



Designation: E2714 – 13 (Reapproved 2020)

Standard Test Method for Creep-Fatigue Testing¹

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.

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 strain.

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 independent (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 $1 \times 10^{-3} \text{ sec}^{-1}$ is often used for this purpose. This value should increase with increasing test temperature.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

- 2.1 *ASTM Standards:*²
[E4 Practices for Force Verification of Testing Machines](#)

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 for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples
- E467** Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
- E606** Test Method for Strain-Controlled Fatigue Testing
- E647** Test Method for Measurement of Fatigue Crack Growth Rates
- E691** Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
- 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 2770: 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
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)
$\epsilon_{min} / \epsilon_{max}$, 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

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>.

$\Delta\epsilon_e, \Delta\epsilon_p, \Delta\epsilon_t$	Elastic strain range, plastic strain range, total strain range (see Fig. 2)
$\Delta\epsilon_{in}$	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
$\sigma, \sigma_{max}, \sigma_{min}$	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 τ_t can be separated into hold (τ_h) and non-hold (τ_{nh}) (that is, steady and dynamic) components, 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).

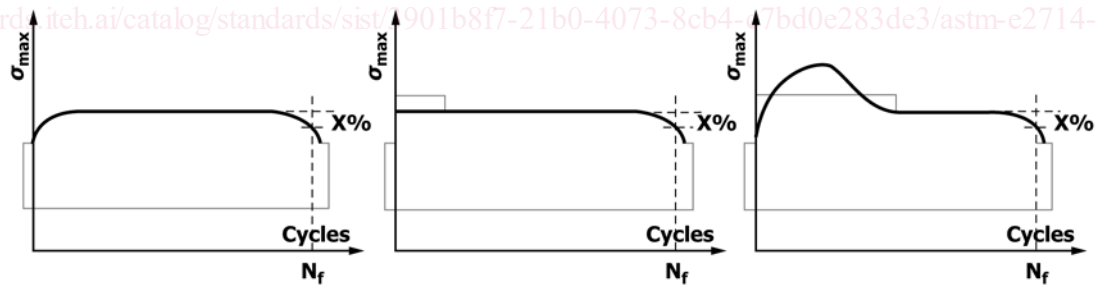
3.4 Definitions of Terms Specific to This Standard:

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

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

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

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



(b) For materials with continuous softening

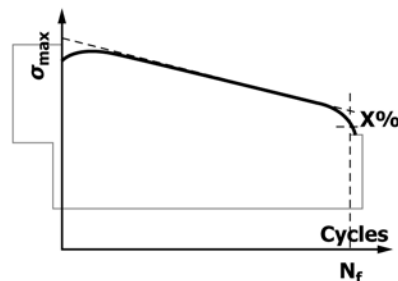


FIG. 1 Crack Formation and End-of-Test Criterion based on Reduction of Peak Stress for (a) Hardening and (b) Softening Materials

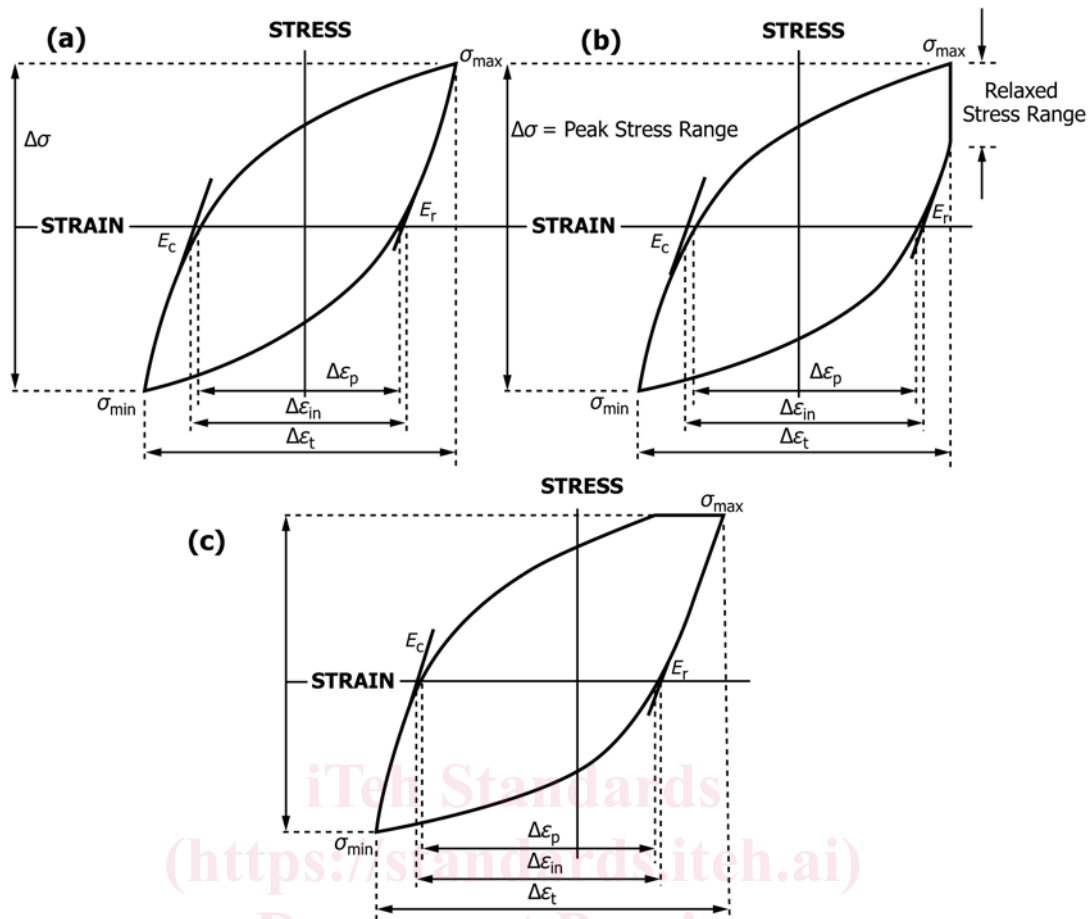


FIG. 2 Examples of Stress-Strain Hysteresis Diagrams (a) Without Hold Time, (b) With Hold Time (Strain Control), (c) With Hold Time (Force Control), see 3.2.1 for list of symbols.

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 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.

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

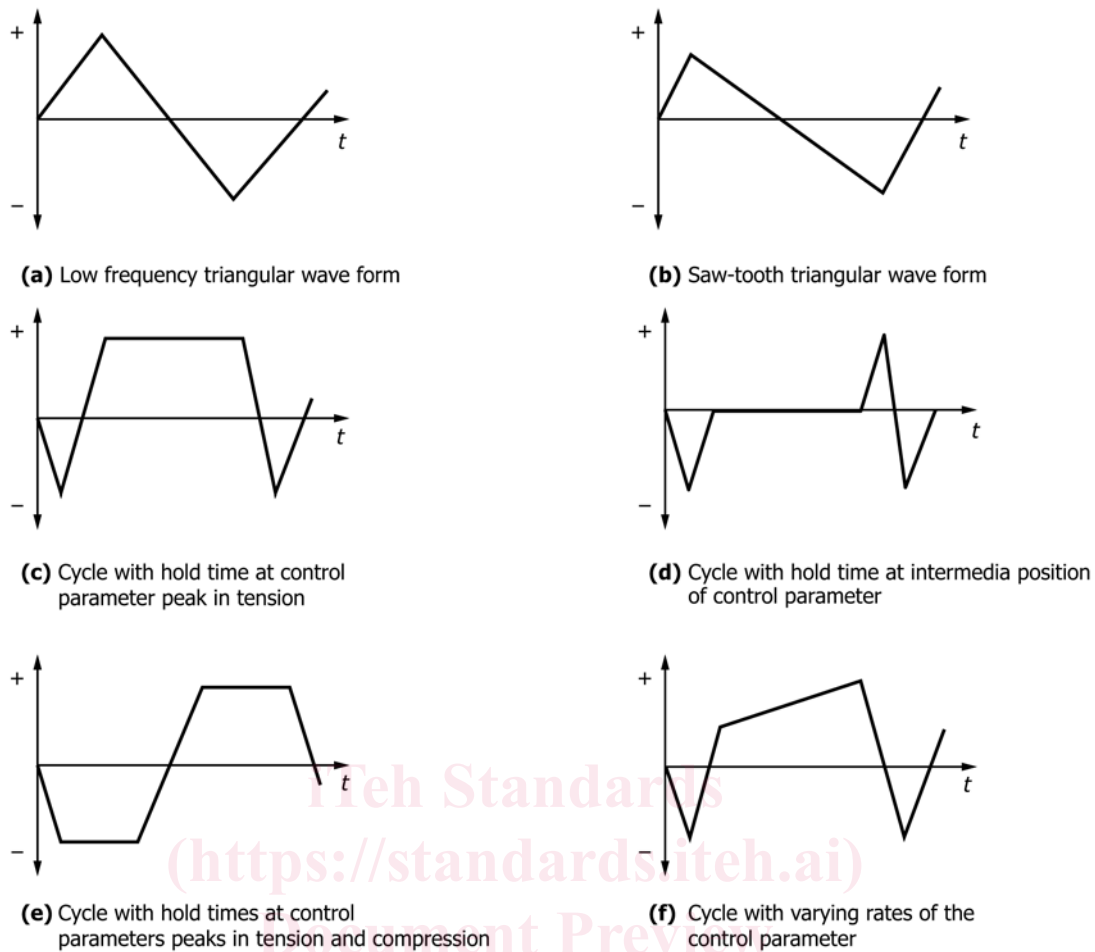


FIG. 3 Example of Creep-Fatigue Cycle Shapes

ASTM E2714-13(2020)

<https://standards.iteh.ai/catalog/standards/sist/3901b8f7-21b0-4073-8cb4-c7bd0e283de3/astm-e2714-132020>

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:

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 [E606-12](#)). 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 E1012-12. 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

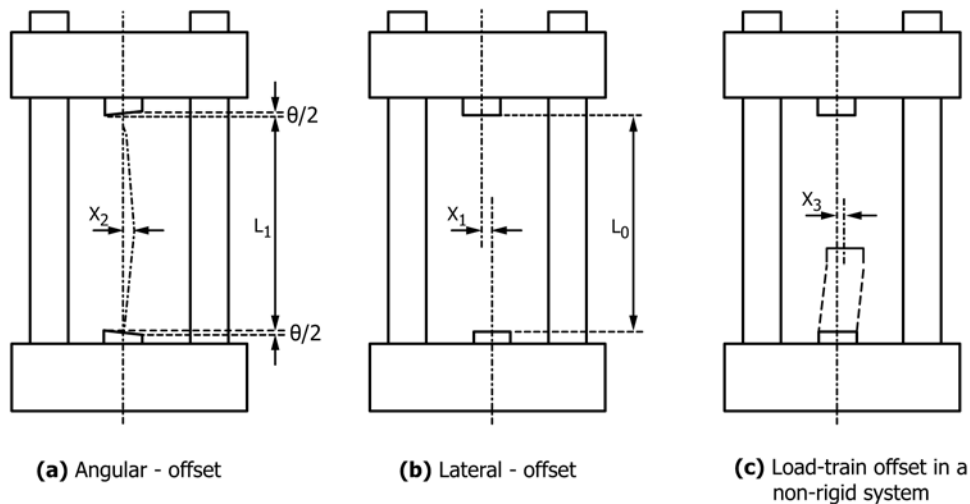


FIG. 4 Bending Mechanisms Due to Misalignment in Fatigue Test Systems

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.

6.5.2 The DCPD or ACPD system should be capable of reliably resolving crack extensions of at least ± 0.1 mm along the specimen surface as well as along the crack depth at the test temperature.

6.5.3 The use of multiple charged couple device (CCD) cameras placed around the test specimen is an alternative technique for observing crack development when induction heating is employed.

6.6 Heating System:

6.6.1 Heating methods used to achieve elevated temperature include (a) resistance furnace heating (b) radiant furnace heating (c) induction heating (see Note 7), or (d) inert gas or liquid heating. The heating device shall be such that the test specimen can be uniformly heated to the specified temperature, with an indicated temperature gradient across the gage section that is less than or equal to the greater of 2°C or 1 percent of the nominal test temperature throughout the duration of the test. A resistance furnace with three individually controlled heating zones provides a good solution for isothermal creep-fatigue testing.

NOTE 7—For induction heating, the choice radio frequency (RF) generator frequency depends on the specimen diameter. It is advisable to select a RF generator with a sufficiently low frequency such as less than 10 kHz to prevent “skin heating effects” when testing large diameter specimens (greater than 20 mm). For majority of testing, suitable RF frequencies range between 70 kHz and 400 kHz. Caution should be exercised when using RF heating while testing ferritic steels. There is evidence that RF heating in ferromagnetic materials may yield longer creep fatigue lives in comparison to resistance heating. (7)

6.6.2 The heating system shall be protected from draughts to avoid undesirable gradients and fluctuations in temperature and the controlled temperature must be maintained within $\pm 2^\circ\text{C}$ throughout the duration of the test.

6.7 Temperature Measurement:

6.7.1 Test specimen temperature shall be measured using thermocouples in contact with the test specimen surface, or by means of other suitable sensors, for example, optical pyrometers that have been calibrated using a trial test specimen equipped with thermocouples and shown to be the same or better than thermocouples. In all cases involving the use of thermocouples, it is essential to ensure that intimate thermal

contact is achieved between test specimen and thermocouple without scratching the gage portion of the test specimen. When using furnace heating, thermocouple beads shall be shielded from direct radiation.

NOTE 8—Optical pyrometers are not recommended for test specimen temperature measurement when the test material is prone to oxidation without the use of supportive observations from thermocouples attached to test specimen shoulders.

6.7.2 When using induction heating, each leg of the thermocouple should be spot-welded 180 degrees around the shoulder of the test specimen from the other leg so that the specimen itself becomes the thermocouple junction (bead). If stress-strain behavior only is to be measured then a thermocouple location on the gage section is acceptable. Calibration and use of methods of temperature measurement shall be carried out according to Test Method E220-02 and Specification E230-03, ISO 9513-1999 or EN 60584-1-1996, EN 60584-2-1993 and BS 1041-4:1992.

NOTE 9—The use of rare metal thermocouples, preferentially Type R or S is recommended for use at temperatures above 400 °C.

NOTE 10—The use of Type K thermocouples above 400 °C is recommended with the following caveat. They may be used only for short duration tests (<500h) at temperatures up to 600 °C. Type N thermocouples may be used for short duration tests (<500h) at temperatures up to 800 °C

6.8 Cycle Counter:

6.8.1 Standard practice should be to record all cycles in a data acquisition system. As a minimum, a digital device should be used to record the number of cycles applied to the test specimen. Five digits are required, thus, for tests lasting less than 10 000 cycles, individual cycles shall be counted. For longer tests, the device shall have a resolution better than 1% of the actual life.

6.9 Data recording:

6.9.1 An automatic digital recording system should be used which is capable of collecting and simultaneously processing the force, displacement and temperature data as a function of time and cycles. The sampling frequency of force-displacement-time data shall be sufficient to ensure correct definition of the hysteresis loop and hold time transient(s). In particular, it should be sufficient to identify values of force and extension at turning points in the hysteresis loop, for example, at cycle maxima and minima, and start and end of hold-time values.

NOTE 11—Adequate number of data points (50 to 200) should be collected to define the hysteresis loop, and additional points (50-200 data points should be collected to fully characterize hold-time transients. Obtaining reliable deformation data from the loading portion of the hysteresis loop generally requires approximately 200 data points.

NOTE 12—The simultaneous recording of stroke position is also recommended to assist in the retrospective diagnosis of disturbances during test, for example, extensometer slippage.

6.9.2 X-Y recordings may instead be used for the purpose of recording force-displacement hysteresis loops. A potentiometric X-Y recorder, or an oscilloscope equipped with a camera are acceptable alternatives. In addition, recorders should be used to monitor force, displacement and temperature as a function of time. This information is required particularly to