



Designation: G129 – 21

Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking¹

This standard is issued under the fixed designation G129; 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 practice covers procedures for the design, preparation, and use of axially loaded, tension test specimens and fatigue pre-cracked (fracture mechanics) specimens for use in slow strain rate (SSR) tests to investigate the resistance of metallic materials to environmentally assisted cracking (EAC). While some investigators utilize SSR test techniques in combination with cyclic or fatigue loading, no attempt has been made to incorporate such techniques into this practice.

1.2 Slow strain rate testing is applicable to the evaluation of a wide variety of metallic materials in test environments which simulate aqueous, nonaqueous, and gaseous service environments over a wide range of temperatures and pressures that may cause EAC of susceptible materials.

1.3 The primary use of this practice is to furnish accepted procedures for the accelerated testing of the resistance of metallic materials to EAC under various environmental conditions. In many cases, the initiation of EAC is accelerated through the application of a dynamic strain in the gauge section or at a notch tip or crack tip, or both, of a specimen. Due to the accelerated nature of this test, the results are not intended to necessarily represent service performance, but rather to provide a basis for screening, for detection of an environmental interaction with a material, and for comparative evaluation of the effects of metallurgical and environmental variables on sensitivity to known environmental cracking problems.

1.4 Further information on SSR test methods is available in ISO 7539 and in the references provided with this practice (1-6).²

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

¹ This practice is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.06 on Environmentally Assisted Cracking.

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² The boldface numbers in parentheses refer to a list of references at the end of this standard.

1.6 *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.* Furthermore, in some cases, special facilities will be required to isolate these tests from laboratory personnel if high pressures or toxic chemical environments, or both, are utilized in SSR testing.

1.7 *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:³

- A370 Test Methods and Definitions for Mechanical Testing of Steel Products
- B557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products
- D1193 Specification for Reagent Water
- E4 Practices for Force Verification of Testing Machines
- E6 Terminology Relating to Methods of Mechanical Testing
- E8/E8M Test Methods for Tension Testing of Metallic Materials
- E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials
- E602 Test Method for Sharp-Notch Tension Testing with Cylindrical Specimens (Withdrawn 2010)⁴
- E616 Terminology Relating to Fracture Testing (Withdrawn 1996)⁴
- E647 Test Method for Measurement of Fatigue Crack Growth Rates

³ 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.

⁴ The last approved version of this historical standard is referenced on www.astm.org.

E1681 Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials

G49 Practice for Preparation and Use of Direct Tension Stress-Corrosion Test Specimens

G111 Guide for Corrosion Tests in High Temperature or High Pressure Environment, or Both

G142 Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both

G193 Terminology and Acronyms Relating to Corrosion

2.2 *ISO Standard*.⁵

ISO 7539 Part 7, Slow Strain Rate Testing

the definitions given in Terminologies **E6**, **E616**, and **G193** shall apply to the terms used in this practice.

4. Summary of Practice

4.1 This practice describes the use of tension and fatigue pre-cracked specimens for the determination of resistance to EAC of metallic materials. The procedure involves the application of very slow strain rates, which are achieved by a constant extension rate on the specimen while monitoring load and extension of the specimen. The SSR test always produces fracture of the test specimen. Typically, the results from tests conducted in the test environment are compared to corresponding test results for the same material in a control environment. The degree of susceptibility to EAC is generally assessed through observation of the differences in the behavior of the material in tests conducted in a test environment from that obtained from tests conducted in the control environment. For smooth tension specimens, either changes in time-to-failure, or specimen ductility, or visual indications of EAC, or often some combination of these methods, are utilized in determining susceptibility to EAC. For notched tension specimens, changes in the notch tensile strength and visual indications of EAC on the primary fracture surface are used in determining susceptibility to EAC. For fatigue pre-cracked specimens, changes in the threshold stress intensity factor and visual indications of EAC on the primary fracture surface are used in determining susceptibility to EAC.

5. Significance and Use

5.1 The slow strain rate test is used for relatively rapid screening or comparative evaluation, or both, of environmental, processing or metallurgical variables, or both, that can affect the resistance of a material to EAC. For example, this testing technique has been used to evaluate materials, heat treatments, chemical constituents in the environment, and temperature and chemical inhibitors.

5.2 Where possible, the application of the SSR test and data derived from its use should be used in combination with service experience or long-term EAC data, or both, obtained through literature sources or additional testing using other testing techniques. In applications where there has been little or no prior experience with SSR testing or little EAC data on the particular material/environment combination of interest, the following steps are recommended:

5.2.1 The SSR tests should be conducted over a range of applied extension rates (that is, usually at least one order of magnitude in applied extension rate above and below 10^{-6} in./s (2.54×10^{-5} mm/s) to determine the effect of strain rate or rate of increase of the stress or stress intensity factor on susceptibility to EAC.

5.2.2 Constant load or strain EAC tests should also be conducted in simulated service environments, and service experience should be obtained so that a correlation between SSR test results and anticipated service performance can be developed.

5.3 In many cases the SSR test has been found to be a conservative test for EAC. Therefore, it may produce failures in the laboratory under conditions which do not necessarily

3. Terminology

3.1 For purposes of this practice the following terms are defined:

3.2 *control environment*—an environment in which SSR specimens are tested that has been shown not to cause EAC or excessive corrosion of the material. The results of tests conducted in this environment may be used as a basis for comparison with corresponding tests conducted in the test environment(s), usually at the same temperature as the test environment.

3.3 *environmentally assisted cracking (EAC)*—cracking of a material caused by the combined effects of stress and the surrounding environment, for example, stress corrosion cracking, hydrogen embrittlement cracking, sulfide stress cracking and liquid metal embrittlement.

3.4 *slow strain rate (SSR)*—a dynamic slowly increasing strain imposed by an external means on the gauge section or notch tip of a uniaxial tension specimen or crack tip of a fatigue pre-cracked specimen for purposes of materials evaluation. The strain rate for a plain or smooth specimen (given in units of extension divided by the gauge length per unit time) or the strain rate at a notch tip of a notched tension specimen or crack tip of a fatigue pre-cracked specimen is applied through the application of a slow constant extension rate (given in units of extension per unit time). The slow constant extension rate produces a gauge section strain rate, which is usually in the range from $10^{-4}/s^{-1}$ to $10^{-7}/s^{-1}$. Rigorous analytical solutions of the local strain rate at a notch tip of a tension specimen or at a crack tip of a fatigue pre-cracked specimen are not available. The average or local strain rate should be slow enough to allow time for certain corrosion processes to take place, but fast enough to produce failure or cracking of the specimen in a reasonable period of time for evaluation purposes. In cases where extremely slow strain rates are being utilized (that is, $10^{-7}/s^{-1}$ to $10^{-8}/s^{-1}$ for smooth tension specimens), an interrupted SSR test can be employed whereby the specimen is strained into the plastic range at the intended strain rate followed by more rapid straining to failure.

3.5 The terminology found in Test Methods and Definitions **A370**, Test Methods **B557**, and Test Method **E602** along with

⁵ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

cause EAC under service application. Additionally, in some limited cases, EAC indications are not found in smooth tension SSR tests even when service failures have been observed. This effect usually occurs when there is a delay in the initiation of localized corrosion processes. Therefore, the suggestions given in 5.2 are strongly encouraged.

5.4 In some cases, EAC will only occur in a specific range of strain rates. Therefore, where there is little prior information available, tests should be conducted over a range of strain rates as discussed in 5.2.

6. Apparatus

6.1 Testing Machines:

6.1.1 Tension testing machines used for SSR testing shall conform to the requirements of Practices E4.

6.1.2 The loads used in SSR testing shall be within the calibrated load ranges of the testing machine in accordance with Practices E4.

6.1.3 The testing machines used for SSR testing shall be capable of accurate application of extension rates in the range of interest for evaluation of EAC. These extension rates are usually between 10^{-4} in./s and 10^{-7} in./s (2.54×10^{-3} mm/s and 2.54×10^{-6} mm/s).

6.1.4 An example of a SSR testing machine setup including the load frame, instrumentation, and local test cell is shown in Fig. 1. Another example of a SSR machine setup with a metal test cell or autoclave can be found in Test Method G142. The test specimen is loaded with a grip assembly and load frame inside the autoclave. The autoclave is equipped with a tensile loading feed-through to provide transmission of loads from the tensile machine to the specimen using a pull rod in combination with the feed-through. Some SSR testing machines may be able to test more than one specimen at a time in a particular environment. However, this type of machine should only be used if it can be shown that failure of one or multiple specimens does not influence the behavior of the other specimens.

6.2 *Gripping Devices*—The types of gripping devices that may be used to transmit the applied load from the testing machine to the tension specimen conform to those described in Test Methods E8/E8M. Alignment procedures are provided in Test Methods E8/E8M.

6.3 *Clevises and Fixtures*—A loading clevis that is suitable for loading pre-cracked compact specimens should conform with clevises described in Test Method E399. A bend test fixture for loading pre-cracked bend specimens should conform with bend fixtures described in Test Method E399. It is important that attention be given to achieving good load train alignment through careful machining of all clevises and fixtures.

6.4 *Displacement Gauges*—An electronic crack mouth opening displacement (CMOD) gauge attached to the front face of pre-cracked specimens and spanning the crack starter notch to detect crack growth during testing should be in accordance with displacement gauges described in Test Method E399. Alternatively, the displacements can be transferred outside the environmental test cell in the case of tests

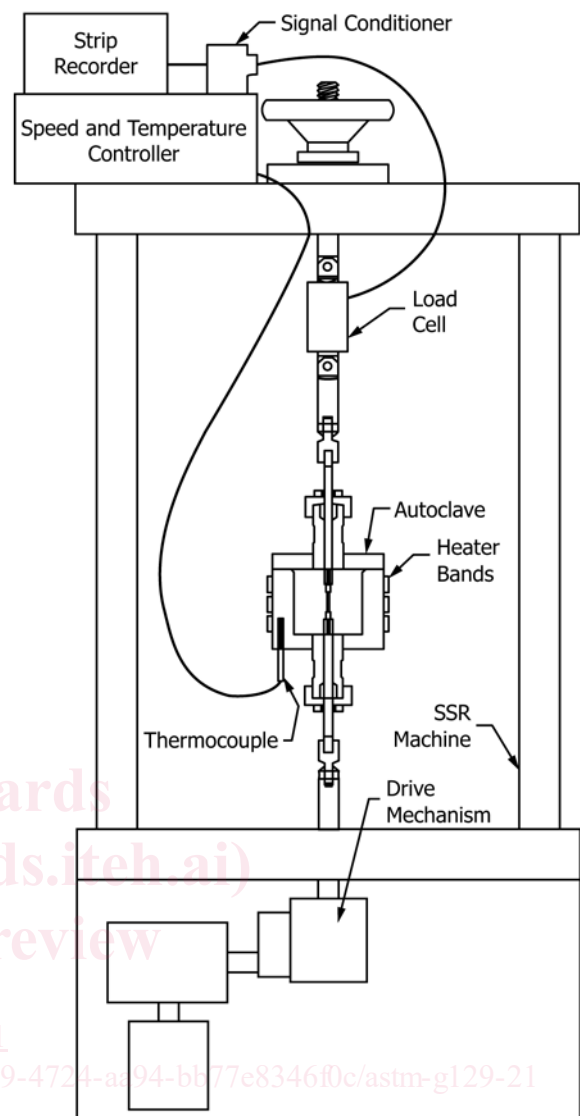


FIG. 1 An Example of SSR Testing Machine

conducted in high temperature or severely corrosive environments. An extensometer placed outside the test cell can be used to detect the crack growth. A displacement gauge can be attached to the specimen at alternative locations to detect crack growth if the proper compliance-crack length relationship has been determined for the measurement location on the specimen.

6.5 *Environmental Test Cells*—Test cells shall be constructed in a manner to facilitate handling and monitoring of the test environment while allowing testing of the tension specimen. This will require the incorporation of a suitable low-friction feed-through in the vessel for application of load to the test specimen. Additionally, the test cell shall be able to safely contain the test environment with adequate accommodation for the temperature and pressure under which the SSR tests will be conducted.

6.5.1 Test cells shall be effectively inert (that is, have a low corrosion rate and not susceptible to EAC in the test environment so that they do not react with or contaminate the environment).

6.5.2 The test cell size should be such that a solution volume-to-exposed specimen surface area is not less than 30 mL/cm².

6.6 *Galvanic Effects*—Eliminate galvanic effects between the test specimen and various metallic components of the gripping fixtures and test cell by electrically insulating or isolating these components unless it is specifically desired to simulate galvanic interactions found in service conditions and their effects on EAC. Check electrical isolation with an ohmmeter, if required, prior to testing. It should be noted that, in some cases, electrical insulation may be bridged by deposits of conductive or semiconductive solid corrosion products during the test, thereby introducing galvanic effects into the SSR test.

7. Reagents

7.1 As is the case with most types of corrosion testing, it is necessary to provide a reproducible chemical environment so that consistent test results can be obtained. This is particularly true in the evaluation for EAC of metallic materials. Therefore, where a test environment is being established from laboratory chemicals, chemicals of reagent grade purity with known contaminant levels are recommended.

7.1.1 When aqueous test environments are being prepared, only distilled or deionized water described in Specification D1193 (Type IV) should be used.

7.2 In some cases, it is also necessary to conduct SSR tests in actual service environments *in situ*, in retrieved samples of service environments, or in simulations of service environments.

7.3 When conducting SSR tests, the chemical nature of the test environment should be characterized with respect to its chemical composition, impurity content, and other necessary information to characterize the possible role of its constituents on EAC behavior.

8. Test Specimens

8.1 The tension specimens used for EAC evaluation with the SSR test should conform to the dimensions and guidelines provided in Test Methods E8/E8M. However, in some cases, the material size, configuration and form, or the confines of various environmental test cells may limit the actual dimensions of the test specimens. In such cases, where non-standard specimens must be utilized, the specimen geometry and dimensions shall be fully described. Care should be taken to only compare the results obtained from specimens with similar geometries.

8.2 In most cases, subsize tension specimens are utilized for SSR tests. Therefore, extreme care must be taken in machining these specimens and surface finish is extremely critical to SSR test results.

8.2.1 To produce tension specimens which have surfaces with minimal cold working, it is recommended that the total metal removed in the last two machining passes be limited to a total of 0.05 mm and have a surface finish of 0.25 μm (10 μin.) rms or better. The method of final machining of the gauge section should be by grinding (not turning) to com-

pletely avoid localized grooves and cold-worked areas. Special care should be taken to machine specimens with minimum run-out to minimize bending stresses during testing.

8.3 In some cases, notched tension test specimens have been used (1) to localize the failure in regions of microstructural interest such as welds or heat-affected zones, (2) to induce local crevice sites for acceleration of EAC or (3) to accelerate hydrogen entry into the specimen due to high hydrostatic stresses for acceleration of hydrogen embrittlement or sulfide stress cracking. In addition, notched tension specimens have been used in SSR tests to provide an estimate of the threshold stress intensity factor for EAC (3). In using such specimens, it is important to conduct the control environment tests using the same specimen geometry and design.

8.4 With the exception of the procedures for minimization of the effects of cold working as given in 8.2.1, the tension specimens should be prepared for testing in accordance with procedures specified in Practice G49 and Test Methods E8/E8M.

8.5 The fatigue pre-cracked specimens used for EAC evaluation with the SSR test should conform to the size requirements and guidelines developed for plane strain conditions in Test Method E399 or the size requirements for predominately linear elastic conditions as stated in Test Method E647. However, in some cases, the material size, configuration, and form, or the confines of various environmental test cells, may limit the actual dimensions of the test specimens. In such cases, where non-standard specimens must be utilized, the specimen geometry and dimensions shall be fully described. Care should be taken to only compare the results obtained from specimens with similar configurations.

8.5.1 The dimensional tolerances and surface finishes should be according to Test Method E399.

8.5.2 Low stress fatigue pre-cracking should be conducted in accordance with procedures in Test Method E1681.

8.5.3 Side-grooved specimens may be used to increase the through-thickness constraint of the specimen and promote straight fronted crack growth with some materials and some environments. This may be desirable if crack growth rate information is to be obtained. The depth of the side-grooves for a particular material can be found by trial and error, however, a total thickness reduction of 20 % has been found to be effective for many materials. Any angle of side groove less than 90° is acceptable and the root radius should be less than 0.4 mm (0.016 in.). It may be necessary to fatigue pre-crack the specimens before side-grooving in order to produce nearly-straight pre-crack fronts. The user should exercise caution when using side-grooved specimens in aggressive environments.

8.6 The test specimen should be degreased and cleaned prior to testing. In the case of fatigue pre-cracked specimens, the specimen should be degreased and cleaned prior to fatigue cracking and care should be taken not to contaminate the specimen prior to testing.

9. Test Environment

9.1 The SSR test is a comparative evaluation and therefore shall be conducted in at least two environments: (1) one in