Designation: E2714 – 09$^{\varepsilon 1}$

Standard Test Method for Creep-Fatigue Testing[1]

This standard is issued under the fixed designation E2714; 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.

ε^1 NOTE—The term "*stress range*" was moved from Definitions Specific to this Standard, 3.4 to Definitions, 3.3 in December 2011.

1. Scope

1.1 This test method covers the determination of mechanical properties pertaining to creep-fatigue deformation or crack formation in nominally homogeneous materials, or both by the use of test specimens subjected to uniaxial forces under isothermal conditions. It concerns fatigue testing at strain rates or with cycles involving sufficiently long hold times to be responsible for the cyclic deformation response and cycles to crack formation to be affected by creep (and oxidation). It is intended as a test method 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. The cyclic conditions responsible for creep-fatigue deformation and cracking vary with material and with temperature for a given material.

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 primarily aimed at providing the material properties required for assessment of defect-free engineering structures containing features that are subject to cyclic loading at temperatures that are sufficiently high to cause creep deformation.

1.4 This test method is applicable to the determination of deformation and crack formation or nucleation properties as a consequence of either constant-amplitude strain-controlled tests or constant-amplitude force-controlled tests. It is primarily concerned with the testing of round bar test specimens subjected to uniaxial loading in either force or strain control. The focus of the procedure is on tests in which creep and fatigue deformation and damage is generated simultaneously within a given cycle. It does not cover block cycle testing in which creep and fatigue damage is generated sequentially. Data that may be determined from creep-fatigue tests performed under conditions in which creep-fatigue deformation and damage is generated simultaneously include *(a)* cyclic stress-strain deformation response *(b)* cyclic creep (or relaxation) deformation response *(c)* cyclic hardening, cyclic softening response *(d)* cycles to formation of a single crack or multiple cracks in test specimens.

NOTE 1—A crack is believed to have formed when it has nucleated and propagated in a specimen that was initially uncracked to a specific size that is detectable by a stated technique. For the purpose of this standard, the formation of a crack is evidenced by a measurable increase in compliance of the specimen or by a size detectable by potential drop technique. Specific details of how to measure cycles to crack formation are described in 9.5.1.

1.5 This test method is applicable to temperatures and strain rates for which the magnitudes of time-dependent inelastic strains (creep) are on the same order or larger than time-independent inelastic

NOTE 2—The term *inelastic* is used herein to refer to all nonelastic strains. The term *plastic* is used herein to refer only to time dependant (that is, non-creep) component of inelastic strain. 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 measurement.

1.6 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E4 Practices for Force Verification of Testing Machines

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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.

E8/E8M Test Methods for Tension Testing of Metallic Materials

E83 Practice for Verification and Classification of Extensometer Systems

E111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus

E139 Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E220 Test Method for Calibration of Thermocouples By Comparison Techniques

E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

E606 Practice for Strain-Controlled Fatigue Testing

E647 Test Method for Measurement of Fatigue Crack Growth Rates

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

E1823 Terminology Relating to Fatigue and Fracture Testing

E2368 Practice for Strain Controlled Thermomechanical Fatigue Testing

2.2 *BSI Standards:*[3]

BS 7270: 2000 Method for Constant Amplitude Strain Controlled Fatigue Testing

BS 1041-4:1992 Temperature measurement – Part 4: Guide to the selection and use of thermocouples

2.3 *CEN Standards:*[4]

EN 60584-1–1996 Thermocouples – Reference tables (IEC 584-1)

EN 60584 -2– 1993 Thermocouples – Tolerances (IEC 584-2)

PrEN 3874–1998 Test methods for metallic materials – constant amplitude force-controlled low cycle fatigue testing

PrEN 3988–1998 Test methods for metallic materials – constant amplitude strain-controlled low cycle fatigue testing

2.4 *ISO Standards:*[5]

ISO 12106–2003 Metallic materials – Fatigue testing - Axial strain-controlled method

ISO 12111–2005 (Draft) Strain-controlled thermo-mechanical fatigue testing method

ISO 7500-1–2004 Metallic materials – Verification of static uniaxial testing machines – Part 1. Tension/compression testing machines – Verification and calibration of the force measuring system

ISO 9513–1999 Metallic materials – Calibration of extensometers used in axial testing

ISO 5725–1994 Accuracy (trueness and precision) of measurement methods

2.5 *JIS Standard:*[6]

JIS Z 2279–1992 Method of high temperature low cycle fatigue testing for metallic materials

3. Terminology

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

3.2 Symbols, standard definitions, and definitions specific to this standard are in 3.2.1, 3.3, and 3.4, respectively.

3.2.1 *Symbols:*

Symbol	Term
d [L]	Diameter of gage section of cylindrical test specimen
D_g, [L]	Diameter of grip ends
N, E, E_o, E_N , [FL^{-2}]	Elastic modulus, initial modulus of elasticity, modulus of elasticity at cycle
E_T, E_C [FL^{-2}]	Tensile modulus, compressive modulus
P [F]	Force
l, l_o [L]	Extensometer gage length, original extensometer gage length
L, L_o, [L]	Length of parallel section of gage length, original length of parallel section of gage length
N, N_f	Cycle number, cycle number to crack formation
r,[L}	Transition radius (from parallel section to grip end)
$\varepsilon_{min} / \varepsilon_{max}$, R_ε	Strain ratio
$\sigma_{min} / \sigma_{max}$, R_σ	Stress ratio
τ	Time
T [θ]	Specimen temperature
T_i [θ]	Indicated specimen temperature
N versus σ_{max}	Crack formation or end-of-life criterion is expressed as a percentage reduction in maximum stress from the cycles, N versus σ_{max} curve when the stress falls sharply (see Fig. 1), or a specific percentage decrease in the modulus of elasticity ratios in the tensile and compressive portions of the hysteresis diagrams, or as a specific increase in crack size as indicated by an electric potential drop monitoring instrumentation.
ε, ε_{max}, ε_{min}	Strain, maximum strain in the cycle, minimum strain in the cycle
ε_{ea}, ε_{pa}, ε_{ta}	Elastic strain amplitude, plastic strain amplitude, total strain amplitude
$\Delta\varepsilon_e$, $\Delta\varepsilon_p$, $\Delta\varepsilon_t$	Elastic strain range, plastic strain range, total strain range (see Fig. 2)
$\Delta\varepsilon_{in}$	Inelastic strain range, (see Fig. 2) is the sum of the plastic strain range and the creep strains during the cycle; it is the distance on the strain axis between points of intersections of the strain axis and the extrapolated linear regions of the hysteresis loops during tensile and compressive unloadings

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[3] Available from British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsi-global.com.

[4] Available from European Committee for Standardization (CEN), 36 rue de Stassart, B-1050, Brussels, Belgium, http://www.cenorm.be.

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

[6] Available from Japanese Standards Organization (JSA), 4-1-24 Akasaka Minato-Ku, Tokyo, 107-8440, Japan, http://www.jsa.or.jp..

σ, σ_{max}, σ_{min}	Stress, maximum stress in the cycle, minimum stress in the cycle
$\Delta\sigma$	Stress range

3.3 *Definitions:*

3.3.1 *cycle*—In fatigue, one complete sequence of values of force (strain) that is repeated under constant amplitude loading (straining)

3.3.2 *hold-time,* τ_h *[T]*—In fatigue testing, the amount of time in the cycle where the controlled test variable (force, strain, displacement) remains constant with time (Fig. 3).

3.3.2.1 *Discussion*—Hold- time(s) are typically placed at peak stress or strain in tension and/or compression, but can also be placed at other positions within the cycle.

3.3.3 *total cycle period,* τ_t *[T],*—The time for completion of one cycle. The parameter τt can be separated into hold and non-hold components (τ_{nh}), where the total cycle time is the sum of the hold time and the non-hold time.

3.3.4 *hysteresis diagram*—The stress-strain path during one cycle (see Fig. 2).

3.3.5 *initial modulus of elasticity,* E_o *,* $[FL^{-2}]$ —The modulus of elasticity determined during the loading portion of the first cycle.

3.3.6 *modulus of elasticity at cycle N,* (E_N, $[FL^{-2}]$ —The average of the modulus of elasticity determined during increasing load portion (see E_c in Fig. 2) and the decreasing load portion (E_T in Fig. 2) of the hysteresis diagram for the N_{th} cycle.

3.3.7 *stress range,* $\Delta\sigma$ *,* $[FL^{-2}]$—The difference between the maximum and minimum stresses.

3.3.7.1 *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" (see Fig. 2b).

3.4 *Definitions:* Definitions of Terms Specific to This Standard:

3.5 *DCPD and ACPD*—Direct current and alternating current electrical potential drop crack monitoring instrumentation.

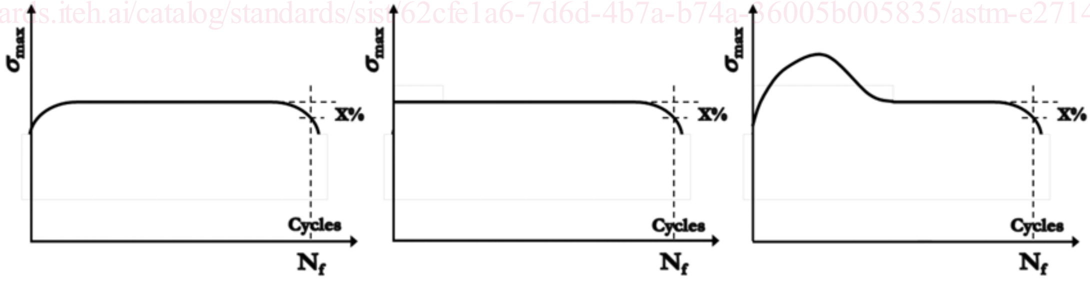
3.6 *homologous temperature*—The specimen temperature in °K divided by the melting point of the material also in °K.

3.7 *crack formation*—A crack is believed to have formed when it has nucleated and propagated in a specimen that was initially un-cracked to a size that is detectable by a stated technique.

4. Significance and Use

4.1 Creep-fatigue testing is typically performed at elevated temperatures and involves the sequential or simultaneous application of the loading conditions necessary to generate cyclic deformation/damage enhanced by creep deformation/damage or vice versa. Unless such tests are performed in vacuum or an inert environment, oxidation can also be responsible for important interaction effects relating to damage accumulation. The purpose of creep-fatigue tests can be to

(a) For materials with stable or steady-state behavior after hardening



(b) For materials with continuous softening

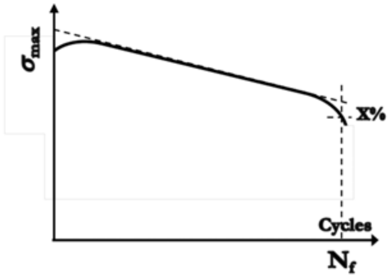


FIG. 1 Crack Formation and End-of-Test Criterion based on Reduction of Peak Stress for (a) Hardening and (b) Softening Materials

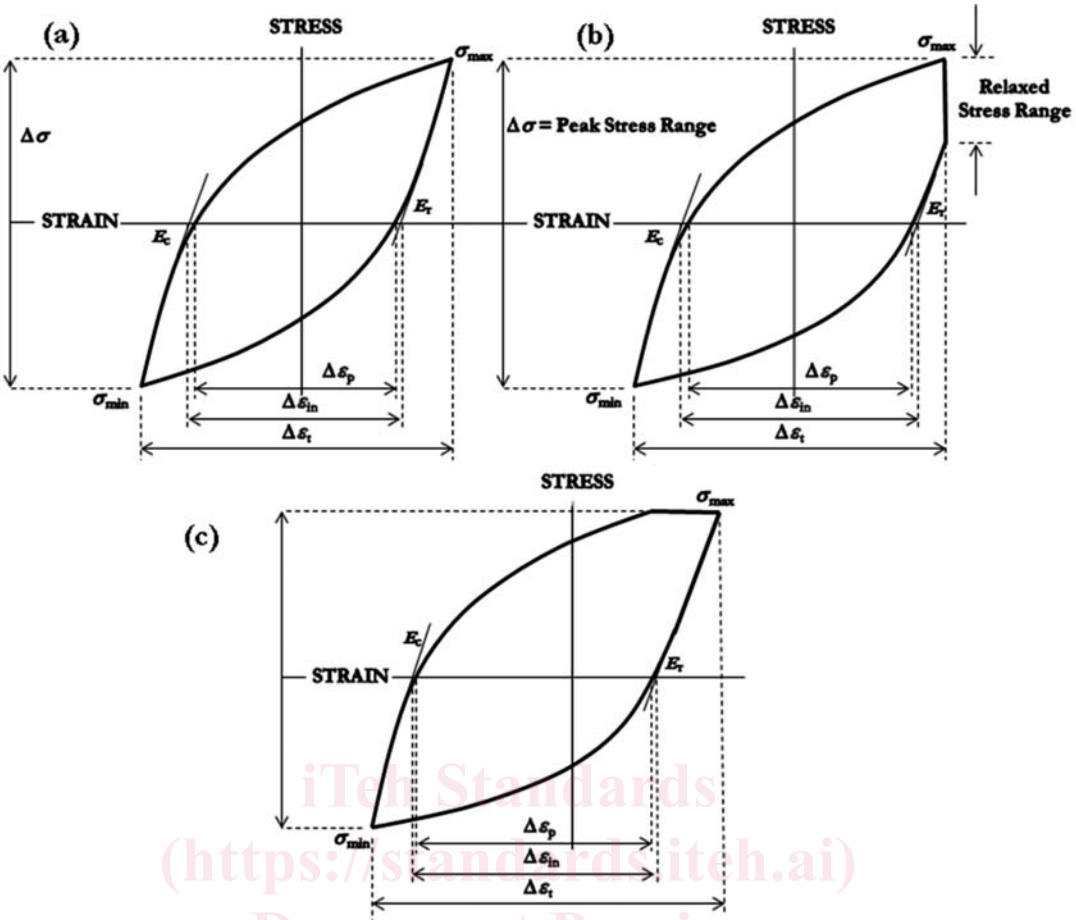


FIG. 2 Examples of Stress-Strain Hysteresis Diagrams (a) Without Hold Time, (b) With Hold Time (Strain Control), (c) With Hold Time (Force Control), see 3.2.1 for list of symbols.

determine material property data for *(a)* assessment input data for the deformation and damage condition analysis of engineering structures operating at elevated temperatures *(b)* the verification of constitutive deformation and damage model effectiveness *(c)* material characterization, or *(d)* development and verification of rules for new construction and life assessment of high-temperature components subject to cyclic service with low frequencies or with periods of steady operation, or both.

4.2 In every case, it is advisable to have complementary continuous cycling fatigue data (gathered at the same strain/loading rate) and creep data determined from test conducted as per Practice E139 for the same material and test temperature(s). The procedure is primarily concerned with the testing of round bar test specimens subjected (at least remotely) to uniaxial loading in either force or strain control. The focus of the procedure is on tests in which creep and fatigue deformation and damage is generated simultaneously within a given cycle. Data which may be determined from creep-fatigue tests performed under such conditions may characterize *(a)* cyclic stress-strain deformation response *(b)* cyclic creep (or relaxation) deformation response *(c)* cyclic hardening, cyclic softening response or (d) cycles to crack formation, or both.

4.3 While there are a number of testing Standards and Codes of Practice that cover the determination of low cycle fatigue deformation and cycles to crack initiation properties (See Practice E606, BS 7270: 2000, JIS Z 2279–1992, PrEN 3874, 1998, PrEN 3988–1998, ISO 12106–2003, ISO 12111–2005, and Practice E2368-04 and (**1, 2, 3**)[7], some of which provide guidance for testing at high temperature (for example, Practice E606, ISO 12106–2003, and Practice E2368-04, there is no single standard which specifically prescribes a procedure for creep-fatigue testing.

5. Functional Relationships

5.1 Empirical relationships that have been commonly used for description of creep-fatigue data are given in Appendix X1. These relationships typically have limitations with respect to material types such as high temperature ferritic and austenitic steels versus nickel base alloys. Therefore, original data should be reported to the greatest extent possible. Data reduction methods should be detailed along with assumptions. Sufficient information should be recorded and reported to permit analysis, interpretation, and comparison with results for other materials analyzed using currently popular methods.

6. Apparatus

6.1 *Test machines:*

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

(a) Low frequency triangular wave form

(b) Saw-tooth triangular wave form

(c) Cycle with hold time at control parameter peak in tension

(d) Cycle with hold time at intermedia position of control parameter

(e) Cycle with hold times at control parameters peaks in tension and compression

(f) Cycle with varying rates of the control parameter

FIG. 3 Example of Creep-Fatigue Cycle Shapes

6.1.1 Tests shall be conducted using a servo-controlled tension-compression fatigue machine that has been verified in accordance with ISO 7500-1–2004 or Practices E4-03 and E467-04. Hydraulic and electromechanical machines are acceptable. The testing machine shall have been designed for smooth start-up without any backlash when passing through zero force. It shall possess a high degree of lateral stiffness to maintain accurate alignment during compression loading suitable for meeting the requirements described in section 6.3.

6.1.2 The complete loading system comprising of the force transducer, loading grips and test specimen shall have great lateral rigidity to meet requirements specified in 6.3. Further, it must be capable of executing the prescribed cycle in either strain or force control. The control stability should be such that the maximum and minimum limits of the control variable are maintained within 1% of its range.

6.2 *Force transducer:*

6.2.1 The force transducer and its associated electronics shall comply with ISO 7500-1–2004. Alternatively, the force transducer calibration should be verified in accordance with Practices E4-03 and Practice E467-04 .

6.2.2 The force transducer shall be designed for tension-compression fatigue testing and shall have high axial and lateral rigidity to meet the requirements specified in 6.3. Its capacity shall be sufficient to measure the axial forces applied during the test to accuracies better than 1% of the reading.

6.2.3 The force transducer shall be temperature compensated and not have zero drift nor sensitivity variation greater than 0.002% of the full scale per °C (See Practice E606). During test, the force transducer shall be maintained at a temperature within its temperature compensation range specified by the manufacturer.

6.3 *Loading Grips:*

6.3.1 To minimize bending strains or in other words to ensure uniform axial strain throughout the gage section of the specimen, test specimen fixtures should be aligned such that the major axis of the test specimen closely coincides with the force axis throughout each cycle. It is important that the accuracy of alignment be kept consistent from specimen to specimen. Alignment should be checked by means of a trial test diameter. The trial test specimen should be turned about its axis, installed, and checked for each of four orientations within the fixtures. The maximum bending strains so determined must not exceed 5% of the minimum axial strain range imposed during any test program for all four orientations.

NOTE 3—For specimens with uniform gage length, it is good practice to also place similar set of gages at one or two additional axial positions within the gage section. In such cases, one set of strain gages should be placed at the center of the gage length to detect misalignment that causes relative rotation of the specimen ends about axes perpendicular to the specimen axis. The additional set of gages should be placed away from the gage length center to detect relative lateral displacement of the specimen ends. The more uniform the axial strain and lower the bending strain, the more repeatable the test results will be from specimen to specimen.

6.3.2 The loading train should incorporate cooling arrangements to limit heat transfer from the hot zone to the testing machine and in particular the force transducer. The zero point and sensitivity of force transducers are subject to thermal drift and may be permanently damaged by temperatures in excess of 50°C. Suitable cooling arrangements include forced air cooling of fins at the outer ends of the loading bars or water cooling coils or jackets. Care should be taken to ensure that force transducer calibration and load train alignment are not affected by the presence of the cooling devices.

6.3.3 The loading bars incorporate grips to locate the test specimen and these should satisfy certain basic design requirements arising directly from the need for tension-compression loading without lost motion through zero force at the test specimen/grip interface(**4, 5, 6**) and Practice E1012-99. To achieve this, the design should provide the following basic features, *(a)* a loading surface through which the load in one direction will be transmitted *(b)* a surface ensuring alignment of the test specimen axis *(c)* a second loading surface through which the load in the reverse direction is transmitted *(d)* an arrangement maintaining the loading surfaces in contact with the specimen, whatever the state of loading, within the working range of the design. Common loading train misalignment problems that can lead to specimen bending are shown in Fig. 4 and must be avoided.

6.4 *Extensometer:*

6.4.1 The extensometer used shall be suitable for measuring dynamic displacements over long periods during which there shall be minimal drift, slippage and instrument hysteresis. Extensometers used for measurement and to control deformation in the test specimen gage section shall be suitable for dynamic measurements over periods of time, that is, should have a rapid response and with a low hysteresis (not greater than 0.1% of extensometer output). Strain gage or LVDT type transducers are generally used and should be calibrated according to Practice E83-02 and, ISO 9513–1999. Suitable extensometers that meet these requirements are those that are Grade B2 or better as specified by Practice E83-02 or Class 0.5 or better as specified by ISO 9513–1999.

6.4.2 Extensometers for parallel gage section test specimens shall measure longitudinal extension. A side-entry contacting extensometer with rounded contact edges is recommended for the purpose. These usually employ light spring pressure to maintain contact between the probes and the test specimen surface and in such circumstances, the extensometer body should be independently supported to minimize the forces between the probe tips and the test specimen surface (see Note 4).

NOTE 4—If specimens with ridges are used for characterizing cycles to crack formation, the tests should be considered invalid if cracking is limited only to the regions near the ridges. This configuration is more desirable when the purpose of the test is only to determine cyclic deformation properties.

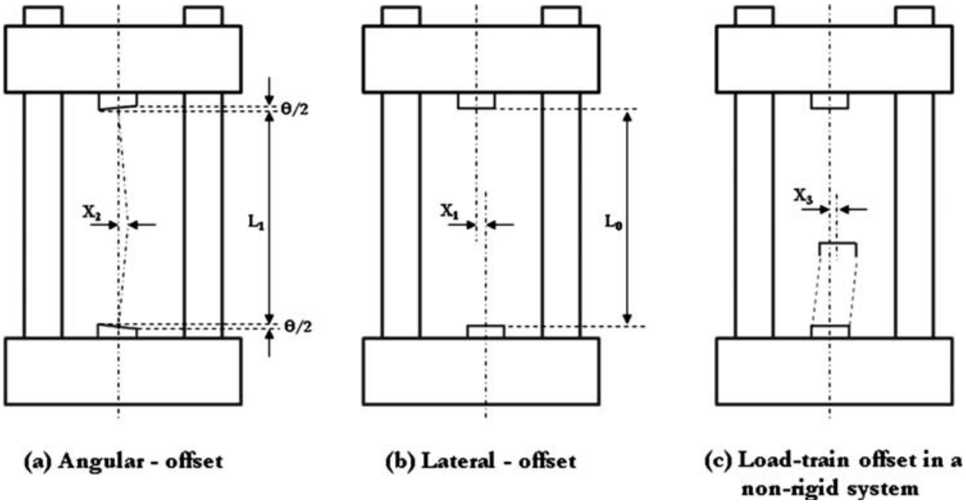
6.4.3 For hour-glass profiled test specimens, an extensometer measuring diametral deformation may be used such that the extensometer tips contact the test specimens across the minimum diameter. The extensometer should be supported and counterbalanced and should be adjusted to minimize the contact force imposed on the test specimen to prevent notching.

NOTE 5—The repeatability and sensitivity of diametral extensometers are significantly lower than those for axial extensometers and are not recommended as an alternative means of strain control in creep-fatigue tests when the use of an axial extensometer is feasible.

6.5 *Crack Monitoring:*

6.5.1 A direct current (DCPD) or alternating current (ACPD) electrical potential-drop crack monitoring system as per Practice E647 may be used in certain circumstances to determine crack formation in parallel gage section test specimens, although this is not required.

NOTE 6—The test specimen (or loading grips) should be electrically insulated from the test machine loading frame and ancillary equipment in order to avoid unstable potential drop recordings associated with electrical ground loops.



(a) Angular - offset

(b) Lateral - offset

(c) Load-train offset in a non-rigid system

FIG. 4 Bending Mechanisms Due to Misalignment in Fatigue Test Systems