



Designation: ~~G111–21~~ G111 – 21a

Standard Guide for Corrosion Tests in High Temperature or High Pressure Environment, or Both¹

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1. Scope

1.1 This guide covers procedures, specimens, and equipment for conducting laboratory corrosion tests on metallic materials under conditions of high pressure (HP) or the combination of high temperature and high pressure (HTHP). See 3.2 for definitions of high pressure and temperature.

~~1.2 Tests conducted under HP or HTHP by their nature have special requirements. This guide establishes the basic considerations that are necessary when these conditions must be incorporated into laboratory corrosion tests.~~

1.2 The procedures and methods in this guide are applicable for conducting mass loss corrosion, localized corrosion, and electrochemical tests as well as for use in environmentally induced cracking tests that need to be conducted under HP or HTHP conditions.

1.3 The primary purpose for this guide is to promote consistency of corrosion test results. Furthermore, this guide will aid in the comparison of corrosion data between laboratories or testing organizations that utilize different equipment.

1.4 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.

1.5 *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.*

1.6 *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

[E8/E8M Test Methods for Tension Testing of Metallic Materials](#)

[G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens](#)

¹ This guide is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.05 on Laboratory Corrosion Tests.

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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.

~~G3G4 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing~~
Guide for Conducting Corrosion Tests in Field Applications

G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements

G30 Practice for Making and Using U-Bend Stress-Corrosion Test Specimens

G31 Guide for Laboratory Immersion Corrosion Testing of Metals

G34 Test Method for Exfoliation Corrosion Susceptibility in 2XXX and 7XXX Series Aluminum Alloys (EXCO Test)

G38 Practice for Making and Using C-Ring Stress-Corrosion Test Specimens

G39 Practice for Preparation and Use of Bent-Beam Stress-Corrosion Test Specimens

G46 Guide for Examination and Evaluation of Pitting Corrosion

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

G59 Test Method for Conducting Potentiodynamic Polarization Resistance Measurements

G78 Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments

G106 Practice for Verification of Algorithm and Equipment for Electrochemical Impedance Measurements

G129 Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking

G170 Guide for Evaluating and Qualifying Oilfield and Refinery Corrosion Inhibitors in the Laboratory

G184 Practice for Evaluating and Qualifying Oil Field and Refinery Corrosion Inhibitors Using Rotating Cage

G185 Practice for Evaluating and Qualifying Oil Field and Refinery Corrosion Inhibitors Using the Rotating Cylinder Electrode

G193 Terminology and Acronyms Relating to Corrosion

G208 Practice for Evaluating and Qualifying Oilfield and Refinery Corrosion Inhibitors Using Jet Impingement Apparatus

3. Terminology

3.1 *Definitions*—The definitions of terms given in Terminology G193 shall be considered as applying to this guide.

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3.2 Definitions of Terms Specific to This Standard:

3.2.1 ~~high pressure—temperature and high pressure, HTHP, n—a pressure above ambient atmospheric pressure that cannot be contained in normal laboratory glassware. Typically, this is greater than 0.07 MPa (10 psig); for the purpose of this guide, any combination of pressure and temperature that requires the use of an autoclave.~~

3.2.2 ~~high temperature—effectively non-reactive, adj—temperatures above ambient laboratory temperature where sustained heating of the environment is required; free of significant mass loss or localized corrosion, stress corrosion cracking (SCC), or other embrittlement phenomena in the test environment; not contaminate the test environment with corrosion or other reaction products; and not significantly consume, absorb, or adsorb reactive chemical species from the test environment.~~

3.3 Abbreviations and Acronyms:

3.3.1 *AI*—artificial intelligence

3.3.2 *ALARP*—as low as reasonably practicable

3.3.3 *CUE*—corrosion under excursions

3.3.4 *HV*—high velocity

3.3.5 *ML*—machine learning

3.3.6 *PVT*—pressure volume temperature

3.3.7 *RT*—radiography testing (X-ray)

3.3.8 *SCC*—stressed-corrosion cracking

3.3.9 *SME*—subject matter expert

3.3.10 *UT*—ultrasonic testing

4. Summary of Guide

4.1 This guide describes the use of corrosion coupons, ~~stressed SCC—stress corrosion cracking~~ specimens, and electrochemical electrodes in HP and HTHP environments. It also includes guidelines for the use of ~~high pressure—high-pressure~~ test cells with these specimens to ~~conduct~~obtain reproducible, accurate corrosion test data.

4.2 Typically, HP and HTHP tests involve exposure of test specimens to a liquid (aqueous or non-aqueous), gaseous or multiphase environment, or both, in an appropriate test cell. The test cell ~~must~~shall be able to resist corrosion and ~~environmental cracking~~ cracking (mechanical and environmental) in the test environment while containing the pressurized, heated environment. Furthermore, the test specimens in the HP or HTHP test, or both, can be exposed in either stressed or unstressed condition in either the free corroding state or under electrochemical polarization.

5. Significance and Use

5.1 ~~HP and HTHP corrosion—Autoclave tests are commonly used to evaluate the corrosion performance of metallic materials under conditions that attempt to simulate service conditions that involve HP or HTHP in combination with service environments and non-metallic materials under simulated HP and HTHP service conditions.~~ Examples of service environments ~~where in which~~ HP and HTHP corrosion tests have been ~~utilized~~used include chemical processing, petroleum production and refining, food processing, pressurized cooling water, electric power systems, and aerospace propulsion.

5.2 For the applications of corrosion testing listed in 5.1, the service environment involves handling corrosive and potentially hazardous media under conditions of high pressure or high temperature, or both. The temperature and ~~pressure usually enter directly into the~~ pressure, among other parameters, usually drive the composition and properties of the aqueous phase and, hence,

the severity of the corrosion process. Consequently, the laboratory evaluation of corrosion severity cannot be performed in conventional low pressure glassware without making potentially invalid assumptions as to the potential effects of high temperature and pressure on corrosion severity.

5.3 Therefore, there is a substantial need to provide standardized methods by which corrosion testing can be performed under HP and HTHP. In many cases, however, the standards used for exposure of specimens in conventional ~~low pressure~~ low-pressure glassware experiments cannot be followed due to the limitations of access, volume, and visibility arising from the construction of ~~high pressure~~ high-pressure test cells. This guide refers to existing corrosion standards and practices, as applicable, and then goes further in areas where in which specific guidelines for performing HP and HTHP corrosion testing are needed.

6. Apparatus

~~6.1 The test cell shall be constructed to applicable standards and codes so that it will have an adequate pressure rating to safely handle the test pressure.~~

~~6.2 The test cell shall be made of materials that are corrosion resistant and effectively non-reactive with the test environment.~~

~~6.2.1 The term *effectively non-reactive* shall mean that the test cell shall be free of significant mass loss or localized corrosion, SCC, or other embrittlement phenomena in the test environment, not contaminate the test environment with corrosion or other reaction products, and not consume or absorb reactive chemical species from the test environment.~~

~~6.3 The test cell shall have a seal mechanism that can withstand both the pressures, temperatures, and corrosive environment to be used in the test. Periodic hydrostatic testing of the test cell is recommended to ensure pressure capabilities.~~

~~6.1 The test cell shall be designed to have the necessary inlet and outlet ports to allow the test environment to be established in a controllable manner, monitored and sampled during the exposure period, released in a controlled manner at the completion of the test, and if over temperature or pressure conditions may occur, adequate over pressure release and over temperature control equipment should be utilized.~~ Test Cell:

6.1.1 Shall be constructed to applicable standards and codes so that it will have an adequate pressure rating to handle the test pressure safely.

6.1.2 Shall be made of materials that are corrosion resistant and effectively non-reactive with the test environment. -21a

6.1.3 Shall have a seal mechanism that can withstand both the pressures, temperatures, and corrosive environment to be used in the test. Periodic hydrostatic testing of the test cell is recommended to ensure pressure retaining capabilities.

6.1.4 Shall be designed to have the necessary inlet and outlet ports to allow the test environment to be established in a controllable manner, monitored and sampled during the exposure period, released in a controlled manner at the completion of the test, and, if over temperature or pressure conditions may occur, adequate over pressure release and over temperature control equipment should be used.

~~6.5 In cases where external loading fixtures are used for stressing specimens in the HP and HTHP test environment, specially designed feed-throughs shall be used which provide for a minimum of friction force.~~

~~6.6 Test cell feed-throughs required for external stressing may be designed to balance the internal pressure in the test vessel.~~

~~6.7 Any frictional or pressure forces (or thermal expansion) acting on the specimen through the stressing fixtures must be taken into account when determining the actual load on the specimen.~~

6.2 Stressing and electrode feed-throughs shall be designed so that the electrodes or stressing rods and specimens cannot be ejected from the test cell under pressure. Furthermore, they shall provide for electrical isolation of the specimen from the test cell unless galvanic coupling is specifically desired. Test Cell Feedthroughs:

6.2.1 Should be designed to minimize frictional forces when external loading fixtures are used for stressing specimens.

6.2.2 May be designed to balance the internal pressure in the test vessel with the external stressing assembly.

6.2.3 Shall be designed so that the electrodes or stressing rods and specimens cannot be ejected from the test cell under pressure.

6.2.4 Shall provide the electrical isolation of the specimen from the test cell unless galvanic coupling is specifically desired.

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~~6.3 Gripping devices shall be designed such that they are in compliance with Test Methods E8/E8M where application of load to the specimen is required.~~Specimen Under Applied Load:

6.3.1 Any frictional or pressure forces (or thermal expansion) acting on the specimen through the stressing fixtures should be taken into account when determining the actual load on the specimen.

6.3.2 Gripping devices should be designed such that they are in compliance with Test Methods E8/E8M where application of load to the specimen is required.

6.4 Agitation:

6.4.1 Agitation can be achieved by using a magnetic stir bar/plate, mechanically agitating the autoclave, for example, rollers within an oven recirculating the fluid through a pump, or using magnetic/mechanical feedthrough stirrers designed for this purpose. Care should be taken to ensure that components of the pump or stirrer are inert to the test environment.

NOTE 1—The potential for oxygen contamination and pressure loss increase with the use of pumps and additional autoclave ports.

6.4.2 Descriptions of test methods and equipment designs for testing under turbulent flow conditions, defined as a function of wall shear stress or mass transfer coefficient, can be found collectively in Guide G170, Practice G184 (rotating cage autoclaves), Practice G185 (rotating cylinder electrodes), and Practice G208 (jet impingement).

7. Reagents

7.1 In corrosion testing, providing a reproducible chemical environment in which to expose the corrosion test specimens is necessary.

7.2 In cases where the test environment is established by the mixing of chemicals in the laboratory, chemicals of reagent-grade reagent-grade purity with known contaminant levels are recommended. ~~Simulations of service environments can be formulated in which laboratory corrosion tests can be conducted.~~

7.3 In HP/HTHP corrosion testing, a common practice is to conduct tests in environments that have been sampled and retrieved from field or plant locations. ~~In both cases described in Detailed 7.2 and 7.3, detailed information as to the chemical composition of the environment should be obtained. Particular attention should be given to the levels of impurities and contaminants that may be in the environment. Furthermore, under some conditions, these environments may be prone to changes after sampling or during testing, which can affect the corrosion test results.~~

~~7.4 In many cases, the test cells used to conduct HP tests are limited in volume and may not be designed to accommodate replenishment of the environment. Therefore, monitoring the chemical composition of the environment during the exposure may be necessary to identify if depletion of reactive constituents or concentration of constituents has occurred. In some cases, replenishment or changing of the test environment may be necessary so that a valid corrosion test can be conducted.~~

7.4 In all cases, it is recommended that the test environment be fully documented with respect to its chemical composition.

8. Sampling and Test Specimens

8.1 Sampling Selection Process—Refer to G4, Standard Guide for Conducting Corrosion Tests in Field Applications.

8.2 Preparation of Specimens:

8.2.1 The Frequently, the primary objective is to prepare a reproducible metallic surface with an absolute minimum of ~~cold working~~ cold working followed by cleaning and degreasing. However, there are cases where the as-received surface is the desired test surface, or where the effect of cold working is to be studied.

8.2.2 Since test cells for HP and HTHP tests are usually of metallic construction, care must be taken to electrically isolate the

specimens from the test cell unless galvanic coupling is specifically desired in the test. In cases where the test cell is used as a member of a galvanic couple, care must be taken to ensure that the galvanic action (anodic or cathodic) does not degrade the integrity of the test cell.

8.3 Corrosion Specimens:

8.3.1 Prepare specimens used in HP or HTHP corrosion tests in accordance with Practice **G1** and Guide **G31**. Commonly, test cells used for HP and HTHP exposure tests are restricted in volume. The available volume in the test cell often decreases with increasing pressure rating. Therefore, it is frequently necessary to restrict the size and surface area of corrosion coupons used in HP and HTHP corrosion tests to attain a given volume to area ratio.

8.3.2 ~~The ratio of solution volume to specimen surface area is important and a minimum ratio of 30 mL/cm² is often set for the volume of corrosive liquid to the surface area of the metal that can be corroded, for example, 200 L/m² should be to 400 L/m² maintained, where or 20 mL/cm² possible. If to 40 mL/cm² (Guide **G31**, Test Method **G34**, and Practice **G185** the ratio drops below this level, it should be shown that there will not be an unacceptably high depletion rate of important environmental constituents, or there will not be an undesirable amount of metal ion impurities added into). The origin of this concept is to minimize the buildup of corrosion products, which could subsequently impact solution pH, scaling tendencies, general corrosion rate, pit initiation, and pitting rates. Additionally, *R* can impact the rate at which reactants are depleted and potentially undesirable changes to the test environment during occur. Consequently, an acceptable value for *R* the period of exposure. In all cases, the solution volume to specimen will depend on the highest expected corrosion rate and the test duration. Another factor, not accounted for by *R*, surfaces area used in the test should be stated. If the test cell, specimen holders or stressing fixtures can contribute to the conditions stated above then they should be included in the calculation of specimen surface area. arises from the possibility that certain chemicals, for example, components in a corrosion inhibitor, may adsorb (competitively) on metal surfaces other than the test specimen. Hence, in designing a test, one might also consider how the ratio of total immersed metal surface area to liquid volume compares with that in the field.~~

8.4 Stressed Corrosion Specimens:

8.4.1 Both self-stressed and externally stressed specimens are acceptable for testing at HP and HTHP. Methods for the fabrication and use of appropriate stressed specimens are given in the Section 2 referenced documents. These include tension, bent beam, C-ring, and U-bend specimens in accordance with Practices **G129**, **G49**, **G39**, **G38**, and **G30**, respectively. Fracture mechanics specimens can also be accommodated.

8.4.2 For similar reasons given in **8.28.3**, when testing multiple specimens, it is recommended that the size of the specimens be restricted to the smallest applicable specimen provided for under the appropriate standards.

8.4.3 ~~Due to~~ Because of the limited access of the specimens in HP and HTHP tests, ~~self-stressed~~ self-stressed specimens are usually more convenient than specimens that require external stressing fixtures.

8.4.4 In cases such as direct tension and fracture mechanics tests, use of external loading frames and fixtures in conjunction with HP and HTHP corrosion tests may be desirable. In these cases, take both the frictional (sealing) forces and pressure forces acting on the specimens into account when determining the effect of applied stress.