

Standard Test Method

Laboratory Corrosion Testing of Metals

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Foreword

NACE Unit Committee T-5A on Corrosion in Chemical Processes issues this standard with a dual purpose. The first purpose is to standardize, as much as possible, immersion corrosion testing. In this sense, this standard is reasonable and effective without imposing inflexible requirements as to apparatus, conditions, or techniques. The actual conditions of the test will be determined by the problem at hand and limited only by the ingenuity of the individual investigator. The second purpose of this standard is to present to the user a consensus on the best technology in this field of laboratory corrosion testing. As such, this standard enumerates and discusses the many factors that must be considered, controlled, and reported in order to aid in correlation or reproducibility of such tests.

The techniques described permit the investigator to reproduce to a considerable extent in the laboratory, through judicious experimental design, the process conditions that govern corrosion mechanisms. The methods described are also applicable to materials qualification tests for quality control. However, the latter require more rigid definition of apparatus, conditions, and technique.

This standard was originally published in 1969 and has been updated several times. It was last revised in 1995 by NACE International Work Group T-5A-29b, a component of Unit Committee T-5A on Corrosion in Chemical Processes. It was reaffirmed in 2000 by Unit Committee T-5A, and is issued by NACE International under the auspices of Group Committee T-5 on Corrosion Problems in the Process Industries.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 3rd ed., Paragraph 8.4.1.8. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state that which is considered good and is recommended but is not absolutely mandatory. *May* is used to state that which is considered optional.

**NACE International
Standard
Test Method**

Laboratory Corrosion Testing of Metals

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Section 1: General

1.1 This standard describes the factors that influence laboratory corrosion tests. These factors include test specimen preparation, apparatus, test conditions (solution composition, temperature, velocity, aeration, volume, method of supporting test specimens, duration of test), methods of cleaning test specimens, evaluation of results, and calculation of corrosion rates. This standard also emphasizes the importance of recording all pertinent data and provides a check list for reporting test data.

1.2 Note that the evaluation of localized attack is not within the scope of this standard. The ultimate purpose is better correlation of results in the future and the reduction of conflicting reports through a more detailed recording of meaningful factors and conditions.

1.3 Experience shows that all metals and alloys do not respond alike to the many factors that control corrosion and that "accelerated" corrosion tests may not yield meaningful results. Consequently, it is impractical to propose an inflexible standard laboratory corrosion testing procedure for general use except for material qualification tests, where standardization is obviously required.

1.4 In designing any corrosion test, consideration must be given to the various factors discussed in this test method because they have been found to greatly affect the results obtained. It is prudent to discuss various aspects of the design of any corrosion test, including, but not limited to, test duration, test specimen surface area-to-volume ratio, accelerating factors, and test apparatus, with a corrosion scientist or engineer for consideration of these factors.

Section 2: Test Specimens

2.1 Number of Test Specimens

2.1.1 Experience shows that at least duplicate test specimens should be exposed in each test. Under laboratory tests, corrosion rates of duplicate specimens are usually within $\pm 10\%$ of each other when the attack is uniform. If the rates exceed this variance, retesting should be considered. Occasional exceptions, in which a large difference is observed, can occur under conditions of borderline passivity of metals or alloys that depend on a passive film for their resistance to corrosion.

2.2 Test Specimen Size, Shape, and Type

2.2.1 The size and shape of corrosion test specimens vary with the purpose of the test, nature of the materials, and test apparatus used. A large ratio of surface area to mass and a small ratio of edge area to total area are desirable.

2.2.1.1 Exposure of sheared edges shall be avoided unless the purpose of the test is to study effects of the shearing operation. It may be desirable to test a surface representative of the material and metallurgical condition used in practice.

2.2.2 A rectangular or circular test specimen is preferred for laboratory corrosion testing. Its size and dimensions shall be determined by the test vessel being used and the volume of the test solution available.

2.2.2.1 Typically, rectangular test specimens 20 mm by 50 mm (0.75 in. by 2.0 in) with a

thickness of 1.6 to 4.8 mm (0.063 to 0.19 in.), with or without a hole, are preferred.

2.2.2.2 If circular specimens are used, they shall be cut from sheet or plate, not bar stock, to minimize the exposed end grain (unless the intent is to test or evaluate bar stock).

2.2.3 All test specimens shall be measured carefully to permit accurate calculation of the exposed areas. Measurements taken with metric-calibrated calipers shall be accurate to within 0.01 mm. Measurements taken with U.S. customary-calibrated calipers shall be accurate to within 0.001 in.

2.2.4 The use of welded specimens is often desirable because some welds may be cathodic or anodic to the base metal and may affect the corrosion of welded components.

2.2.4.1 The heat-affected zone is also of importance but should be studied separately because welds on test specimens may not adequately reproduce heat input or size effects of full-size vessels.

2.2.4.2 A complete discussion of corrosion testing of welded coupons or the effect of heat treatment on the corrosion resistance of a metal is not within the scope of this standard. However, important factors to be considered include the welding technique to be used, the filler metal chemistry, and whether the weld will be ground smooth, cleaned and/or passivated, or left as welded.

2.2.5 Cast and wrought alloys considered equivalent often have different corrosion resistance in identical service conditions. Therefore, caution shall be used in selecting representative test materials.

2.3 Test Specimen Surface Finish

2.3.1 More reproducible results can be expected if a substantial layer of metal is removed from the test specimens to eliminate variations in the condition of the original metallic surface. If clad alloy specimens are used, special attention must be given to ensure that excessive alloy (clad metal) is not removed. Testing of clad specimens requires special consideration, such as whether to test the clad side only, to remove the backing by milling, etc. Details for testing clad alloys are beyond the scope of this standard.

2.3.2 Final surface treatment of the specimens shall include finishing with new No. 120 abrasive paper or cloth, or the equivalent, unless the surface is to be used in the mill-finished condition. This resurfacing may cause some surface work hardening to an extent that will be determined by the vigor of the surfacing operation, but the work hardening is not usually significant.

2.3.2.1 Test specimens of different alloy compositions shall never be ground on the same paper or cloth.

2.3.2.2 Wet grinding shall be used on alloys that work harden quickly, such as austenitic stainless steels.

2.4 Test Specimen Identification

2.4.1 The test specimen shall be stamped, etched, notched, or engraved with an appropriate identifying mark.

2.4.1.1 The stamp may introduce stresses and cold work in the test specimen that could be responsible for localized corrosion and/or stress corrosion cracking (SCC).

2.4.1.2 SCC at the identifying mark is a positive indication of susceptibility to such corrosion; however, the absence of cracking should not be interpreted as indicating resistance. Additional types of tests should be performed to specifically study the effects of stress. Such tests are not within the scope of this standard.

2.4.2 The relative location of test specimens in the test apparatus should be recorded prior to testing to permit test specimen identification in the event the identification mark is corroded away.

2.5 Test Specimen Final Preparation

2.5.1 Test specimens shall be scrubbed with a bleach-free scouring powder followed by thorough rinsing in water. For relatively soft metals such as aluminum, magnesium, and copper, scrubbing with abrasive powder is not always needed and can mar the surface of the test specimen.

2.5.2 The test specimens shall be rinsed in a suitable solvent (such as acetone or methanol) and dried using warm air or inert gas. The use of towels for drying may introduce an error through contamination of the test specimens with oils or lint.

2.5.3 The dried test specimens shall be weighed on an analytical balance to an accuracy of 0.001 g or better. Test specimens shall be handled with gloves, tweezers, or tongs to avoid contamination of the surface after cleaning.

Section 3: Test Apparatus

3.1 A versatile and convenient test apparatus consisting of, but not mandated to, a kettle or flask of suitable size (usually 500 to 5,000 mL, a reflux condenser with or without an atmospheric seal, a sparger for controlling atmosphere or aeration, a thermowell and temperature-regulating device, a heating device (mantle, hot plate, or bath), and a test specimen support system should be used. If agitation is required, the test apparatus can be modified to accept a suitable stirring mechanism, such as a magnetic stirrer.

3.2 These suggested components can be modified, simplified, or made more sophisticated to fit the needs of a particular investigation. The suggested test apparatus is basic. The chosen test apparatus is limited only by the judgment and ingenuity of the investigator.

3.2.1 A reaction/resin kettle can be used when configuration and size of test specimens do not permit entry through the narrow neck of a flask. Refer to ASTM⁽¹⁾ G 31¹ for typical test apparatus. Personal experience of the investigator may also be useful.

⁽¹⁾ American Society for Testing and Materials (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

3.2.2 In some cases, a wide-mouth jar with a suitable closure may be sufficient for simple, ambient-temperature immersion tests.

3.2.3 Open-beaker tests should not be used because of evaporation and contamination. If beakers are used,

cover plates or watch glasses should be placed over the openings.

3.2.4 In more complex tests, provisions might be needed for continuous flow or replenishment of the corrosive liquid while simultaneously maintaining a controlled atmosphere.

Section 4: Test Conditions

4.1 Selection of the conditions for a laboratory corrosion test are determined by the purpose of the test.

4.1.1 If the test is to be a guide for the selection of a material for a particular application, the limits of controlling factors in service must be determined. These factors include oxygen concentration, temperature, rate of flow, pH value, and other important characteristics of the solution.

4.2 An effort shall be made to duplicate all service conditions in the laboratory corrosion test.

4.3 Test conditions shall be controlled throughout the test in order to ensure reproducible results.

4.4 Composition of the Test Solution

4.4.1 Test solutions shall be prepared accurately from chemicals conforming to the standards of the Committee on Analytical Reagents of the American Chemical Society⁽²⁾ and using reagent water (ASTM D 1193,³ Type IV or better), except in those cases in which naturally occurring solutions or those taken directly from plant processes are used.

4.4.2 The composition of the test solution shall be accurately controlled and shall be described as completely and precisely as possible when the results are reported.

4.4.2.1 Minor constituents should not be overlooked because they often affect corrosion rates.

4.4.2.2 Chemical content shall be reported as parts per million or percentage by weight of the test solution; molarity or normality is also helpful in defining the concentration of chemicals in the test solution. Solution density and pH should also be reported.

4.4.3 The composition of the test solution should be checked by analysis before and after testing to determine the extent of change in composition.

4.4.4 Evaporation losses shall be controlled by a constant-level device or by frequent additions of the evaporating component of the test solution to maintain the original volume within $\pm 5\%$.

4.4.5 In some cases, composition of the test solution may change as a result of catalytic decomposition, by reaction with the test specimen, or through the buildup of corrosion products in the solution. These changes should be determined, if possible. When required, the exhausted constituents should be added or a fresh solution provided during the course of the test.

4.4.6 When possible, only one type of metal shall be exposed in a given volume of test solution. If several different metals are exposed in the same solution, the corrosion products from one metal may affect the rate of attack on another metal. For example, copper corrosion products can reduce corrosion of stainless steel and titanium but can accelerate corrosion of aluminum.

4.5 Temperature of Test Solution

4.5.1 Temperature of the test solution shall be controlled within $\pm 1^\circ\text{C}$ or $\pm 2^\circ\text{F}$ or 1% and shall be stated in the report of test results.

4.5.2 If no specific temperature, such as boiling, is required, or if a temperature range is to be investigated, the selected temperatures used in the test must be reported.

4.5.3 For processes that are conducted at ambient temperatures, the laboratory tests should be conducted at the highest temperature anticipated for stagnant storage in summer months. This temperature may be as high as 40 to 55°C (104 to 131°F) in some areas. The variation in temperature should also be reported, e.g., $40^\circ\text{C} \pm 1^\circ\text{C}$ ($104^\circ\text{F} \pm 2^\circ\text{F}$).

4.5.4 Tests at the boiling point should be conducted with minimum possible heat input, and inert material boiling chips shall be used to minimize bumping, which is a safety hazard.

⁽²⁾ American Chemical Society (ACS), 1155 16th St., NW, Washington, DC 20036.

4.6 Aeration/Deaeration of Test Solution

4.6.1 Most tests related to process equipment should be run with the natural atmosphere inherent in the process, such as the vapors of the boiling liquid or a controlled gas atmosphere.

4.6.2 Unless specified, the test solution shall not be aerated. If aeration is used, the test specimens shall not be located in the direct air stream from the sparger. Extraneous effects can be encountered if the air stream impinges on the test specimens.

4.6.3 If complete exclusion of dissolved oxygen is necessary, specific techniques are required, such as prior heating of the test solution and sparging with an inert gas (usually nitrogen). A liquid atmospheric seal (i.e., vapor lock) is required on the test vessel to prevent further contamination.

4.6.4 If oxygen saturation of the test solution is desired, this can best be achieved by sparging. For other degrees of aeration, the test solution should be sparged with synthetic mixtures of air or oxygen with an inert gas. It must be noted that air contains carbon dioxide (CO₂), which can affect pH; therefore, zero-air grade is recommended for such mixtures.

4.6.5 Other atmospheres may also be used as required. Sparging the gas into the test solution should ensure saturation; however, other techniques may be employed or required to achieve saturation.

4.6.6 The report of test results shall include the amount, concentration, and flow rates of introduced gases.

4.7 Test Solution Velocity

4.7.1 The effect of velocity is not usually determined in normal laboratory tests, although specific tests have been designed for this purpose. Controlled-velocity tests are outside the scope of this standard.

4.7.2 In tests conducted below the boiling point, thermal convection may be an adequate source of liquid agitation.

4.7.3 In test solutions with high viscosities, supplemental controlled stirring is recommended.

4.7.4 Gas sparging can effectively agitate the test solution and prevent stagnation and the development of unwanted concentration gradients during the test.

4.8 Volume of Test Solution

4.8.1 The volume of the test solution shall be large enough to avoid any appreciable change in the test solution's corrosiveness through either exhaustion of

corrosive constituents or accumulation of corrosion products that might affect further corrosion.

4.8.2 The preferred minimum ratio of test solution volume to test specimen surface area is 20 mL/cm² (130 mL/in.²).

4.8.3 When the test objective is to determine the effect of a metal or alloy on the characteristics of the test solution (for example, to determine the effects of metals on dyes), it is desirable to reproduce the ratio of test solution volume to exposed metal surface area that exists in practice. The actual time of contact of the metal with the test solution also must be taken into account. Any necessary distortion of the test conditions must be considered when interpreting the results.

4.9 Method of Supporting Test Specimens

4.9.1 The supporting device and container shall not be affected by or cause contamination of the test solution.

4.9.2 The method of supporting test specimens varies with the test apparatus used but should be designed to isolate the test specimens from each other physically and electrically and to insulate the test specimens from any uncoated metallic container or supporting device used within the test apparatus. Caution against creating crevice sites under separators is urged.

4.9.3 Shape and form of the test specimen support shall assure free contact of the test specimen with the test solution, the liquid line, or the vapor phase. If clad alloys are exposed, special procedures are required to ensure that only the cladding is exposed, unless the purpose is to test the ability of the cladding to protect cut edges in the test solution.

4.9.4 Some common supports are glass or ceramic rods, glass cradles, glass hooks, fluorocarbon plastic strings, and various insulated or coated metallic supports.

4.10 Duration of Test

4.10.1 The duration of any test should be determined by the nature and purpose of the test.

4.10.2 Materials that experience severe corrosion generally do not need lengthy tests to obtain accurate corrosion rates. However, metals that build up protective corrosion product films with exposure to the test solution may be exceptions. For example, lead exposed to sulfuric acid corrodes at an extremely high rate at first, while building a protective film; then the rates decrease considerably so that further corrosion is negligible. Short tests on such materials could indicate a high corrosion rate and could be misleading.

4.10.3 Short-time tests also could give misleading results on alloys that form passive films, such as stainless steels. Under borderline conditions with respect to maintaining passivity, a prolonged test may be needed to permit breakdown of the passive film and subsequently more rapid attack. Experience suggests that tests run for long periods are considerably more realistic than those conducted for short durations under these conditions.

4.10.4 The planned interval test is an excellent procedure for evaluating the effect of time on corrosion of the metal and also on the corrosiveness of the environment in laboratory tests.⁴ The procedures for determination of test times and for the evaluation of results are given in Figure 1. Other procedures that require the removal of solid corrosion products between exposure periods do not accurately measure the normal changes of corrosion with time unless this simulates the operating conditions. For example, in laboratory tests simulating flow systems (e.g., vapor condensers), long-term tests may seriously underestimate the plant condition corrosiveness by allowing corrosion products to saturate the test solution and create films that do not occur in service.

4.10.5 If anticipated corrosion rates are moderate or low, Equation (1) gives a suggested test duration:⁴

$$\text{Duration of test (h)} = \frac{50}{\text{corrosion rate (mm/y)}} \text{ or } \frac{2,000}{\text{corrosion rate (mpy)}} \quad (1)$$

Examples: When the corrosion rate is expected to be 1 mm/y, the test duration should be at least 50 h. If the

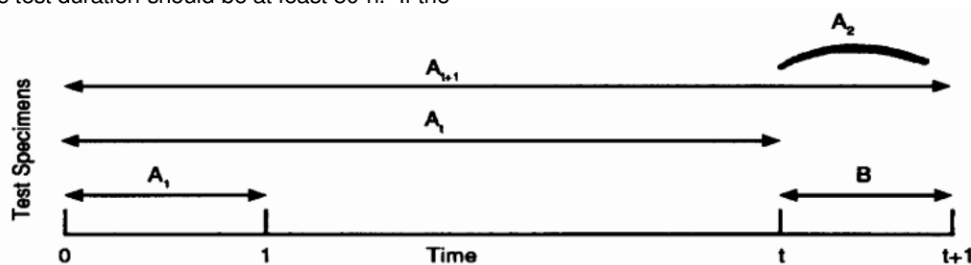
rate is expected to be 0.1 mm/y, the duration should be at least 500 h; when the expected corrosion rate is 10 mpy, the test duration should be at least 200 h.

4.10.5.1 This method of estimating test duration is useful only as an aid in deciding, after a test has been done, whether it is desirable to repeat the test for a longer period. Common testing periods are 24 to 240 h (1 to 10 days).

4.10.5.2 This equation for test duration is acceptable for general corrosion rates only. Localized attack, e.g., pitting, stress corrosion cracking, crevice attack, etc., normally has a longer initiation period before attack begins.

4.10.5.3 For accurate results, the duration of the test shall not be so long that the original test specimen size or the exposed area is drastically reduced or that the metal is perforated.

4.10.6 In some cases, it may be necessary to know the extent of contamination caused by the products of corrosion; this can be accomplished by analysis of the test solution after corrosion has occurred. The corrosion rate can be calculated from the concentrations of one or more of the test specimen's constituent elements found in the test solution, and it can be compared with that determined from the mass loss of the test specimens. However, some of the corrosion products usually adhere to the test specimen or to the test apparatus as a scale. Therefore, the corrosion rate calculated from the metal content in the test solution is not always correct.



Identical test specimens all placed in the same corrosive fluid. Imposed conditions of the test kept constant for entire time $t+1$.

Letters A_1 , A_t , A_{t+1} , and B represent corrosion damage experienced by each test specimen. A_2 is calculated by subtracting A_t from A_{t+1} .

	Occurrences During Corrosion Test	Criteria
Liquid Corrosiveness	unchanged	$A_1 = B$
	decreased	$B < A_1$
	increased	$A_1 < B$
Metal Corrodibility	unchanged	$A_2 = B$
	decreased	$A_2 < B$
	increased	$B < A_2$

FIGURE 1: Planned Interval Test⁴

Combinations of Situations		
Liquid Corrosiveness	Metal Corrodibility	Criteria
1. unchanged	unchanged	$A_1 = A_2 = B$
2. unchanged	decreased	$A_2 < A_1 = B$
3. unchanged	increased	$A_1 = B < A_2$
4. decreased	unchanged	$A_2 = B < A_1$
5. decreased	decreased	$A_2 < B < A_1$
6. decreased	increased	$A_1 > B < A_2$
7. increased	unchanged	$A_1 < A_2 = B$
8. increased	decreased	$A_1 < B > A_2$
9. increased	increased	$A_1 < B < A_2$

Source: Chemical Engineering Progress 43, 6 (1947): p. 315. Reproduced with permission.

Example of Planned Interval Corrosion Test

Conditions: Duplicate strips of low-carbon steel, each 20 mm x 75 mm (0.75 in. x 3.0 in.) with a total surface area of 3,200 mm² (5.0 in.²), immersed in 200 mL of 10% AlCl₃ - 90% SbCl₃ mixture through which dried HCl gas was slowly bubbled at atmospheric pressure. Temperature 90°C (194°F). Density of low-carbon steel is 7.85 g/cm³.

	Interval, days	Mass Loss, mg	Penetration ^(A)		Apparent Corrosion Rate ^(B)	
			mm	mils	mm/y	mpy
A ₁	0-1	1,080	0.0430	1.69	15.7	620
A _t	0-3	1,430	0.0560	2.24	6.90	270
A _{t+1}	0-4	1,460	0.0580	2.29	5.30	210
B	3-4	70	0.0020	0.11	1.0	40
A ₂	calc. 3-4	30	0.001	0.05	0.50	18

^(A) Penetration is calculated using Equation (2).

$$\text{Penetration} = \frac{(\text{mass loss in mg})(\text{C factor})}{\left(\text{area in mm}^2 \text{ or in.}^2 \right) \left(\text{density in g/cm}^3 \right)} \quad (2)$$

where C factor = 1 for mm; C factor = 0.061 for mils

^(B) The apparent corrosion rate is calculated using Equation (3)

$$\text{Apparent Corrosion Rate} = \frac{(\text{Penetration in mm or mils})(365)}{\text{time in days}} \quad (3)$$

From penetration information: $A_2 < B < A_1$ 0.001 < 0.002 < 0.043 mm (0.05 < 0.11 < 1.69 in.)

Therefore, the test solution markedly decreased in corrosiveness during testing and suggests the formation of a partially protective scale on the steel.

FIGURE 1 Continued

Section 5: Cleaning Test Specimens After the Test

5.1 Before test specimens are cleaned, their appearance shall be observed and recorded. Location of deposits, variations in types of deposits, and variations in corrosion products are extremely important in evaluating localized corrosion, such as pitting and concentration cell attack.

5.2 Cleaning test specimens after the test is a vital step in the corrosion test procedure and, if not done properly, can cause misleading results.

5.2.1 Generally, the cleaning procedure should remove all corrosion products from test specimens with a minimum removal of sound metal.

5.2.2 Set rules cannot be applied to test specimen cleaning because procedures vary depending on the type of metal being cleaned and the degree of adherence of corrosion products.

5.3 Cleaning methods can be divided into three general categories: mechanical, chemical, and electrolytic. Detailed procedures are described in ASTM G 1.⁵

5.3.1 Mechanical cleaning includes scrubbing, scraping, brushing, mechanical shocking, and ultrasonic procedures. Scrubbing with a bristle brush (e.g., a hard nylon toothbrush) and bleach-free scouring powder is the most popular of these methods. A rubber eraser, stopper, or bung may be used on soft

metals. Other methods are used principally as supplements to remove heavily encrusted corrosion products before scrubbing. Care shall be used to avoid the removal of sound metal.

5.3.2 Chemical cleaning implies the removal of material from the surface of the test specimen by dissolution in an appropriate chemical solution. Solvents such as acetone and alcohol are used to remove oil, grease, or resin and are usually applied prior to other methods of cleaning. Chemicals are chosen for application to a specific material (see ASTM G 1). Some treatments in general use are presented in Table 1.

TABLE 1:
Some Methods for Chemical Cleaning of Corrosion Test Specimens After Exposure

Material	Chemical	Time	Temperature	Remarks
Aluminum and Aluminum Alloys	70% HNO ₃	2 to 3 min	Room	Follow by light scrub.
	or 2% CrO ₃ + 5% H ₃ PO ₄ solution	10 min	79 to 85 °C (175 to 185 °F)	Used when oxide film resists HNO ₃ treatment. Follow by 70% HNO ₃ treatment previously described.
Cobalt and Cobalt Alloys	10% HCl	Until clean	Room	—
Copper and Copper Alloys	15 to 20% HCl	2 to 3 min	Room	Follow by light scrub.
	or 5 to 10% H ₂ SO ₄	2 to 3 min	Room	Follow by light scrub.
Lead and Lead Alloys	1% acetic acid	10 min	Boiling	Follow by light scrub. Removes PbO.
	or 5% ammonium acetate	5 min	Hot	Follow by light scrub. Removes PbO and/or PbSO ₄ .
Iron and Steel	concentrated HCl + 50 g/L SnCl ₂ + 20 g/L SbCl ₃	25 min max.	Cold	—
Magnesium and Magnesium Alloys	15% CrO ₃ , 1% AgCrO ₄ solution	15 min	Boiling	—
Nickel and Nickel Alloys	10 to 20 % HCl	Until clean	Room	For Ni-Mo and Ni-Cu alloys, conditions should be maintained such that oxygen does not enter the system (e.g., closed vials)
	or 10% H ₂ SO ₄	Until clean	Room	—
Stainless Steels	10% HNO ₃	Until clean	60 °C (140 °F)	Avoid contamination with chlorides.
Tin and Tin Alloys	10% Na ₃ PO ₄	10 min	Boiling	Follow by scrub.
Zinc	10% NH ₄ Cl followed by 5% CrO ₃ ,	5 min	Room	Follow by light scrub.
	1% AgNO ₃ solution, or saturated ammonium acetate	20 s Until clean	Boiling Room	— Follow by light scrub.

5.3.3 Electrolytic cleaning should be preceded by scrubbing to remove loosely adhering corrosion products (see ASTM G 1).

5.3.3.1 Precautions must be taken to ensure good electrical contact with the test specimen, to avoid contamination of the test solution with easily reducible metal ions, and to ensure that inhibitor

decomposition has not occurred. Instead of using a proprietary inhibitor, 0.50 g/L of an inhibitor such as diorthotolyl thiourea or quinoline ethiodide can be used.

5.4 Whichever treatment is used to clean test specimens after a corrosion test, its effect in removing metal shall be determined, and the mass loss shall be corrected accordingly. A "blank" test specimen should be weighed

before and after exposure to the cleaning procedure to establish this mass loss.

5.4.1 Following removal of all scale, the test specimen shall be treated as discussed in Paragraph 2.5.2.

5.4.2 A description of the cleaning method shall be included with the data reported.

Section 6: Evaluation of Results

6.1 After corroded test specimens have been cleaned, they shall be reweighed with an accuracy corresponding to that of the original weighing. The mass loss during the test period can be used as the principal measure of corrosion. Sometimes, all corrosion products cannot be removed. In this case, the mass loss should be reported but the observation made that some corrosion products were not removed.

6.2 After the test specimens have been reweighed, they shall be examined carefully (i.e., under low magnification) for the presence of localized attack. If there are pits, the average and maximum depths of pits shall be determined after measurement with a pit gauge or a calibrated microscope that can be focused first on the edge and then on the bottom of the pit. See ASTM G 46,⁶ but note that the evaluation of localized attack is not within the scope of this standard.

6.3 General corrosion rates calculated from mass loss on materials that exhibit localized pitting or crevice corrosion

may seriously underestimate the rate of corrosion penetration that is occurring. In these cases, mass loss rates may not be appropriate for ranking alloys or predicting performance.

6.4 If the material being tested is suspected of being subject to dealloying forms of corrosion such as dezincification or to intergranular attack, a cross-section of the test specimen should be microscopically examined to determine the type and depth of such attack.

6.5 The test specimen may be subjected to simple bending tests to determine whether any embrittlement has occurred. Caution shall be used during the mechanical deformation of the test specimens due to possible sudden cracking or parting of the metal.

6.6 Photographic documentation of the test specimens, before and after testing, may assist in the evaluation of test results.

Section 7: Calculating Corrosion Rates

7.1 The calculation of corrosion rates requires several pieces of information and several assumptions.

7.1.1 The use of corrosion rates implies that all mass loss has been due to general corrosion and not to localized corrosion, such as pitting or corrosion-sensitized areas on welded coupons. When localized corrosion occurs, maximum pit depth and pit density shall be reported. General corrosion accompanied by localized corrosion shall be reported with the notation: "Localized corrosion observed. Corrosion rate in mm/y (mpy) may be misleading."

7.1.2 The use of corrosion rates also implies that the material has not been internally attacked, such as by dezincification or intergranular corrosion.

7.1.3 Internal attack can be expressed as a corrosion rate, if desired. However, the calculations shall not be based on mass loss, which is usually small, but on microsections that show depth of attack.

7.2 Assuming that localized or internal attack is not present, the corrosion rate expressed as millimeters per year can be calculated by Equation (4).

$$\text{mm/y} = \frac{\text{mass loss} \times 87.6}{(\text{area})(\text{time})(\text{metal density})} \quad (4)$$

where test specimen mass loss is expressed in mg, area in cm² of test specimen surface exposed, time in hours exposed, and the metal density in g/cm³.

The corrosion rate expressed as mils per year can be calculated by Equation (5).

$$\text{mpy} = \frac{\text{mass loss} \times 534.57}{(\text{area})(\text{time})(\text{metal density})} \quad (5)$$

where test specimen mass loss is expressed in mg, area in in.² of metal surface exposed, time in hours exposed, and the metal density in g/cm³.

Section 8: Reporting the Data

8.1 The importance of reporting all data as completely as possible cannot be overemphasized.

8.2 Expansion of the testing program in the future or correlating the results with tests of other investigators is possible only if all pertinent information is properly recorded.

8.3 The following check list is a recommended guide for reporting all important information and data:

8.3.1 Corrosive media and concentration (changes during test).

8.3.2 Volume of test solution.

8.3.3 Temperature (maximum, minimum, average).

8.3.4 Aeration or controlled-atmosphere composition (describe conditions or technique).

8.3.5 Agitation (describe conditions or technique).

8.3.6 Type of test apparatus used.

8.3.7 Location of test specimen within test apparatus (liquid, vapor, interface).

8.3.8 Duration of each test.

8.3.9 Chemical composition, trade name, producing mill, and the UNS⁽³⁾ number (or material designation) of metals tested.

8.3.10 Form and metallurgical conditions of test specimens, including heat treatments applied.

8.3.11 Exact size, shape, and area of test specimens.

8.3.12 Method used to prepare test specimens for test.

8.3.13 Number of test specimens of each material tested, and whether test specimens were tested separately or which test specimens were tested in the same container.

8.3.14 Method used to clean test specimens after exposure and the extent of any error expected by this treatment.

8.3.15 Actual mass loss for each test specimen.

8.3.16 Appearance of each test specimen during and after exposure, and the evaluation of attack, if other than general corrosion. Photo documentation may be of assistance.

8.3.17 Corrosion rates for each test specimen expressed as millimeters per year or mils per year.

8.3.18 Number and depths of pits or crevices.

8.3.19 Extent of localized corrosion (i.e., intergranular attack, dealloying) should be documented.

8.4 Minor occurrences or deviations from the proposed test procedure often can have significant effects and should be reported if known.

8.5 Statistics can be a valuable approach for determining the precision of measured results when replicated test specimens are used. In general, the standard deviation from the average shall be reported whenever an average value is reported. Statistical tests should be used whenever conclusions are drawn about the significance of differences between measured results (see ASTM G 16⁷ for details).

⁽³⁾ Metals and Alloys in the Unified Numbering System (latest revision), a joint publication of the American Society for Testing and Materials and the Society of Automotive Engineers Inc. (SAE), 400 Commonwealth Drive, Warrendale, PA 15096-0001.

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5. ASTM G 1 (latest revision), "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens" (West Conshohocken, PA: ASTM).
6. ASTM G 46 (latest revision), "Standard Guide for Examination and Evaluation of Pitting Corrosion" (West Conshohocken, PA: ASTM).
7. ASTM G 16 (latest revision), "Standard Guide for Applying Statistics to Analysis of Corrosion Data" (West Conshohocken, PA: ASTM).