_N = \frac{6M}{B(W-a)^2} \tag{10}$$

DISCUSSION—3 In compact specimens (tension and bending),

$$\sigma_N = \frac{2P(2W+a)}{B(W-a)^2} \tag{11}$$

DISCUSSION—4 In arc-shaped specimens (tension and bending),

$$\sigma_N = \frac{2P(3X+2W+a)}{B(W-a)^2} \tag{12}$$

DISCUSSION—5 In Notes 1 to 4:

d = diameter of notched section of a circumferentially notched specimen, m (in.),
P = force, N (lbf),
B = specimen thickness, m (in.),
W = specimen width, m (in.),
a = crack size (length of notch or notch plus precrack), m (in.),
X = loading hole offset, m (in.), and
M = bending moment, Nm (in.-lb).

The result, σ_N, is given in Pa (psi). See Test Method E399 for further explanations on symbols. **E399, E602**

notch length, a_n (L)—the distance from a reference plane to the front of the machined notch. The reference plane depends on the specimen form, and normally is taken to be either the boundary, or a plane containing either the forceline or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation.

notch-mouth displacement, Vn [L]—the Mode I (also called opening mode) component of crack or notch displacement due to elastic and permanent deformation. The displacement is measured across the mouth of the notch on the specimen edge. **E1921**

notch tensile strength (*NTS*) [FL^{-2}]—the maximum nominal (net-section) stress that a notched tensile specimen is capable of sustaining.

DISCUSSION—1 See definitions of nominal (net-section) stress and sharp-notch strength.

DISCUSSION—2 Values of notch tensile strength may depend upon section size, notch sharpness, and the eccentricity of the notch. See **sharp-notch strength**. **E1823**

occurrences spectrum— *in fatigue loading*, representation of spectrum loading contents by the number of times a particular loading parameter (peak, range, and so forth) occurs within each specified loading interval between lower and upper bound values. **E1823**

original crack size, a_o, [L]—the physical crack size at the start of testing.

Discussion—In Test Method E1820, a_{oq} is used to denote original crack size estimated from compliance **E561, E740, E813, E1152, E1820**

original ligament, b_o [L]—distance from the original crack front to the back edge of the specimen, that is:

$$b_o = W - a_o \tag{13}$$

E1820

parameter—*in statistics*, a constant (usually to be estimated) defining some property of the population frequency distribution, such as the population median or the population standard deviation. **E1823**

peak—*in fatigue loading*, the point where the first derivative of the force-time history changes from positive to negative sign; the point of maximum force in constant amplitude loading (see Fig. 4). For force histories with hold times see Fig. 7. **E1049**

physical crack extension, Δa_p [L]—an increase in physical crack size.

$$\Delta ap = ap - a_o \tag{14}$$

E813, E1152

physical crack size, a_p [L]—the distance from a reference plane to the observed crack front. This distance may represent an average of several measurements along the crack front. The reference plane depends on the specimen form, and normally is taken to be either the boundary, or a plane containing either the force line or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation. **E561, E813, E1152**

plane-strain fracture toughness, K_{Ic} [$FL^{-3/2}$]—the crack-extension resistance under conditions of crack-tip plane strain in Mode I for slow rates of loading under predominantly linear-elastic conditions and negligible plastic-zone adjustment. The stress intensity factor, K_{Ic}, is measured using the operational procedure (and satisfying all of the validity requirements) specified in Test Method E399, that provides for the measurement of crack-extension resistance at the onset (2% or less) of crack extension and provides operational definitions of crack-tip sharpness, onset of crack-extension, and crack-tip plane strain. **E399**

Discussion—See also **crack-extension resistance**, **crack-tip plane strain**, and **mode**.

plane-strain fracture toughness, J_{Ic} [FL^{-1}]—the crack-extension resistance under conditions of crack-tip plane strain in Mode I with slow rates of loading and substantial plastic deformation. The J-integral, J_{Ic} , is measured using the operational procedure (and satisfying all of the validity requirements) specified in Test Method E1820, that provides for the measurement of crack-extension resistance near the onset of stable crack extension. **E1820**

plane-stress fracture toughness, K_c [$FL^{-3/2}$]—crack-extension resistance under conditions that do not approach crack-tip plane strain to the degree required by an empirical criterion.

Discussion—In Practice E561, plane-stress fracture toughness is represented by an *R*-curve. When plane-stress fracture toughness is used to define conditions for crack instability, it is designated K_c , a quantity dependent on specimen configuration by Practice E561. The value of *K* at the tangency between the *R*-curve and the configuration-dependent applied *K* curve is K_c . The effective crack size concept may be used to compute plasticity-adjusted values of stress-intensity factor, *K*, if the crack-tip plastic zone is surrounded by an elastic stress field. **E561**

plastic-zone adjustment, r_Y [L]—an addition to the physical crack size to account for plastic crack-tip deformation enclosed by a linear-elastic stress field.

Discussion—1 Commonly the plastic-zone adjustment is given as follows:

$$\text{Plane} - \text{Stress Mode } 1: r_Y = \frac{K^2}{2\pi\sigma_Y{}^2} \tag{15}$$

$$\text{Plane} - \text{Strain Mode } I: r_Y = \frac{\alpha K^2}{2\pi\sigma_Y{}^2} \tag{16}$$

where:

α = ⅓ to ¼ , and
σ_Y = effective yield strength.

Discussion—2 See also **crack size**. **E561**

point estimate—the estimate of a parameter given by a single statistic, for example, sample average (see **sample average**) (**arithmetic average**). **E1823**

pop-in—a discontinuity in the force against clip gage displacement record. This discontinuity is characterized by a sudden increase in displacement and, generally, a decrease in force. Subsequently, the displacement and force increase to above their respective values at pop-in. **E1290**

population (or universe)— *in fatigue testing*, the totality of the set of test specimens, real or conceptual, that could be prepared in the specified way from the material under consideration. **E1823**

power spectral density—the limiting mean-square value (for example, of acceleration, velocity, displacement, stress, or other random variable) per unit bandwidth of frequency, that is the limit of the mean-square value of a given rectangular bandwidth divided by the bandwidth, as the bandwidth approaches zero. **E1823**

precision—the closeness of agreement between randomly selected individual measurements or test results for a given set of experimental variables.

Discussion—1 The standard deviation of the error of measurement may be used as a measure of "imprecision."

Discussion—2 The estimate of precision usually contains two components of variance. One component is due to the variability of the test material. The other component is due to variability in the test method application. Special test setups may permit the separation of these two components of variance. **E1823**

precrack force, P_M [F]—the allowable precrack force. **E1737**

random loading—*in fatigue loading*, a spectrum loading (straining) where the peak and valley forces (strains) and their sequence result from a random process; the loading (straining) is usually described in terms of its statistical properties, such as the probability density function, the mean, the root mean square, the irregularity factor, and others as appropriate. **E1823**

random-ordered loading— *in fatigue loading*, a spectrum loading that is generated from a distinct set of peak and valley forces into a loading sequence by using a specific random sequencing process; a sequence of finite length is usually repeated identically. **E1823**

raw data—the sampled values of a sensor output. **E2208, E2443**

reference electrode—the electrode (for example, hydrogen electrode, normal calomel electrode, or saturated calomel electrode) against which the electrical potential of a specimen is measured. **E1823**

reference load [F]—*for spectrum loading*, used in Practices E1049 to denote the loading level that represents a steady-state condition upon which load variations are superimposed. The reference load may be identical to the mean force of the history, but this is not required. **E1049**

remaining ligament, *b* [L]—the difference between the width of the specimen (w) and the physical crack size (a_p) that is,

$$b = W - a_p \tag{17}$$

remaining ligament, b [L]—distance from the physical crack front to the back edge of the specimen, that is,(b=W– a_p) **E1820**

replicate (repeat) tests—nominally identical tests on different randomly selected test specimens conducted at the same nominal value of the independent variable *X*.

Discussion—Such replicate or repeat tests should be conducted independently; for example, each replicate test should involve a separate set of the test machine and its settings. **E739**

residual strength, σ_r [FL^{-2}]—the maximum value of the gross stress, neglecting the area of the crack, that a cracked specimen is capable of sustaining.

Discussion—In part-through surface crack (PS) specimens, gross stress is the ratio of the maximum force (P_{max}) to the product of test section width (W) times thickness (B), P_{max} /(BW). It represents the stress at fracture normal to and remote from the plane of the crack. **E740**

response curve for *N* cycles—a curve fitted to observed values of percentage survival at *N* cycles for several stress levels, where *N* is the preassigned number such as 10^6, 10^7, and so forth. It is an estimate of the relationship between applied stress and the percentage of the population that would survive *N* cycles.

Discussion—1 Values of the median fatigue strength at *N* cycles and the fatigue strength for *p* % survival at *N* cycles may be derived from the response curve for *N* cycles if *p* falls within the range of the percent survival values actually observed.

Discussion—2 Caution should be used in drawing conclusions from extrapolated portions of the response curves. In general, the curves should not be extrapolated to other values of *p*. **E1823**

reversal (slope reversal)— *in fatigue loading*, the occurrence where the first derivative of the force-time (strain-time) history changes sign, (see Fig. 4). For force (strain) histories with hold times, see Fig. 7.

Discussion—The number of reversals in constant amplitude loading (straining), is equal to twice the number of cycles. **E1049**

run-out—no fatigue failure at a specified number of force cycles. **E468, E739**

sample—the specimens from the population selected for test purposes.

Discussion—The method of selecting the sample fixes the statistical inferences or generalizations that may be made about the population. **E1823**

sample average (arithmetic average)—the sum of all the observed values in a sample divided by the sample size. It is a point estimate of the population mean. **E1823**

sample median—the (*1*) middle value when all observed values in a sample are arranged in order of magnitude if an odd number of items (units) are tested or (*2*) the average of the two middle-most values if an even number of items (units) are tested. It is a point estimate of the population median, or 50 % value. **E1823**

sample percentage—the percentage of observed values between two stated values of the variable under consideration. It is a point estimate of the percentage of the population between the same two stated values. (One stated value may be "minus infinity" or "plus infinity.") **E1823**

sample standard deviation, *s*—the square root of the sample variance. It is a point estimate of the population standard deviation, a measure of the "spread" of the frequency distribution of a population.

Discussion—This value of *s* provides a statistic that is used in computing interval estimates and several test statistics. For small sample sizes, *s* underestimates the population standard deviation. (See a statistics text for an unbiased estimate of the standard deviation of a normal population.) **E1823**

sample variance, s^2—the sum of the squares of the differences between each observed value and the sample average divided by the sample size minus one. It is a point estimate of the population variance.

Discussion—This value of s^2 provides both an unbiased point estimate of the population variance and a statistic that is used in computing the interval estimates and several test-statistics. Some texts define s^2 as "the sum of the squares of the differences between each observed value and the sample average divided by the sample size," but such a mean square statistic is not as useful. **E1823**

sharp-notch strength, σ_s [FL^{-2}]—the maximum nominal (net-section) stress that a sharply notched specimen is capable of sustaining.

Discussion—1 Values of sharp-notch strength may depend on notch and specimen configuration as these affect the net cross section and the elastic stress concentration.

Discussion—2 The tension specimens used in Test Methods E338 and E602 have notch root radii that approach current machining limits. The radius in such specimens is believed to be small enough that any smaller radius would result in notch strength essentially unchanged from an engineering viewpoint. **E338, E602**

significance level—the stated probability (risk) that a given test of significance will reject the null hypothesis (that a specified effect is absent) when the hypothesis is true. **E1823**

significant—statistically significant. An effect or difference between populations is said to be present if the value of a test statistic is significant, that is, lies outside of selected limits.

DISCUSSION—An effect that is statistically significant may or may not have engineering significance. **E1823**

slow stable crack extension [L]—a displacement controlled crack extension beyond the stretch zone width. The extension stops when the applied displacement is held constant. **E1290**

***S-N* curve—**a plot of stress against the number of cycles to failure. The stress can be maximum stress, S_{max} ; minimum stress, S_{min} ; stress range, ΔS or S_r ; or alternating stress, S_a. The curve indicates the *S-N* relationship for a specified value of S_m, *A*, or *R* and a specified probability of survival. For *N*, a log scale is commonly used. For *S*, either a logarithmic or a linear scale is used. **E1823**

***S-N* curve for 50 % survival—**a curve fitted to the median values of fatigue life at each of several stress levels. It is an estimate of the relationship between applied stress and the number of cycles-to-failure that 50 % of the population would survive.

DISCUSSION—1 This is a special case of the more general definition of *S-N* curve for *p* % survival.

DISCUSSION—2 In the literature, the abbreviated term "*S-N* curve" usually has meant either the *S-N* curve drawn through the mean (averages) or the medians (50 % values) for the fatigue life values. Since the term " *S-N* curve" is ambiguous, its use in technical papers should be accompanied by an adequate description. **E1823**

***S-N* curve for *p* %survival—**a curve fitted to the fatigue life for *p* % survival values at each of several stress levels. It is an estimate of the relationship between applied stress and the number of cycles-to-failure that *p* % of the population would survive where *p* may be any percent, such as 95, 90, and so forth.

DISCUSSION—Caution should be used in drawing conclusions from any extrapolated portion of an *S-N* curve. In general, *S-N* curves should not be extrapolated beyond observed life values. **E1823**

specimen center of pin hole distance, *H [L],** *n*—the distance between the center of the pin holes on a pin-loaded specimen. **E1820**

specimen gage length, *d* [L]— the distince between the points of displacment measure (for example, clip gage, gage length). **E1820**

specimen span, *S* [L] —distance between specimen supports. **E1820, E1921**

specimen temperature, *T* [θ]— *in fatigue testing*, the average temperature in the specimen test section during isothermal testing, or the temperature in the specimen test section at any instant of time during cyclic-temperature testing. **E1823**

specimen thickness, *B* [L]—the distance between the parallel sides of a test specimen. **E1457, E1820, E1921, E2472**

DISCUSSION—for side-grooved specimens, the specimen thickness, B_N, is the distance between the roots of the side grooves. See also **net thickness**.

specimen width, *W* [L] —the distance from a reference position (for example, the front edge of a bend specimen or the force line of a compact specimen) to the rear surface of the specimen. **E1457, E1820**

spectrum loading—*in fatigue loading*, a force-time program consisting of some (or all) unequal peak and valley forces. (Also known as *variable amplitude loading* or *irregular loading*.) **E1049**

stable crack extension [L]—a displacement-controlled crack extension beyond the stretch-zone width. The extension stops when the applied displacement is held constant. **E1820**

statistic—a summary value calculated from the observed values in a sample. **E1823**

steady-state crack—a crack that has advanced slowly until the crack-tip plastic zone size and crack-tip sharpness remain constant with further crack extension. Although crack-tip conditions can be a function of crack velocity, the steady-state crack-tip conditions for metals have appeared to be independent of the crack velocity within the range attained by the loading rates specified in Test Method E1304. **E1304**

stress, [FL^{-2}]—force acting over a unit area. Traditionally, the symbol for stress is either *S* or σ , as a matter of choice. **E1823**

stress concentration factor—See **theoretical stress concentration factor (or stress concentration factor) k_t** .

stress-corrosion cracking, SCC—a cracking process that requires the simultaneous action of a corrodent and sustained tensile stress. **E1681**

stress cycle—See **cycle**.

stress-intensity factor, *K*, K_1, K_2, K_3, K_I, K_{II}, K_{III} [FL$^{-3/2}$]— the magnitude of the mathematically ideal, crack-tip stress field (stress-field singularity) for a particular mode in a homogeneous, linear-elastic body.

DISCUSSION—Values of *K* for the modes 1, 2, and 3 are given by the following equations:

$$K_1 = \underset{r \to 0}{limit}\ \sigma_y \ (2\pi r)^{1/2} \tag{18}$$

$$K_2 = \underset{r \to 0}{limit}\ \tau_{xy} \ (2\pi r)^{1/2}, \text{ and} \tag{19}$$

$$K_3 = \underset{r \to 0}{limit}\ \tau_{yz} \ (2\pi r)^{1/2} \tag{20}$$

where:

r = distance (in a cylindrical coordinate system) from the crack tip to a location where the stress is calculated. (See Fig. 8 for the description of modes.) **E399, E561, E647, E1304**

stress-intensity factor at crack initiation, K_o [FL$^{-3/2}$]—the value of K at the onset of rapid fracturing.

DISCUSSION—In Test Method E1221, only a nominal estimate of the initial driving force is needed. For this reason, K_o is calculated on the basis of the original crack or notch size and the crack-mouth opening displacement at the initiation of a fast-running crack. **E1221**

*stress-intensity-factor calibration, K calibration***—**See **applied- *K* curve** in 3.4.

stress-intensity factor range, ΔK [FL$^{-3/2}$]—*in fatigue*, the variation in the stress-intensity factor in a cycle, that is

$$\Delta K = K_{max} - K_{min} \tag{21}$$

DISCUSSION—1 The loading variables R, ΔK, and K_{max} are related such that specifying any two uniquely defines the third in accordance with the following relationships:

$$\Delta K = (1 - R)K_{max} \text{ for } R \geq 0, \text{ and} \tag{22}$$

$$\Delta K = K_{max} \text{ for } R < 0. \tag{23}$$

DISCUSSION—2 These preceding stress-intensity-factor range definitions do not include local crack-tip effects; for example, crack closure, residual stress, and blunting.

DISCUSSION—3 While the operational definition of ΔK states that ΔK does not change for a constant value of K_{max} when $R < 0$, increases in fatigue crack growth rates can be observed when R becomes more negative. Excluding compressive forces in the calculation of ΔK does not influence the material's response (da/dN) which is independent of the operational definition of ΔK. For predicting crack-growth lives generated under various R conditions, the life prediction methodology must be consistent with the data reporting methodology. **E647**

stress intensity factor threshold for environment assisted cracking, K_{EAC} [FL$^{-3/2}$] —the highest value of the stress intensity factor (K) at which crack growth is not observed for a specified combination of material and environment and where the measured value may depend on specimen thickness. **E1681**

stress intensity factor threshold for plane strain environment-assisted cracking, K_{IEAC} [FL$^{-3/2}$] — the highest value of the stress intensity factor (K) at which crack growth is not observed for a specified combination of material and environment and where the specimen size is sufficient to meet requirements for plane strain as described in Test Method E399. **E1681**

stress range, σ_s, [FL^{-2}]—The difference between the maximum and minimum stresses.

DISCUSSION—For creep-fatigue tests, the difference between the maximum and minimum stresses is called the "peak stress range" and for tests conducted under strain control, the difference between the stresses at the points of reversal of the control parameter is called the "relaxed stress range." **E2714**

stretch zone width (*SZW*) [L]—the length of crack extension that occurs during crack-tip blunting, for example, prior to the onset of unstable brittle crack extension, pop-in, or slow stable crack extension. The *SZW* is co-planar with the original (unloaded) fatigue precrack and refers to an extension of the original crack. **E1290**

tensile strength, σ_{TS} [FL^{-2}]—the maximum tensile stress that 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. **E6, E28**

test of significance—a statistical test that, by use of a specified test statistic, purports to provide a test of a null hypothesis (under certain assumptions); for example, that an imposed treatment in the experiment is without effect.

DISCUSSION—Recognizing the possibility of false rejection, the rejection of the hypothesis being tested usually indicates that an effect is present. **E1823**

test statistic—a function of the observed values in a sample that is used in a test of significance. **E1823**

theoretical elastic stress concentration factor (or stress concentration factor) k_t —the ratio of the greatest stress in the region of a notch or other stress concentrator as determined by the theory of elasticity (or by experimental procedures that give equivalent values) to the corresponding nominal stress.

DISCUSSION—The theory of plasticity should not be used to determine k_t. **E1823**

tolerance interval—an interval computed so that it will include at least a stated percentage of the population with a stated probability. **E1823**

tolerance level—the stated probability that the tolerance interval includes at least the stated percentage of the population. It is not the same as a confidence level but the term confidence level is frequently associated with tolerance intervals. **E1823**

tolerance limits—the two statistics that define a tolerance interval. (One value may be "minus infinity" or "plus infinity.") **E1823**

total cycle period, τ_t [T] — the time for the completion of one cycle. The parameter τ_t can be separated into hold and non-hold (that is, steady and dynamic) components:

$$\tau_t = \sum \tau_h + \sum \tau_{nh} \tag{24}$$

where:

$\sum \tau_h$ = sum of all the hold portions of the cycle and,
$\sum \tau_{nh}$ = sum of all the non-hold portions of the cycle.

τ_t also is equal to the reciprocal of the overall frequency when the frequency is held constant. **E606**

transition time, t_T [T]—time required for extensive creep conditions to develop in a cracked body under sustained loading. For specimens, this is typically the time required for the creep deformation zone to spread through a substantial portion of the uncracked ligament, or in the region that is under the influence of a crack in the case of a finite crack in a semi-infinite medium. This limit is employed to validate the steady state correlating parameter C^*. An estimate of transition time for materials that creep according to the power-law can be obtained from the following equation:

$$t_T = \frac{K^2 (1 - \upsilon^2)}{E (n+1) C^*}$$

where:

υ = Poisson's ratio, and
n = secondary creep exponent

E1457, **E1921**, **E2760**

trough—See **valley**.

truncation—*in fatigue loading*, the exclusion of cycles with values above or below a specified level (referred to as truncation level) of a loading parameter (peak, valley, range, and so forth). **E1823**

unstable brittle crack extension [L]—an abrupt crack extension occurring with or without prior stable crack extension in a standard fracture test specimen under crosshead or clip gage displacement control. **E1290**

valley—*in fatigue loading*, the occurrence where the first derivative of the force-time history changes from negative to positive sign; (also known as *trough*); the point of minimum force in constant amplitude loading (see Fig. 4). For force histories with hold times see Fig. 7. **E1049**

variable amplitude loading— See **spectrum loading**.

wave form—the shape of the peak-to-peak variation of a controlled mechanical test variable (for example, load, strain, displacement) as a function of time. **E1823**

yield strength, σ_{YS} [FL^{-2}]—the stress at which a material exhibits a specific limiting deviation from the proportionality of stress to strain at the test temperature. This deviation is expressed in terms of strain. **E6**, **E28**, **E1457**, **E1921**

Discussion—1 It is customary to determine yield strength by either (1) Offset Method (usually a strain of 0.2 % is specified) or (2) Total-Extension-Under-Force Method (usually a strain of 0.5 % is specified although other values of strain may be used).

Discussion—2 Whenever yield strength is specified, the method of test must be stated along with the percent offset or total strain under force. The values obtained by the two methods may differ.

Young's modulus—see **modulus of elasticity**.

zero crossings—*in fatigue loading*, the number of times that the force-time history crosses zero force level with a positive slope or negative slope, or both, as specified, during a given period. **E1823**

3.4 *Definitions of Terms (Specific to the Indicated Standards)*—Each term is followed by the designation(s) of the standard(s) of origin. The listing of terms is alphabetical. Some Definitions of Terms are quite similar to the Definitions. The Definitions of Terms herein apply to specific standards.

adjusted compliance ratio, U_{ACR} —a dimensionless parameter representing the ratio of secant to open-crack compliances, both adjusted by the initial compliance. **E647**

crack arrest reference temperature, T_{KIa} [°C]— The test temperature at which the median of the K_{Ia} distribution will equal 100 MPa√m (91.0 ksi√in.). **E1221**

crack-arrest fracture toughness, K_a [FL$^{-3/2}$]—the value of the stress-intensity factor shortly after crack arrest.

DISCUSSION—1 The in-plane specimen dimensions must be large enough for adequate enclosure of the crack-tip plastic zone by a linear-elastic stress field.

DISCUSSION—2 In Test Method E1221, side-grooved specimens are used. The calculation of K_a is based upon measurements of both the arrested crack size and of the crack-mouth opening displacements prior to initiation of a fast-running crack and shortly after crack arrest. **E1221**

crack depth, *a* [L]—*in part-through surface-crack specimens (PS)*, the distance from, and normal to, the cracked plate surface to the point of maximum penetration of the crack front into the material. Crack depth is less than the specimen thickness.

DISCUSSION—In Practice E740, crack depth is the original depth a_o and the subscript $_o$ is everywhere implied. **E740**

crack jump behavior— *in chevron-notch specimen tests*, that type of sporadic crack growth which is characterized primarily by periods during which the crack front is nearly stationary until a critical force is reached, whereupon the crack becomes unstable and suddenly advances at high speed to the next arrest point, where it remains nearly stationary until the force again reaches a critical value, and so forth. (see Fig. 5).

DISCUSSION—A chevron-notch specimen is said to have a crack jump behavior when crack jumps account for more than one half of the change in unloading slope ratio as the unloading slope ratio passes through the range from $0.8r_c$ to $1.2r_c$. Only those sudden crack advances that result in more than a 5 % decrease in force during the advance are counted as crack jumps (Fig. 5). The parameter r_c is the unloading slope ratio at the critical crack size. **E1304**

crack size, *a* [L]—in Test Method E1457, the physical crack size is represented as a_p . The subscript p is everywhere implied. **E1457**

creep crack growth behavior—a plot of the time rate of crack growth, da/dt, as a function of C*(t). **E1457**

critical crack size [L]—the crack size in a chevron-notch specimen at which the specimen's stress-intensity factor coefficient, Y^*, is a minimum, or equivalently, the crack size at which the maximum force would occur in a purely linear elastic fracture mechanics test. At the critical crack size, the width of the crack front is approximately one third the dimension B. **E1304**

critical slope ratio, r_c—the unloading slope ratio at the critical crack size. **E1304**

dial energy, KV [FL]—absorbed energy as indicated by the impact machine encoder or dial indicator, as applicable. **E1820**

drop-weight tear test (DWTT)—a test of plain-carbon or low-alloy pipe steels over the temperature range where the fracture changes from a brittle to a ductile mode. The mode can be determined from the appearance of propagating fractures. **E436**

dynamic stress intensity factor, K_{Jd}—The dynamic equivalent of the stress intensity factor K_J, calculated from J using the equation specified in this test method. **E1820**

dynamic ultimate tensile strength, σ_{TSd} *[FL^{-2}]*—dynamic equivalent of the ultimate tensile strength, measured at the equivalent strain rate of the fracture toughness test. **E1820**

dynamic yield strength, σ_{YSd} *[FL^{-2}]*—dynamic equivalent of the yield strength, measured at the equivalent strain rate of the fracture toughness test. **E1820**

dynamic tear (DT) energy [J]—the total energy required to fracture standard DT specimens tested in accordance with the provisions of Test Method E604.

DISCUSSION—1 With pendulum-type machines, the DT energy value recorded is the difference between the initial and the final potential energies of the pendulum or pendulums.

DISCUSSION—2 With drop-weight machines, the DT energy value recorded is the difference between the initial potential energy of the hammer and the final energy of the hammer, as determined by a calibrated energy absorption system. **E604**

effective unloading slope ratio, *r*—the ratio of an effective unloading slope to that of the initial elastic loading slope on a test record of force versus specimen mouth opening displacement.

DISCUSSION—1 This unloading slope ratio provides a method of determining the crack size at various points on the test record thus allowing evaluation of the stress intensity factor coefficient Y^*. The effective unloading slope ratio is measured by performing unloading-reloading cycles during the test as indicated schematically in Fig. 5 and Fig. 6. For each unloading-reloading trace, the effective unloading slope ratio, r, is defined in terms of the tangents of two angles:

$$r = \tan\theta/\tan\theta_o \quad (25)$$

where:

$\tan\theta_o$ = slope of the initial elastic line, and
$\tan\theta$ = slope of an effective unloading line.

The effective unloading line is designated as having an origin at the high point where the displacement reverses direction on unloading (slot mouth begins to close) and joining the low point on the reloading line where the force is one half that at the high point.

DISCUSSION—2 For a brittle material with linear elastic behavior, the unloading-reloading lines of an unloading-reloading cycle would be linear and coincident. For many engineering materials, deviations from linear elastic behavior and hysteresis are commonly observed to varying degrees.

DISCUSSION—3 Although r is measured only at those crack positions associated with unloading-reloading cycles, r nevertheless is defined at all points during a chevron-notch specimen test. For any particular point, r is the value that would be measured if an unloading-reloading cycle were performed at that point. **E1304**

environment-assisted cracking, EAC—a cracking process in which the environment promotes crack growth or higher crack growth rates than would occur without the presence of the environment. **E1681**

equivalent-energy fracture toughness (*K-EE*) [$FL^{-3/2}$]—the crack extension resistance determined by the procedure specified in Practice E992.

DISCUSSION—The thickness, B, of the standard specimen from which the result is obtained should be identified in quoting the result. For specimens thicker than the standard specimens, both B and W should be specified. **E992**

fixed-force or fixed-displacement applied *K* curves—curves obtained from a fracture mechanics analysis of a specific specimen configuration. **E561**

general yield force, P_{gy} *[F]* —in an instrumented impact test, applied force corresponding to general yielding of the specimen ligament. It corresponds to F_{gy}, as used in Test Method E2298. **E1820**

initial crack extension increment (CCI) after full forceup, δa_i [L]—the recommended time taken to crack extension of δa_i=0.2 mm after first application of force for defining a crack growth period, $t_{0.2}$, in hours as a function of $C^*(t)$, C_t, or K value taken at crack length ao + δa_i 0.2 mm. **E1457**

initial crack time to 0.2 mm, $t_{0.2}$ [T]—the time to δa_i=0.2 mm (0.008 in) of crack extension, δa, by creep after full loading. This size is chosen as the limit of accuracy set for crack extension measurements in laboratory geometries. **E1457**

initial open-crack compliance, C_{oi} [LF^{-1}] —the notch open-crack compliance before a crack has formed. **E647**

initial secant compliance, C_{si} [LF^{-1}]—the notch secant compliance before a crack has formed. **E647**

J_c [FL^{-1}]—The property J_c determined by Test Method E1820 characterizes the fracture toughness of materials at fracture instability prior to the onset of significant stable tearing crack extension. The value of J_c determined by Test Method E1820 represents a measure of fracture toughness at instability without significant stable crack extension that is independent of in-plane dimensions; however, there may be a dependence of toughness on thickness (length of crack front).

DISCUSSION—The dynamic equivalent of J_c is $J_{cd,X}$, with X = order of magnitude of J-integral rate. **E1820**

J_u [FL^{-1}]—The quantity J_u determined by Test Method E1820 measures fracture instability after the onset of significant stable tearing crack extension. It may be size-dependent and a function of test specimen geometry. It can be useful to define limits on ductile fracture behavior.

DISCUSSION—The dynamic equivalent of J_c is $J_{cd,X}$, with X = order of magnitude of J-integral rate. **E1820**

J-integral rate, $\dot{J}$ [$FL^{-1}T^{-1}$]—derivative of J with respect to time. **E1820**

***K*-decreasing test—**a test in which the normalized K-gradient is nominally negative. In Test Method E647, K-decreasing tests involve force shedding as the crack grows either continuously or by a series of decremental steps. **E647**

***K*-increasing test—**a test in which the normalized K-gradient is nominally positive. For the standard specimens in Test Method E647, the constant-force-amplitude test will result in a K-increasing test where the normalized K-gradient increases but is always positive. **E647**

machine capacity, MC [FL]—maximum available energy of the impact testing machine. **E1820**

minimum stress-intensity factor coefficient, Y^*_m — the minimum value of the stress intensity factor coefficient, Y^*. **E1304**

normalized crack size, *a/W*—the ratio of crack size, a, to specimen width, W. **E813**

normalized *K*-gradient, $C = (1/K)\cdot dK/da$ [L^{-1}]—the fractional rate of change of K with increasing crack size.

DISCUSSION—When C is held constant, the percentage change in K is constant for equal increments of crack size. The following identity is true for the normalized K-gradient in a constant force-ratio test:

$$\frac{1}{K}\cdot\frac{dK}{da} = \frac{1}{K_{\max}}\cdot\frac{dK_{\max}}{da} = \frac{1}{K_{\min}}\cdot\frac{dK_{\min}}{da} = \frac{1}{\Delta K}\cdot\frac{d\Delta K}{da} \quad (26)$$

open-crack compliance, C_o [LF^{-1}]—the open-crack compliance for the specimen at a given crack size.

DISCUSSION—for the purposes of this appendix, all compliance values may be expressed as either EvB/P or v/P, where E is elastic modulus, v is displacement between two points, B is specimen thickness, and P is force. The former is dimensionless, while the latter has dimensions of LF^{-1}. For consistency with Appendix X2, all compliances in this appendix are assumed to be calculated as $C = v/P$. **E647**

plane-strain (chevron-notch) fracture toughness, K_{Iv} or K_{Ivj} [$FL^{-3/2}$]—under conditions of crack-tip plane strain in a chevron-notched specimen: K_{Iv} relates to extension resistance with respect to a slowly advancing steady-state crack. K_{Ivj} relates to crack extension resistance with respect to a sporadically advancing crack.

DISCUSSION—For slow loading rates the measured fracture toughness, K_{Iv} or K_{Ivj} , is the value of stress-intensity factor obtained using the operational procedure, and satisfying all of the validity requirements, specified in Test Method E1304. **E1304**

plane-strain (chevron-notch) fracture toughness, K_{IvM} [$FL^{-3/2}$]—determined similarly to K_{Iv} or K_{Ivj} using the same specimen, or specimen geometries, but using a simpler analysis based on the maximum test force. Unloading-reloading cycles are not required in a test to determine K_{IvM} . **E1304**

plane-strain crack-arrest fracture toughness, K_{Ia} [$FL^{-3/2}$]—the value of crack-arrest fracture toughness, K_a , for a crack that arrests under conditions of crack-front plane-strain.

DISCUSSION—The requirements for attaining conditions of crack-front plane-strain are specified in the procedures of Test Method E1221. **E1221**

precracked Charpy, PCC, specimen—SE(B) specimen with W = B = 10 mm (0.394 in.) **E1921**

secant compliance, C_s [LF^{-1}]—the secant compliance for the specimen at a given crack size as defined by the secant of the unloading compliance curve between the maximum force and minimum force. **E647**

smooth crack growth behavior—generally, crack extension in chevron-notch specimens which is characterized by slow, continuously advancing crack growth, and a relatively smooth force displacement record (Fig. 6). However, any test behavior is automatically characterized as smooth crack-growth behavior unless it satisfies the conditions shown in Fig. 5 for crack-jump behavior. **E1304**

strain rate, $\dot{\varepsilon}$—derivative of strain ε with respect to time. **E1820**

stress-intensity factor coefficient, *Y—**a dimensionless parameter that relates the applied force and specimen geometry to the resulting crack-tip stress-intensity factor in a chevron-notch specimen test. **E1304**

stress-intensity factor range based on adjusted compliance ratio, ΔK_{ACR} [$FL^{-3/2}$]—in fatigue, the stress-intensity factor range computed using the Adjusted Compliance Ratio method. **E647**

stress-intensity factor rate, $\dot{K}$ [$FL^{-3/2}T^{-1}$] —derivative of *K* with respect to time. **E1820**

surface-crack length, 2*c* [L]—in part-through surface crack (PS) specimens, a distance measured on the specimen surface between the two points at which the crack front intersects the specimen surface. Crack length is less than the specimen width.

DISCUSSION—In Practice E740, crack length is the original surface length, $2c_o$, and the subscript o is everywhere implied. **E740**

time to fracture, t_f [T]—time corresponding to specimen fracture. **E1820**

t_i [T]—time corresponding to the onset of crack propagation. **E1820**

v_0 [LT^{-1}]—in an instrumented impact test, striker velocity at impact. **E1820**

W_m [FL]—in an instrumented impact test, absorbed energy at maximum force. **E1820**

W_t [FL]—in an instrumented impact test, total absorbed energy calculated from the complete force/displacement test record. **E1820**

W_0 [FL]—in an instrumented impact test, available impact energy. **E1820**

ANNEXES

(Mandatory Information)

A1. UNITS

A1.1 For stress intensity factor, *K*, and any measure of fracture toughness expressed in terms of *K*, the recommended unit is MPa $(m)^{1/2}$. The corresponding customary unit is ksi $(in.)^{1/2}$.

A1.2 For the crack-extension force, *G*, and for the elastic energy release rate, which in plane measurement problems is equal to *J*, and any measure of fracture toughness expressed in terms of *G* or *J*, the recommended unit is kJ/m^2. The corresponding customary unit is $in.\text{-}lb/in.^2$

A1.3 For crack tip opening displacement, δ, and any measure of fracture toughness expressed in terms of δ, the recommended unit is metre. The corresponding customary unit is mil.

A2. DESIGNATION CODES FOR SPECIMEN CONFIGURATION, APPLIED LOADING, AND CRACK OR NOTCH ORIENTATION

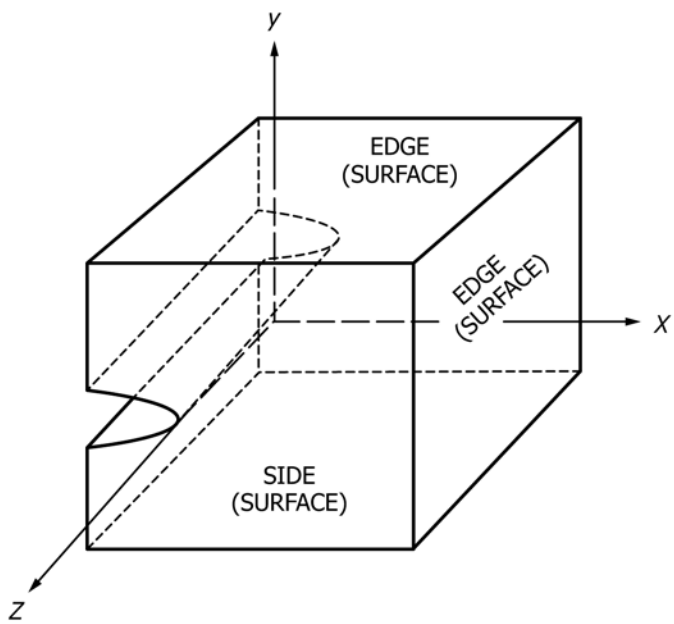


FIG. A2.1 Three-Dimensional View of Ideal Crack

A2.1 A consistent, uniform, systematic specimen code is described herein.[7] It has the following basic format:

1	2	3
Specimen Configuration	(Applied Loading)	(Crack or Notch Orientation)

These three elements of the designation code are presented in this annex as follows: A2.2 on Specimen Configuration, A2.3 on Applied Loading, and A2.4 on Crack or Notch Orientation.

A2.2 *Designation Code for Specimen Configuration:*

A2.2.1 Most specimens can be analyzed and illustrated in a plan view that is normal to the front of the notch or crack. From this plan view, the term edge (which is normally used to represent a line) represents a line boundary of the specimen. In test specimens, the two surfaces parallel to this plan view are termed side surfaces, and the four surfaces normal to this plan view (the boundaries in the plan view) are termed edge surfaces. Fig. A2.1 illustrates two edge surfaces and one side surface of a specimen that contains a mathematically ideal crack.

A2.2.1.1 The following specimen designations treat the specimen configurations that are used at present. As new specimens develop, they will be added to this listing. The symbol code of abbreviations for specimen configuration has one, two, or three capital letters.

M	Middle
DE	Double Edge
SE	Single Edge (0.6 < H/W)
C	Compact version of SE with H/W = 0.6
MC	Modified Compact (0.3 < H/W < 0.6)
DC	Disk-Shaped Compact (formerly called round compact specimen)
A	Arc
DB	Double Beam (H/W < 0.3)
RDB	Round Double Beam (formerly called short rod)
R-BAR	Round Bar
PS	Part-Through Surface (formerly designated SCT and PTC)

Examples are given in Fig. A2.2.

A2.2.1.2 Note that the words "cracked" and" notched" are not part of the code. For example, a standard compact that is notched (non-pre-cracked) is designated "notched C," and a precracked standard compact (specimen used in Method E399) is a" pre-cracked C." Likewise, the terms "chevron" and" contoured" are not part of the code and they are spelled out when needed, as in the chevron RDB specimen.

A2.3 *Designation Code for Applied Loading:*

A2.3.1 The applied loading code consists of a one-letter abbreviation that is enclosed in parentheses and immediately follows the specimen code. The following list contains examples of applied loading. Examples are given in Fig. A2.2.

(T)	Tension
(B)	Bending
(M_x)	Torsion with a moment about the *x*-axis of the specimen (formerly called double torsion loading)
(M_z)	Moment about the *z*-axis of the specimen
(W)	Wedge loading
(W_b)	Wedge loading with a bolt

A2.4 *Designation Code for Crack or Notch Orientation:*

A2.4.1 Crack-, notch-, or fracture-plane orientation is designated by a hyphenated code with the first letter(s) representing the direction normal to the crack plane and the second letter(s) designating the expected direction of crack propagation. It is presented in parentheses and follows the designations for the specimen configuration and applied loading.

A2.4.2 The fracture toughness of a material usually depends on the orientation and direction of propagation of the crack in relation to the anisotropy of the material, which depends, in turn, on the principal directions of mechanical working or grain flow. The orientation of the crack plane should be identified wherever possible in accordance with the following systems.[8] In addition, the product form should be identified (for example, straight rolled plate, cross rolled plate, pancake forging, and so forth).

A2.4.3 For rectangular sections, the reference directions are identified as in the examples for a rolled plate, Fig. A2.3 and Fig. A2.4. The same system would be suitable for sheet, extrusions, and forgings with nonsymmetrical grain flow.

NOTE A2.1—The same geometry based system is useful extrusions or forged parts having circular cross section. In most cases, the L direction corresponds to the direction of the maximum grain flow, but some products, such as pancake, disk, or ring forgings can have the R or C

[7] Wilhem, D. P., "Standard Designation Code for Fracture Specimens, Loading and Orientation," *Standardization News*, Vol 10 , No. 5, May 1982.

[8] Goode, R. J., "Identification of Fracture Plane Orientation", *Materials Research and Standards (MIRSA)*, ASTM, Vol 12, No.9, September 1972

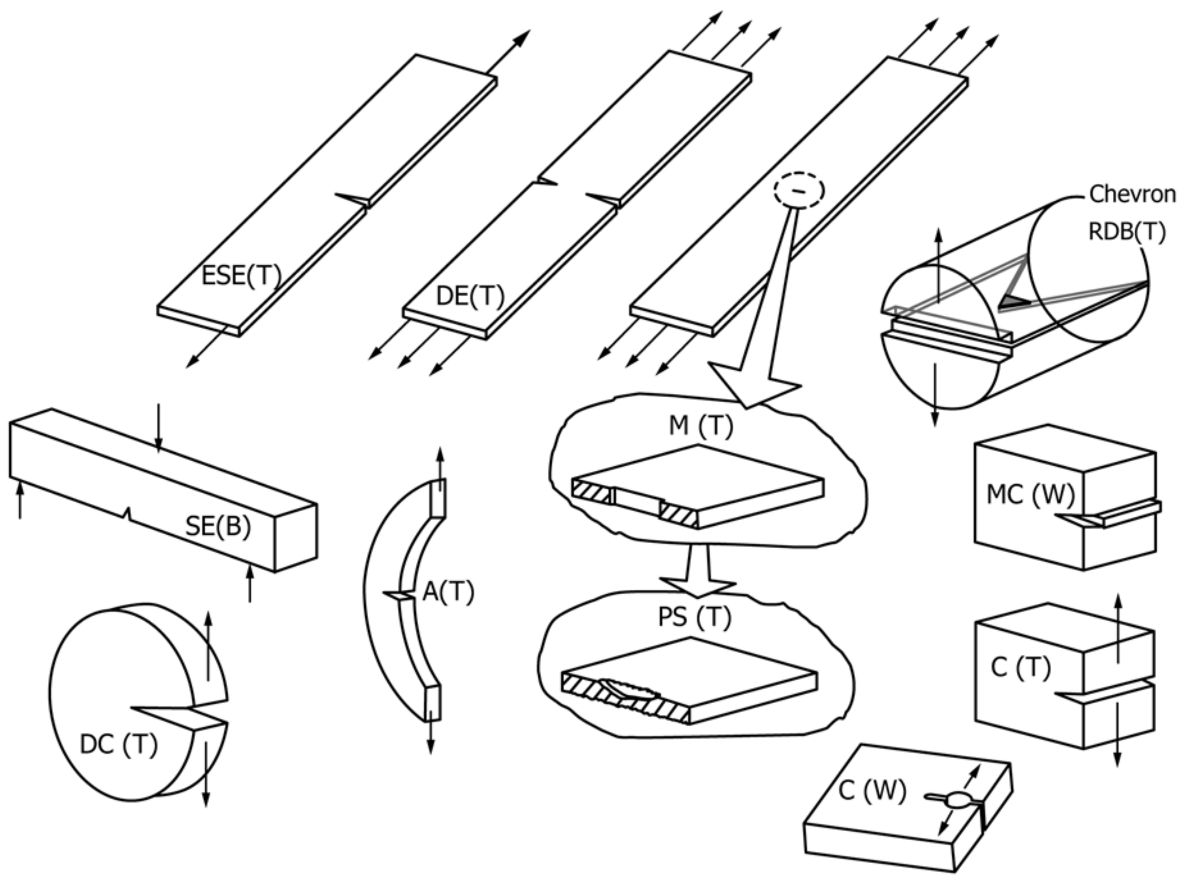


FIG. A2.2 Examples of Designation Codes for Specimen Configuration and Applied Loading

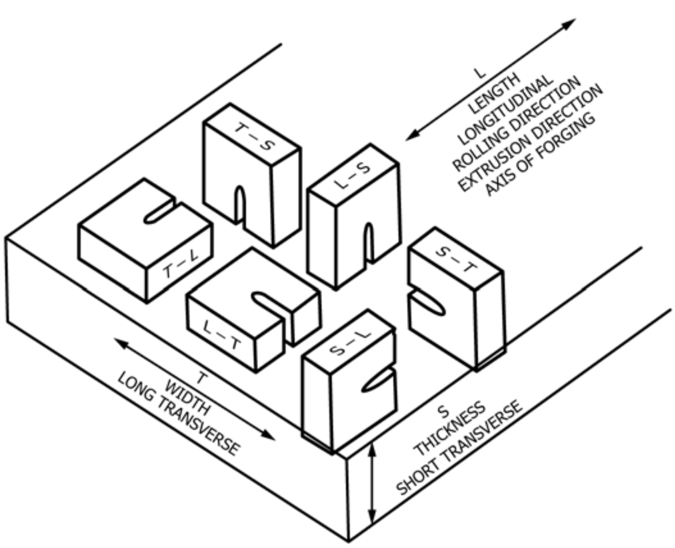


FIG. A2.3 Crack Plane Orientation Code for Rectangular Sections

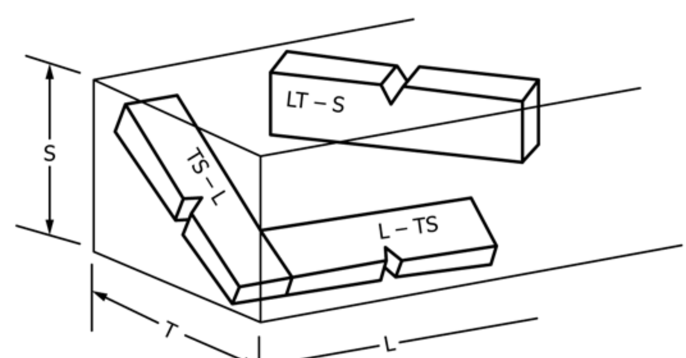


FIG. A2.4 Crack Plane Orientation Code for Rectangular Sections Where Specimens Are Tilted with Respect to the Reference Directions

directions correspond to the direction of maximum grain flow, depending on the method of manufacture.

L = direction of principal deformation (maximum grain flow),
T = direction of least deformation, and
S = third orthogonal direction.

A2.4.3.1 Using a two-letter code, the first letter designates the direction normal to the crack plane, and the second letter the expected direction of crack propagation. For example, in Fig. A2.3, the T-L specimen has a fracture plane whose normal is in the width direction of a plate and an expected direction of crack propagation coincident with the direction of maximum grain flow or longitudinal direction.

A2.4.3.2 For specimens that are tilted with respect to two of the reference axes, Fig. A2.4, the orientation is identified by a three-letter code. The code L-TS, for example, means that the crack-plane is perpendicular to the direction of principal deformation (L direction), and the expected fracture direction is intermediate between T and S. The code TS-L means that the crack-plane is perpendicular to a direction intermediate between T and S and the expected fracture is in the L direction.

A2.4.4 For cylindrical sections, where grain flow cam be in the longitudinal, radial, or circumferential direction, specimen location and crack plane orientation shall reference original cylindrical section geometry such that the L direction is always axial direction for L-R-C system, as indicated in Fig. A2.5, regardless of the maximum grain flow. Note that this is a geometry based system. As such, the direction of maximum grain flow shall be reported when the direction is known.

NOTE A2.2—The same geometry based system is useful for extrusions or forged parts having circular cross section. In most cases, the L direction corresponds to the direction of maximum grain flow, but some products, such as pancake, disk or ring forgings *can* have the R or C directions correspond to the direction of maximum grain flow, depending on the method of manufacture.

L = axial direction,
R = radial direction, and
C = circumferential or tangential direction.

A2.4.5 The arc-shaped specimen is intended to measure the fracture toughness so that the plane normal to the crack is in the circumferential or tangential direction. This is designated the C-R orientation. For other orientations, a bend or compact specimen should be used.

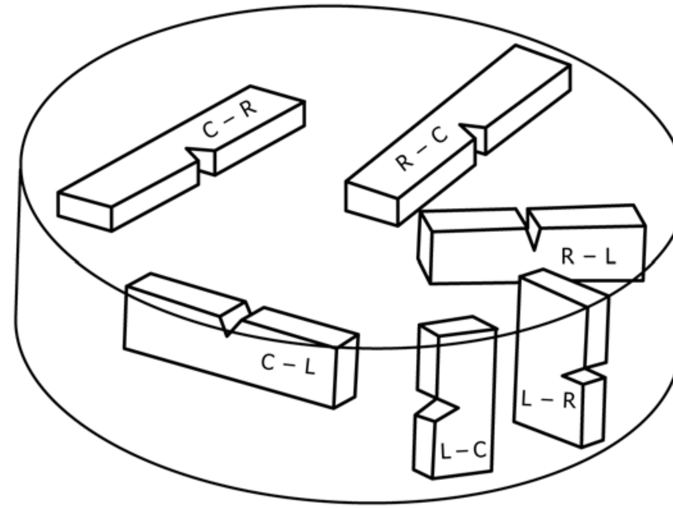


FIG. A2.5 Crack Plane Orientation Code for Bar and Hollow Cylinder

APPENDIX

(Nonmandatory Information)

X1. ABBREVIATED METRIC PRACTICE GUIDE FOR FATIGUE AND FRACTURE TESTING

X1.1 For additional information see "Metric Practice Guide E380." In Vol 03.01 of the *Annual Book of ASTM Standards*, see also "Excerpts from Standard for Metric Practice," under the heading Related Material in the gray pages.

X1.2 *Selected SI Units and Symbols:*

Quantity [dimension symbol]	Unit (SI symbol)	Formula
length [L]	metre (m)	
mass [M]	kilogram (kg)	
time [T]	second (s)	
thermodynamic temperature [θ]	kelvin (K)	
energy, work, torque [FL]	joule (J)	N·m
force [F]	newton (N)	kg·m/s^2
frequency [T^{-1}]	hertz (Hz)	(cycle)/s
pressure, stress [FL^{-2}]	pascal (Pa)	N/m^2

X1.3 *SI Prefixes:*

Multiplication Factor	Prefix	SI Symbol
1 000 000 = 10^6	mega	M
1000 = 10^3	kilo	k
0.001 = 10^{-3}	milli	m
0.000001 = 10^{-6}	micro	μ

X1.4 *Selected Conversion Factors:*

To Convert From	To	Multiply By
dyne·cm	N·m	1.000 000* E-07
erg	joule (J)	1.000 000* E-07
erg/cm^2	J/m^2	1.000 000* E-03
ft (foot)	metre (m)	3.048 000* E-01
ft·lbf (foot-pound)	joule (J)	1.355 818 E + 00
in. (inch)	metre (m)	2.540 000* E-02
in.	mm	2.540 000* E + 01
in.·lbf	joule (J)	1.129 848 E-01
in.·lbf/in.^{2}	J/m^2	1.751 268 E + 02
in.·lbf/in.^{2}	kJ/m^2	1.751 268 E-01
kgf (kilogram-force)	newton (N)	9.806 650* E + 00
kgf/mm^2	pascal (Pa)	9.806 650* E + 06
kgf/mm^2	MPa	9.806 650* E + 00
kgf/mm$^{3/2}$	MP$\sqrt{m}$	3.101 135 E-01
kilocalorie	joule (J)	4.186 800* E + 03
kip (1000 lbf)	newton (N)	4.448 222 E + 03
kip/in.^{2} (ksi)	pascal (Pa)	6.894 757 E + 06
ksi (kip/in.^{2})	pascal (Pa)	6.894 757 E + 06
ksi	MPa	6.894 757 E + 00
ksi$\sqrt{in.}$	Pa$\sqrt{m}$	1.098 843 E + 06
ksi$\sqrt{in.}$	MPa$\sqrt{m}$	1.098 843 E + 00
lbf (pound-force, poundal)^A	newton (N)	4.448 222 E + 00
lbf/in.	N/m	1.751 268 E + 02
lbf/in.^{2} (psi)	pascal (Pa)	6.894 757 E + 03
lbm (pound-mass)^B	kilogram (kg)	4.535 924 E-01
mil	metre (m)	2.540 000* E-05
N/mm^2	MPa	1.000 000* E + 00
N/mm$^{3/2}$	MPa$\sqrt{m}$	10$^{-3/2}$ *
psi (lbf/in.^{2})	pascal (Pa)	6.894 757 E + 03
psi	kPa	6.894 757 E + 00
psi$\sqrt{in.}$	Pa$\sqrt{m}$	1.098 843 E + 03
ton (long, 2240 lbm)	kilogram (kg)	1.016 047 E + 03
ton (metric)	kilogram (kg)	1.000 000* E + 03
ton (short, 2000 lbm)	kilogram (kg)	9.071 847 E + 02
ton-force (2000 lbf)	newton (N)	8.896 444 E + 03
ton-force/in.^{2}	pascal (Pa)	1.378 952 E + 07$^{A, B}$

^{A} The exact conversion factor is 4.448 221 615 260 5* E + 00.
^{B} The exact conversion factor is 4.535 923 7* E-01.

NOTE X1.1—Factors with an asterisk (*) are exact.