Designation: E606/E606M − 12

Standard Test Method for Strain-Controlled Fatigue Testing[1]

1. Scope

1.1 This test method covers the determination of fatigue properties of nominally homogeneous materials by the use of test specimens subjected to uniaxial forces. It is intended as a guide for fatigue testing performed in support of such activities as materials research and development, mechanical design, process and quality control, product performance, and failure analysis. While this test method is intended primarily for strain-controlled fatigue testing, some sections may provide useful information for force-controlled or stress-controlled testing.

1.2 The use of this test method is limited to specimens and does not cover testing of full-scale components, structures, or consumer products.

1.3 This test method is applicable to temperatures and strain rates for which the magnitudes of time-dependent inelastic strains are on the same order or less than the magnitudes of time-independent inelastic strains. No restrictions are placed on environmental factors such as temperature, pressure, humidity, medium, and others, provided they are controlled throughout the test, do not cause loss of or change in dimension with time, and are detailed in the data report.

NOTE 1—The term *inelastic* is used herein to refer to all nonelastic strains. The term *plastic* is used herein to refer only to the time-independent (that is, noncreep) component of inelastic strain. To truly determine a time-independent strain the force would have to be applied instantaneously, which is not possible. A useful engineering estimate of time-independent strain can be obtained when the strain rate exceeds some value. For example, a strain rate of 1×10^{-3} sec^{-1} is often used for this purpose. This value should increase with increasing test temperature.

1.4 This test method is restricted to the testing of uniform gage section test specimens subjected to axial forces as shown in Fig. 1(a). Testing is limited to strain-controlled cycling. The test method may be applied to hourglass specimens, see Fig. 1(b), but the user is cautioned about uncertainties in data analysis and interpretation. Testing is done primarily under constant amplitude cycling and may contain interspersed hold times at repeated intervals. The test method may be adapted to guide testing for more general cases where strain or temperature may vary according to application specific histories. Data analysis may not follow this test method in such cases.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products
E3 Guide for Preparation of Metallographic Specimens
E4 Practices for Force Verification of Testing Machines
E8/E8M Test Methods for Tension Testing of Metallic Materials
E9 Test Methods of Compression Testing of Metallic Materials at Room Temperature
E83 Practice for Verification and Classification of Extensometer Systems
E111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus
E112 Test Methods for Determining Average Grain Size
E132 Test Method for Poisson's Ratio at Room Temperature
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E209 Practice for Compression Tests of Metallic Materials at Elevated Temperatures with Conventional or Rapid Heating Rates and Strain Rates
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
E384 Test Method for Knoop and Vickers Hardness of Materials
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials

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[1] This test method is under the jurisdiction of ASTM Committee E08 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.05 on Cyclic Deformation and Fatigue Crack Formation.

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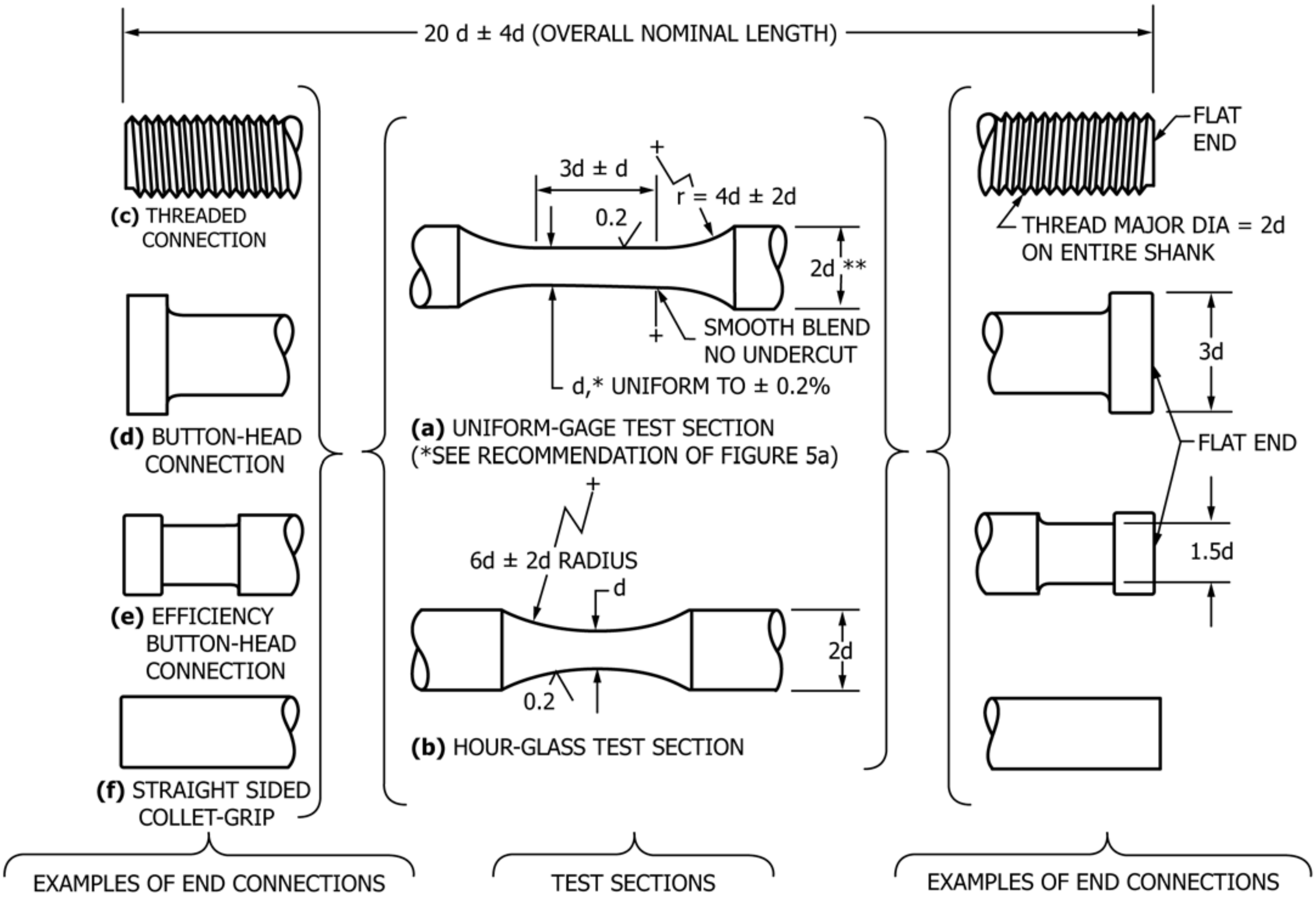
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



NOTE 1—* Dimension d is recommended to be 6.35 mm (0.25 in.). See 7.1. Centers permissible. ** This diameter may be made greater or less than 2d depending on material hardness. In typically ductile materials diameters less than 2d are often employed and in typically brittle materials diameters greater than 2d may be found desirable.

NOTE 2—Threaded connections are more prone to inferior axial alignment and have greater potential for backlash, particularly if the connection with the grip is not properly designed.

FIG. 1 Recommended Low-Cycle Fatigue Specimens

E466 Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials
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
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (***S-N***) and Strain-Life (ε-***N***) Fatigue Data
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
E1049 Practices for Cycle Counting in Fatigue Analysis
E1245 Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis
E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 The definitions in this test method are in accordance with Terminology E1823.

3.2 *Definitions:*Additional definitions associated with time-dependent deformation behavior observed in tests at elevated homologous temperatures are as follows:

3.2.1 *hold period,* τ_h—, the time interval within a cycle during which the stress or strain is held constant.

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

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

3.2.3 *total cycle period,* τ_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:

$$\tau_t = \sum \tau_h + \sum \tau_{nh} \tag{1}$$

where:

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

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

The following equations are often used to define the instantaneous stress and strain relationships for many metals and alloys:

$$\varepsilon = \varepsilon_{in} + \varepsilon_e \tag{2}$$

$$\varepsilon_e = \frac{\sigma}{E^*} \text{ (see Note 2)}$$

and the change in strain from any point (1) to any other point (3), as illustrated in Fig. 2, can be calculated as follows:

$$\varepsilon_3 - \varepsilon_1 = \left(\varepsilon_{3in} + \frac{\sigma_3}{E^*}\right) - \left(\varepsilon_{1in} + \frac{\sigma_1}{E^*}\right) \tag{3}$$

All strain points to the right of and all stress points above the origin are positive. The equation would then show an increase in inelastic strain from 1 to 3 or:

$$\varepsilon_{3in} - \varepsilon_{1in} = \varepsilon_3 - \varepsilon_1 + \frac{\sigma_1}{E^*} - \frac{\sigma_3}{E^*} \tag{4}$$

Similarly, during the strain hold period, the change in the inelastic strain will be equal to the change in the stress divided by E^*, or:

$$\varepsilon_{3in} - \varepsilon_{2in} = \frac{\sigma_2 - \sigma_3}{E^*} \tag{5}$$

NOTE 2—E^* represents a material parameter that may be a function of environment and test conditions. It also may vary during a test as a result of metallurgical or physical changes in the specimen. In many instances, however, E^* is practically a constant quantity and is used rather extensively in isothermal, constant-rate testing, in the analysis of hysteresis loops. In such cases, a value for E^* can best be determined by cycling the specimen prior to the test at stress or strain levels below the elastic limit. E^* is NOT the monotonic Young's modulus.

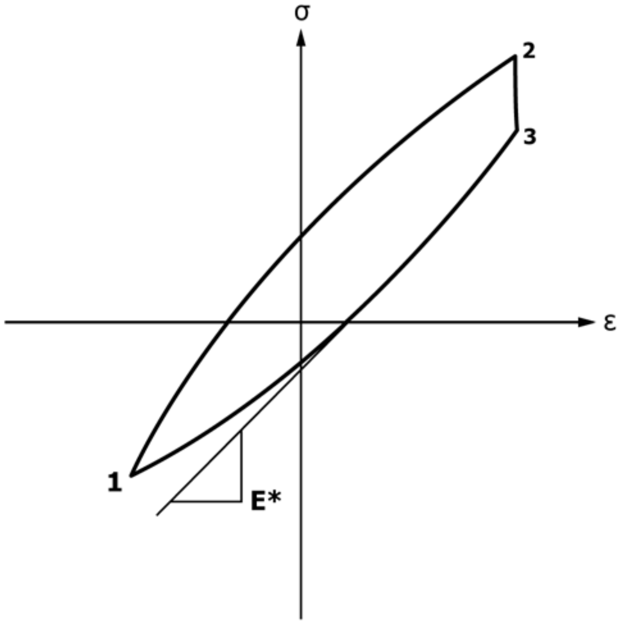


FIG. 2 Analyses of a Total Strain versus Stress Hysteresis Loop Containing a Hold Period

4. Significance and Use

4.1 Strain-controlled fatigue is a phenomenon that is influenced by the same variables that influence force-controlled fatigue. The nature of strain-controlled fatigue imposes distinctive requirements on fatigue testing methods. In particular, cyclic total strain should be measured and cyclic plastic strain should be determined. Furthermore, either of these strains typically is used to establish cyclic limits; total strain usually is controlled throughout the cycle. The uniqueness of this test method and the results it yields are the determination of cyclic stresses and strains at any time during the tests. Differences in strain histories other than constant-amplitude alter fatigue life as compared with the constant amplitude results (for example, periodic overstrains and block or spectrum histories). Likewise, the presence of nonzero mean strains and varying environmental conditions may alter fatigue life as compared with the constant-amplitude, fully reversed fatigue tests. Care must be exercised in analyzing and interpreting data for such cases. In the case of variable amplitude or spectrum strain histories, cycle counting can be performed with Practice E1049.

4.2 Strain-controlled fatigue can be an important consideration in the design of industrial products. It is important for situations in which components or portions of components undergo either mechanically or thermally induced cyclic plastic strains that cause failure within relatively few (that is, approximately $<10^5$) cycles. Information obtained from strain-controlled fatigue testing may be an important element in the establishment of design criteria to protect against component failure by fatigue.

4.3 Strain-controlled fatigue test results are useful in the areas of mechanical design as well as materials research and development, process and quality control, product performance, and failure analysis. Results of a strain-controlled fatigue test program may be used in the formulation of empirical relationships between the cyclic variables of stress, total strain, plastic strain, and fatigue life. They are commonly used in data correlations such as curves of cyclic stress or strain versus life and cyclic stress versus cyclic plastic strain obtained from hysteresis loops at some fraction (often half) of material life. Examination of the cyclic stress–strain curve and its comparison with monotonic stress–strain curves gives useful information regarding the cyclic stability of a material, for example, whether the values of hardness, yield strength, ultimate strength, strain-hardening exponent, and strength coefficient will increase, decrease, or remain unchanged (that is, whether a material will harden, soften, or be stable) because of cyclic plastic straining (**1**).[3] The presence of time-dependent inelastic strains during elevated temperature testing provides the opportunity to study the effects of these strains on fatigue life and on the cyclic stress-strain response of the material. Information about strain rate effects, relaxation behavior, and

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[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.