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**Designation: G 1 – 03**

# Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens<sup>1</sup>

This standard is issued under the fixed designation G 1; 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.

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~~<sup>1</sup> Note—Editorial corrections were made throughout in January 1999.~~

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<sup>1</sup> This practice is under the jurisdiction of ASTM Committee G-1, G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.05 on Laboratory Corrosion Tests.

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## 1. Scope

1.1 This practice covers suggested procedures for preparing bare, solid metal specimens for tests, for removing corrosion products after the test has been completed, and for evaluating the corrosion damage that has occurred. Emphasis is placed on procedures related to the evaluation of corrosion by mass loss and pitting measurements.

~~NOTE 1—Caution: In measurements. (Warning— In many cases the corrosion product on the reactive metals titanium and zirconium is a hard and tightly bonded oxide that defies removal by chemical or ordinary mechanical means. In many such cases, corrosion rates are established by mass gain rather than mass loss.)~~

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see ~~Note 1 and Note 6.~~ 7.2.

## 2. Referenced Documents

### 2.1 ASTM Standards:

A 262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels<sup>2</sup>

D 1193 Specification for Reagent Water<sup>3</sup>

D 1384 Test Method for Corrosion Test for Engine Coolants in Glassware<sup>4</sup>

D 2776 Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Electrical Methods)<sup>5</sup>

G 15 Terminology Relating to Corrosion and Corrosion Testing<sup>6</sup>

G 16 Guide for Applying Statistics to Analysis of Corrosion Data<sup>6</sup>

G 31 Practice for Laboratory Immersion Corrosion Testing of Metals<sup>6</sup>

G 33 Practice for Recording Data from Atmospheric Corrosion Tests of Metallic-Coated Steel Specimens<sup>6</sup>

G 46 Guide for Examination and Evaluation of Pitting Corrosion<sup>6</sup>

G 50 Practice for Conducting Atmospheric Corrosion Tests on Metals<sup>6</sup>

G 78 Guide for Crevice Corrosion Testing of Iron Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments<sup>6</sup>

## 3. Terminology

3.1 See Terminology G 15 for terms used in this practice.

## 4. Significance and Use

4.1 The procedures given are designed to remove corrosion products without significant removal of base metal. This allows an accurate determination of the mass loss of the metal or alloy that occurred during exposure to the corrosive environment.

<sup>2</sup> Annual Book of ASTM Standards, Vol 01.03.

<sup>3</sup> Annual Book of ASTM Standards, Vol 11.01.

<sup>4</sup> Annual Book of ASTM Standards, Vol 15.05.

<sup>5</sup> Discontinued—R, replaced by Guide G 96. See 1990 Annual Book of ASTM Standards, Vol 03.02.

<sup>6</sup> Annual Book of ASTM Standards, Vol 03.02.

4.2 These procedures, in some cases, may apply to metal coatings. However, possible effects from the substrate must be considered.

## 5. Reagents and Materials

5.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.<sup>7</sup> Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type IV of Specification D 1193.

## 6. Methods for Preparing Specimens for Test

6.1 For laboratory corrosion tests that simulate exposure to service environments, a commercial surface, closely resembling the one that would be used in service, will yield the most meaningful results.

6.2 It is desirable to mark specimens used in corrosion tests with a unique designation during preparation. Several techniques may be used depending on the type of specimen and test.

6.2.1 *Stencil or Stamp*—Most metallic specimens may be marked by stenciling, that is, imprinting the designation code into the metal surface using hardened steel stencil stamps hit with a hammer. The resulting imprint will be visible even after substantial corrosion has occurred. However, this procedure introduces localized strained regions and the possibility of superficial iron contamination in the marked area.

6.2.2 Electric engraving by means of a vibratory marking tool may be used when the extent of corrosion damage is known to be small. However, this approach to marking is much more susceptible to having the marks lost as a result of corrosion damage during testing.

6.2.3 Edge notching is especially applicable when extensive corrosion and accumulation of corrosion products is anticipated. Long term atmospheric tests and sea water immersion tests on steel alloys are examples where this approach is applicable. It is necessary to develop a code system when using edge notches.

6.2.4 Drilled holes may also be used to identify specimens when extensive metal loss, accumulation of corrosion products, or heavy scaling is anticipated. Drilled holes may be simpler and less costly than edge notching. A code system must be developed when using drilled holes. Punched holes should not be used as they introduce residual strain.

6.2.5 When it is undesirable to deform the surface of specimens after preparation procedures, for example, when testing coated surfaces, tags may be used for specimen identification. A metal or plastic wire can be used to attach the tag to the specimen and the specimen identification can be stamped on the tag. It is important to ensure that neither the tag nor the wire will corrode or degrade in the test environment. It is also important to be sure that there are no galvanic interactions between the tag, wire, and specimen.

6.3 For more searching tests of either the metal or the environment, standard surface finishes may be preferred. A suitable procedure might be:

6.3.1 Degrease in an organic solvent or hot alkaline cleaner. (See also Practice G 31.)

NOTE 21—Hot alkalis and chlorinated solvents may attack some metals.

NOTE 32—Ultrasonic cleaning may be beneficial in both pre-test and post-test cleaning procedures.

6.3.2 Pickle in an appropriate solution if oxides or tarnish are present. In some cases the chemical cleaners described in Section 6 will suffice.

NOTE 43—Pickling may cause localized corrosion on some materials.

6.3.3 Abrade with a slurry of an appropriate abrasive or with an abrasive paper (see Practices A 262 and Test Method D 1384). The edges as well as the faces of the specimens should be abraded to remove burrs.

6.3.4 Rinse thoroughly, hot air dry, and store in desiccator.

6.4 When specimen preparation changes the metallurgical condition of the metal, other methods should be chosen or the metallurgical condition must be corrected by subsequent treatment. For example, shearing a specimen to size will cold work and may possibly fracture the edges. Edges should be machined.

6.5 The clean, dry specimens should be measured and weighed. Dimensions determined to the third significant figure and mass determined to the fifth significant figure are suggested. When more significant figures are available on the measuring instruments, they should be recorded.

## 7. Methods for Cleaning After Testing

7.1 Corrosion product removal procedures can be divided into three general categories: mechanical, chemical, and electrolytic.

<sup>7</sup> *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

7.1.1 An ideal procedure should remove only corrosion products and not result in removal of any base metal. To determine the mass loss of the base metal when removing corrosion products, replicate uncorroded control specimens should be cleaned by the same procedure being used on the test specimen. By weighing the control specimen before and after cleaning, the extent of metal loss resulting from cleaning can be utilized to correct the corrosion mass loss.

NOTE 54—It is desirable to scrape samples of corrosion products before using any chemical techniques to remove them. These scrapings can then be subjected to various forms of analyses, including perhaps X-ray diffraction to determine crystal forms as well as chemical analyses to look for specific corrodants, such as chlorides. All of the chemical techniques that are discussed in Section 7 tend to destroy the corrosion products and thereby lose the information contained in these corrosion products. Care may be required so that uncorroded metal is not removed with the corrosion products.

7.1.2 The procedure given in 7.1.1 may not be reliable when heavily corroded specimens are to be cleaned. The application of replicate cleaning procedures to specimens with corroded surfaces will often, even in the absence of corrosion products, result in continuing mass losses. This is because a corroded surface, particularly of a multiphase alloy, is often more susceptible than a freshly machined or polished surface to corrosion by the cleaning procedure. In such cases, the following method of determining the mass loss due to the cleaning procedure is preferred.

7.1.2.1 The cleaning procedure should be repeated on specimens several times. The mass loss should be determined after each cleaning by weighing the specimen.

7.1.2.2 The mass loss should be graphed as a function of the number of equal cleaning cycles as shown in Fig. 1. Two lines will be obtained: AB and BC. The latter will correspond to corrosion of the metal after removal of corrosion products. The mass loss due to corrosion will correspond approximately to point B.

7.1.2.3 To minimize uncertainty associated with corrosion of the metal by the cleaning method, a method should be chosen to provide the lowest slope (near to horizontal) of line BC.

7.1.3 Repeated treatment may be required for complete removal of corrosion products. Removal can often be confirmed by examination with a low power microscope (for example, 7× to 30×). This is particularly useful with pitted surfaces when corrosion products may accumulate in pits. This repeated treatment may also be necessary because of the requirements of 7.1.2.1. Following the final treatment, the specimens should be thoroughly rinsed and immediately dried.

7.1.4 All cleaning solutions shall be prepared with water and reagent grade chemicals.

7.2 Chemical procedures involve immersion of the corrosion test specimen in a specific solution that is designed to remove the corrosion products with minimal dissolution of any base metal. Several procedures are listed in Table A1.1. The choice of chemical procedure to be used is partly a matter of trial and error to establish the most effective method for a specific metal and type of corrosion product scale.

NOTE 6—**Caution:** These scale. (**Warning**—These methods may be hazardous to personnel).

7.2.1 Chemical cleaning is often preceded by light brushing (non metallic bristle) or ultrasonic cleaning of the test specimen to remove loose, bulky corrosion products.

7.2.2 Intermittent removal of specimens from the cleaning solution for light brushing or ultrasonic cleaning can often facilitate the removal of tightly adherent corrosion products.

7.2.3 Chemical cleaning is often followed by light brushing or ultrasonic cleaning in reagent water to remove loose products.

7.3 Electrolytic cleaning can also be utilized for removal of corrosion products. Several useful methods for corrosion test specimens of iron, cast iron, or steel are given in Table A2.1.

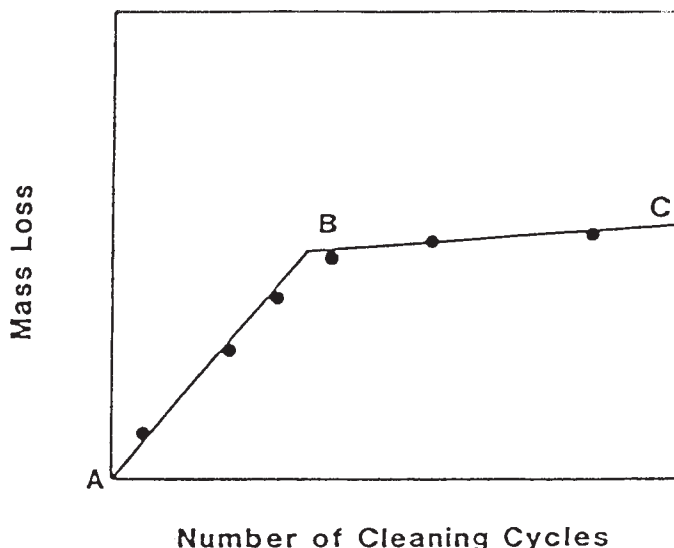


FIG. 1 Mass Loss of Corroded Specimens Resulting from Repetitive Cleaning Cycles

7.3.1 Electrolytic cleaning should be preceded by brushing or ultrasonic cleaning of the test specimen to remove loose, bulky corrosion products. Brushing or ultrasonic cleaning should also follow the electrolytic cleaning to remove any loose slime or deposits. This will help to minimize any redeposition of metal from reducible corrosion products that would reduce the apparent mass loss.

7.4 Mechanical procedures can include scraping, scrubbing, brushing, ultrasonic cleaning, mechanical shocking, and impact blasting (for example, grit blasting, water-jet blasting, and so forth). These methods are often utilized to remove heavily encrusted corrosion products. Scrubbing with a nonmetallic bristle brush and a mild abrasive-distilled water slurry can also be used to remove corrosion products.

7.4.1 Vigorous mechanical cleaning may result in the removal of some base metal; therefore, care should be exercised. These should be used only when other methods fail to provide adequate removal of corrosion products. As with other methods, correction for metal loss due to the cleaning method is recommended. The mechanical forces used in cleaning should be held as nearly constant as possible.

## 8. Assessment of Corrosion Damage

8.1 The initial total surface area of the specimen (making corrections for the areas associated with mounting holes) and the mass lost during the test are determined. The average corrosion rate may then be obtained as follows:

$$\text{Corrosion Rate} = (K \times W)/(A \times T \times D) \quad (1)$$

where:

$K$  = a constant (see 8.1.2),

$T$  = time of exposure in hours,

$A$  = area in  $\text{cm}^2$ ,

$W$  = mass loss in grams, and

$D$  = density in  $\text{g}/\text{cm}^3$  (see Appendix X1).

8.1.1 Corrosion rates are not necessarily constant with time of exposure. See Practice G 31 for further guidance.

8.1.2 Many different units are used to express corrosion rates. Using the units in 7.1 for  $T$ ,  $A$ ,  $W$ , and  $D$ , the corrosion rate can be calculated in a variety of units with the following appropriate value of  $K$ :

Corrosion Rate Units Desired	Constant ( $K$ ) in Corrosion Rate Equation
mils per year (mpy)	$3.45 \times 10^6$
inches per year (ipy)	$3.45 \times 10^3$
inches per month (ipm)	$2.87 \times 10^2$
millimeters per year (mm/y)	$8.76 \times 10^4$
millimetres per year (mm/y)	$8.76 \times 10^4$
micrometers per year (um/y)	$8.76 \times 10^7$
micrometres per year (um/y)	$8.76 \times 10^7$
picometers per second (pm/s)	$2.78 \times 10^6$
picometres per second (pm/s)	$2.78 \times 10^6$
grams per square meter per hour ( $\text{g}/\text{m}^2\text{-h}$ )	$1.00 \times 10^4 \times D$
milligrams per square decimeter per day (mdd)	$2.40 \times 10^6 \times D$
micrograms per square meter per second ( $\mu\text{g}/\text{m}^2\text{-s}$ )	$2.78 \times 10^6 \times D$

NOTE 75—If desired, these constants may also be used to convert corrosion rates from one set of units to another. To convert a corrosion rate in units  $X$  to a rate in units  $Y$ , multiply by  $K_Y/K_X$ ; for example:

$$15 \text{ mpy} = 15 \times (2.78 \times 10^6)/(3.45 \times 10^6) \text{ pm/s} \quad (2)$$

8.1.3 In the case of sacrificial alloy coatings for which there is preferential corrosion of a component whose density differs from that of the alloy, it is preferable to use the density of the corroded component (instead of the initial alloy density) for calculating average thickness loss rate by use of Eq 1. This is done as follows: (1) cleaning to remove corrosion products only and determine the mass loss of the corroded component; (2) stripping the remaining coating to determine the mass of the uncorroded component; (3) chemical analysis of the stripping solution to determine the composition of the uncorroded component; (4) performing a mass balance to calculate the composition of the corroded component; (5) using the mass and density of the corroded component to calculate the average thickness loss rate by use of Eq 1. An example of this procedure is given in Appendix X2.

The procedure described above gives an average penetration rate of the coating, but the maximum penetration for a multiphase alloy may be larger when the corroded phase is not uniformly distributed across the surface. In such cases, it is generally considered good practice to obtain a cross section through the corroded surface for microscopic examination. This examination will reveal the extent of selective corrosion of particular phases in the coating, and help in understanding the mechanism of attack.

8.2 Corrosion rates calculated from mass losses can be misleading when deterioration is highly localized, as in pitting or crevice corrosion. If corrosion is in the form of pitting, it may be measured with a depth gage or micrometer calipers with pointed anvils (see Guide G 46). Microscopical methods will determine pit depth by focusing from top to bottom of the pit when it is viewed from above (using a calibrated focusing knob) or by examining a section that has been mounted and metallographically polished. The pitting factor is the ratio of the deepest metal penetration to the average metal penetration (as measured by mass loss).

NOTE 86—See Guide G 46 for guidance in evaluating depths of pitting.

NOTE 97—See Guide G 78 for guidance in evaluating crevice corrosion.

8.3 Other methods of assessing corrosion damage are:

8.3.1 *Appearance*—The degradation of appearance by rusting, tarnishing, or oxidation. (See Practice G 33.)

8.3.2 *Mechanical Properties*—An apparent loss in tensile strength will result if the cross-sectional area of the specimen (measured before exposure to the corrosive environment) is reduced by corrosion. (See Practice G 50.) Loss in tensile strength will result if a compositional change, such as dealloying taking place. Loss in tensile strength and elongation will result from localized attack, such as cracking or intergranular corrosion.

8.3.3 *Electrical Properties*—Loss in electrical conductivity can be measured when metal loss results from uniform corrosion. (See Test Methods D 2776.)

8.3.4 *Microscopical Examination*—Dealloying, exfoliation, cracking, or intergranular attack may be detected by metallographic examination of suitably prepared sections.

## 9. Report

9.1 The report should include the compositions and sizes of specimens, their metallurgical conditions, surface preparations, and cleaning methods as well as measures of corrosion damage, such as corrosion rates (calculated from mass losses), maximum depths of pitting, or losses in mechanical properties.

## 10. Precision and Bias

10.1 The factors that can produce errors in mass loss measurement include improper balance calibration and standardization. Generally, modern analytical balances can determine mass values to  $\pm 0.2$  mg with ease and balances are available that can obtain mass values to  $\pm 0.02$  mg. In general, mass measurements are not the limiting factor. However, inadequate corrosion product removal or overcleaning will affect precision.

10.2 The determination of specimen area is usually the least precise step in corrosion rate determinations. The precision of calipers and other length measuring devices can vary widely. However, it generally is not necessary to achieve better than  $\pm 1$  % for area measurements for corrosion rate purposes.

10.3 The exposure time can usually be controlled to better than  $\pm 1$  % in most laboratory procedures. However, in field exposures, corrosive conditions can vary significantly and the estimation of how long corrosive conditions existed can present significant opportunities for error. Furthermore, corrosion processes are not necessarily linear with time, so that rate values may not be predictive of the future deterioration, but only are indications of the past exposure.

10.4 Regression analysis on results, as are shown in Fig. 1, can be used to obtain specific information on precision. See Guide G 16 for more information on statistical analysis.

10.5 Bias can result from inadequate corrosion product removal or metal removal caused by overcleaning. The use of repetitive cleaning steps, as shown in Fig. 1, can minimize both of these errors.

10.5.1 Corrosion penetration estimations based on mass loss can seriously underestimate the corrosion penetration caused by localized processes, such as pitting, cracking, crevice corrosion, and so forth.

## 11. Keywords

11.1 cleaning; corrosion product removal; evaluation; mass loss; metals; preparation; specimens

## ANNEXES

### (Mandatory Information)

#### A1. CHEMICAL CLEANING PROCEDURES

TABLE A1.1 CHEMICAL CLEANING PROCEDURES FOR REMOVAL OF CORROSION PRODUCTS

Designation	Material	Solution	Time	Temperature	Remarks
C.1.1	Aluminum and Aluminum Alloys	50 mL phosphoric acid ( $H_3PO_4$ , sp gr 1.69) 20 g chromium trioxide ( $CrO_3$ ) Reagent water to make 1000 mL	5 to 10 min	90°C to Boiling	If corrosion product films remain, rinse, then follow with nitric acid procedure (C.1.2).
C.1.2		Nitric acid ( $HNO_3$ , sp gr 1.42)	1 to 5 min	20 to 25°C	Remove extraneous deposits and bulky corrosion products to avoid reactions that may result in excessive removal of base metal.
C.2.1	Copper and Copper Alloys	500 mL hydrochloric acid (HCl, sp gr 1.19) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	Deaeration of solution with purified nitrogen will minimize base metal removal.



**TABLE A1.1** *Continued*

Designation	Material	Solution	Time	Temperature	Remarks
C.2.2		4.9 g sodium cyanide (NaCN) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	Removes copper sulfide corrosion products that may not be removed by hydrochloric acid treatment (C.2.1).
C.2.3		100 mL sulfuric acid (H <sub>2</sub> SO <sub>4</sub> , sp gr 1.84) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	Remove bulky corrosion products before treatment to minimize copper redeposition on specimen surface.
C.2.4		120 mL sulfuric acid (H <sub>2</sub> SO <sub>4</sub> , sp gr 1.84) 30 g sodium dichromate (Na <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> ·2H <sub>2</sub> O) Reagent water to make 1000 mL	5 to 10 s	20 to 25°C	Removes redeposited copper resulting from sulfuric acid treatment.
C.2.5		54 mL sulfuric acid (H <sub>2</sub> SO <sub>4</sub> , sp gr 1.84) Reagent water to make 1000 mL	30 to 60 min	40 to 50°C	Deaerate solution with nitrogen. Brushing of test specimens to remove corrosion products followed by re-immersion for 3 to 4 s is recommended.
C.3.1	Iron and Steel	1000 mL hydrochloric acid (HCl, sp gr 1.19) 20 g antimony trioxide (Sb <sub>2</sub> O <sub>3</sub> ) 50 g stannous chloride (SnCl <sub>2</sub> )	1 to 25 min	20 to 25°C	Solution should be vigorously stirred or specimen should be brushed. Longer times may be required in certain instances.
C.3.2		50 g sodium hydroxide (NaOH) 200 g granulated zinc or zinc chips Reagent water to make 1000 mL	30 to 40 min	80 to 90°C	Caution should be exercised in the use of any zinc dust since spontaneous ignition upon exposure to air can occur.
C.3.3		200 g sodium hydroxide (NaOH) 20 g granulated zinc or zinc chips Reagent water to make 1000 mL	30 to 40 min	80 to 90°C	Caution should be exercised in the use of any zinc dust since spontaneous ignition upon exposure to air can occur.
C.3.4		200 g diammonium citrate (NH <sub>4</sub> ) <sub>2</sub> HC <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ) Reagent water to make 1000 mL	20 min	75 to 90°C	Depending upon the composition of the corrosion product, attack of base metal may occur.
C.3.5		500 mL hydrochloric acid (HCl, sp gr 1.19) 3.5 g hexamethylene tetramine Reagent water to make 1000 mL	10 min	20 to 25°C	Longer times may be required in certain instances.
C.3.6		Molten caustic soda (NaOH) with 1.5–2.0 % sodium hydride (NaH)	1 to 20 min	370°C	For details refer to Technical Information Bulletin SP29-370, "DuPont Sodium Hydride Descaling Process Operating Instructions."
C.4.1	Lead and Lead Alloys	10 mL acetic acid (CH <sub>3</sub> COOH) Reagent water to make 1000 mL	5 min	Boiling	...
C.4.2		50 g ammonium acetate (CH <sub>3</sub> COONH <sub>4</sub> ) Reagent water to make 1000 mL	10 min	60 to 70°C	...
C.4.3		250 g ammonium acetate (CH <sub>3</sub> COONH <sub>4</sub> ) Reagent water to make 1000 mL	5 min	60 to 70°C	...
C.5.1	Magnesium and Magnesium Alloys	150 g chromium trioxide (CrO <sub>3</sub> ) 10 g silver chromate (Ag <sub>2</sub> CrO <sub>4</sub> ) Reagent water to make 1000 mL	1 min	Boiling	The silver salt is present to precipitate chloride.
C.5.2		200 g chromium trioxide (CrO <sub>3</sub> ) 10 g silver nitrate (AgNO <sub>3</sub> ) 20 g barium nitrate (Ba(NO <sub>3</sub> ) <sub>2</sub> ) Reagent water to make 1000 mL	1 min	20 to 25°C	The barium salt is present to precipitate sulfate.
C.6.1	Nickel and Nickel Alloys	150 mL hydrochloric acid (HCl, sp gr 1.19) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	...
C.6.2		100 mL sulfuric acid (H <sub>2</sub> SO <sub>4</sub> , sp gr 1.84) Reagent water to make 1000 mL	1 to 3 min	20 to 25°C	...
C.7.1	Stainless Steels	100 mL nitric acid (HNO <sub>3</sub> , sp gr 1.42) Reagent water to make 1000 mL	20 min	60°C	...
C.7.2		150 g diammonium citrate (NH <sub>4</sub> ) <sub>2</sub> HC <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ) Reagent water to make 1000 mL	10 to 60 min	70°C	...
C.7.3		100 g citric acid (C <sub>6</sub> H <sub>8</sub> O <sub>7</sub> ) 50 mL sulfuric acid (H <sub>2</sub> SO <sub>4</sub> , sp gr 1.84) 2 g inhibitor (diorthotolyl thiourea or quinoline ethyl iodide or betanaphthol quinoline) Reagent water to make 1000 mL	5 min	60°C	...
C.7.4		200 g sodium hydroxide (NaOH) 30 g potassium permanganate (KMnO <sub>4</sub> ) Reagent water to make 1000 mL <i>followed by</i> 100 g diammonium citrate (NH <sub>4</sub> ) <sub>2</sub> HC <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ) Reagent water to make 1000 mL	5 min	Boiling	...
C.7.5		100 mL nitric acid (HNO <sub>3</sub> , sp gr 1.42) 20 mL hydrofluoric acid (HF, sp gr 1.198–48 %) Reagent water to make 1000 mL	5 to 20 min	20 to 25°C	...

**TABLE A1.1** *Continued*

Designation	Material	Solution	Time	Temperature	Remarks
C.7.6		200 g sodium hydroxide (NaOH) 50 g zinc powder Reagent water to make 1000 mL	20 min	Boiling	Caution should be exercised in the use of any zinc dust since spontaneous ignition upon exposure to air can occur.
C.8.1	Tin and Tin Alloys	150 g trisodium phosphate (Na <sub>3</sub> PO <sub>4</sub> ·12H <sub>2</sub> O) Reagent water to make 1000 mL	10 min	Boiling	...
C.8.2		50 mL hydrochloric acid (HCl, sp gr 1.19) Reagent water to make 1000 mL	10 min	20°C	...
C.9.1	Zinc and Zinc Alloys	150 mL ammonium hydroxide (NH <sub>4</sub> OH, sp gr 0.90) Reagent water to make 1000 mL <i>followed by</i> 50 g chromium trioxide (CrO <sub>3</sub> ) 10 g silver nitrate (AgNO <sub>3</sub> ) Reagent water to make 1000 mL	5 min  15 to 20 s	20 to 25°C  Boiling	...  The silver nitrate should be dissolved in water and added to the boiling chromic acid to prevent excessive crystallization of silver chromate. The chromic acid must be sulfate free to avoid attack of the zinc base metal.
C.9.2		100 g ammonium chloride (NH <sub>4</sub> Cl) Reagent water to make 1000 mL	2 to 5 min	70°C	...
C.9.3		200 g chromium trioxide (CrO <sub>3</sub> ) Reagent water to make 1000 mL	1 min	80°C	Chloride contamination of the chromic acid from corrosion products formed in salt environments should be avoided to prevent attack of the zinc base metal.
C.9.4		85 mL hydriodic acid (HI, sp gr 1.5) Reagent water to make 1000 mL	15 s	20 to 25°C	Some zinc base metal may be removed. A control specimen (3.1.1) should be employed.
C.9.5		100 g ammonium persulfate ((NH <sub>4</sub> ) <sub>2</sub> S <sub>2</sub> O <sub>8</sub> ) Reagent water to make 1000 mL	5 min	20 to 25°C	Particularly recommended for galvanized steel.
C.9.6		100 g ammonium acetate (CH <sub>3</sub> COONH <sub>4</sub> ) Reagent water to make 1000 mL	2 to 5 min	70°C	...

## A2. ELECTROLYTIC CLEANING PROCEDURES

**TABLE A2.1 ELECTROLYTIC CLEANING PROCEDURES FOR REMOVAL OF CORROSION PRODUCTS**

Designation	Material	Solution	Time	Temperature	Remarks
E.1.1	Iron, Cast Iron, Steel	75 g sodium hydroxide (NaOH) 25 g sodium sulfate (Na <sub>2</sub> SO <sub>4</sub> ) 75 g sodium carbonate (Na <sub>2</sub> CO <sub>3</sub> ) Reagent water to make 1000 mL	20 to 40 min	20 to 25°C	Cathodic treatment with 100 to 200 A/m <sup>2</sup> current density. Use carbon, platinum or stainless steel anode.
E.1.2		28 mL sulfuric acid (H <sub>2</sub> SO <sub>4</sub> , sp gr 1.84) 0.5 g inhibitor (diorthotolyl thiourea or quinoline ethyl iodide or betanaphthol quinoline) Reagent water to make 1000 mL	3 min	75°C	Cathodic treatment with 2000 A/m <sup>2</sup> current density. Use carbon, platinum or lead anode.
E.1.3		100 g diammonium citrate ((NH <sub>4</sub> ) <sub>2</sub> HC <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ) Reagent water to make 1000 mL	5 min	20 to 25°C	Cathodic treatment with 100 A/m <sup>2</sup> current density. Use carbon or platinum anode.
E.2.1	Lead and Lead Alloys	28 mL sulfuric acid (H <sub>2</sub> SO <sub>4</sub> , sp gr 1.84) 0.5 g inhibitor (diorthotolyl thiourea or quinoline ethyl iodide or betanaphthol quinoline) Reagent water to make 1000 mL	3 min	75°C	Cathodic treatment with 2000 A/m <sup>2</sup> current density. Use carbon, platinum or lead anode.
E.3.1	Copper and Copper Alloys	7.5 g potassium chloride (KCl) Reagent water to make 1000 mL	1 to 3	20 to 25°C	Cathodic treatment with 100 A/m <sup>2</sup> current density. Use carbon or platinum anode.
E.4.1	Zinc and Cadmium	50 g dibasic sodium phosphate (Na <sub>2</sub> HPO <sub>4</sub> ) Reagent water to make 1000 mL	5 min	70°C	Cathodic treatment with 110 A/m <sup>2</sup> current density. Specimen must be energized prior to immersion. Use carbon, platinum or stainless steel anode.
E.4.2		100 g sodium hydroxide (NaOH) Reagent water to make 1000 mL	1 to 2 min	20 to 25°C	Cathodic treatment with 100 A/m <sup>2</sup> current density. Specimen must be energized prior to immersion. Use carbon, platinum or stainless steel anode.
E.5.1	General (excluding Aluminum, Magnesium and Tin Alloys)	20 g sodium hydroxide (NaOH) Reagent water to make 1000 mL	5 to 10 min	20 to 25°C	Cathodic treatment with 300 A/m <sup>2</sup> current density. A S31600 stainless steel anode may be used.



**APPENDIXES**
**(Nonmandatory Information)**
**X1. DENSITIES FOR A VARIETY OF METALS AND ALLOYS**
**TABLE X1.1 DENSITIES FOR A VARIETY OF METALS AND ALLOYS**

NOTE 1—All UNS numbers that include the letter X indicate a series of numbers under one category.

NOTE 2—An asterisk indicates that a UNS number not available.

Aluminum Alloys		
UNS Number	Alloy	Density g/cm <sup>3</sup>
A91100	1100	2.71
A91199	1199	2.70
A92024	2024	2.78
A92219	2219	2.84
A93003	3003	2.73
A93004	3004	2.72
A95005	5005	2.70
A95050	5050	2.69
A95052	5052	2.68
A95083	5083	2.66
A95086	5086	2.66
A95154	5154	2.66
A95357	5357	2.69
A95454	5454	2.69
A95456	5456	2.66
A96061	6061	2.70
*	6062	2.70
A96070	6070	2.71
A96101	6101	2.70
A97075	7075	2.81
A97079	7079	2.75
A97178	7178	2.83
Stainless Steels		
S20100	Type 201	7.94
S20200	Type 202	7.94
S30200	Type 302	7.94
S30400	Type 304	7.94
S30403	Type 304L	7.94
S30900	Type 309	7.98
S31000	Type 310	7.98
S31100	Type 311	7.98
S31600	Type 316	7.98
S31603	Type 316L	7.98
S31700	Type 317	7.98
S32100	Type 321	7.94
S32900	Type 329	7.98
N08330	Type 330	7.98
S34700	Type 347	8.03
S41000	Type 410	7.70
S43000	Type 430	7.72
S44600	Type 446	7.65
S50200	Type 502	7.82
Other Ferrous Metals		
F1XXXX	Gray cast iron	7.20
GXXXXX–KXXXXX	Carbon steel	7.86
*	Silicon iron	7.00
KXXXXX	Low alloy steels	7.85
Copper Alloys		
C38600	Copper	8.94
C23000	Red brass 230	8.75
C26000	Cartridge brass 260	8.52
C28000	Muntz metal 280	8.39
*	Admiralty 442	8.52
C44300	Admiralty 443	8.52
C44400	Admiralty 444	8.52
C44500	Admiralty 445	8.52
C68700	Aluminum brass 687	8.33
C22000	Commercial bronze 220	8.80
C60800	Aluminum bronze, 5 % 608	8.16
*	Aluminum bronze, 8 % 612	7.78
*	Composition M	8.45

**TABLE X1.1** *Continued*

Aluminum Alloys		
UNS Number	Alloy	Density g/cm <sup>3</sup>
*	Composition G	8.77
C51000	Phosphor bronze, 5 % 510	8.86
C52400	Phosphor bronze, 10 % 524	8.77
*	85-5-5-5	8.80
C65500	Silicon bronze 655	8.52
C70600	Copper nickel 706	8.94
C71000	Copper nickel 710	8.94
C71500	Copper nickel 715	8.94
C75200	Nickel silver 752	8.75
	Lead	
L53305–53405	Antimonial	10.80
L5XXXX	Chemical	11.33
Nickel Alloys		
N02200	Nickel 200	8.89
N04400	Nickel copper 400	8.84
N06600	Nickel chromium iron alloy 600	8.51
<del>N06625</del>	<del>Nickel chromium molybdenum alloy 625</del>	<del>8.44</del>
N06625	Nickel chromium molybdenum alloy 625	8.44
N08825	Iron nickel chromium alloy 825	8.14
N08020	Iron nickel chromium alloy 20 Cb-3	8.08
*	Iron nickel chromium cast alloy 20	8.02
N10665	Nickel molybdenum alloy B2	9.2
N10276	Nickel chromium molybdenum alloy C-276	8.8
N06985	Nickel chromium molybdenum alloy G-3	8.3
Other Metals		
M1XXXX	Magnesium	1.74
R03600	Molybdenum	10.22
P04980	Platinum	21.45
P07016	Silver	10.49
R05200	Tantalum	16.60
L13002	Tin	7.30
R50250	Titanium	4.54
Z13001	Zinc	7.13
R60001	Zirconium	6.53

## **X2. CALCULATION OF AVERAGE THICKNESS LOSS RATE OF AN ALLOY WHEN THE DENSITY OF THE CORRODING METAL DIFFERS FROM THAT OF THE BULK ALLOY**

### **X2.1 Example**

X2.1.1 55% Al-Zn alloy coating on steel sheet exposed for 20.95 years at Point Reyes, CA. (As reported in H.E. Townsend and H.H.Lawson, “Twenty-One Year Results for Metallic-Coated Sheet in the ASTM 1976 Atmospheric Corrosion Tests”).<sup>8</sup>

### **X2.2 Measurements**

X2.2.1 Initial aluminum content of coating,  $C_1$ , as measured by stripping (Table A1.1, C.3.) and chemical analysis of uncorroded specimens.

$$C_1 = 55.0\% \text{ Al} \quad (\text{X2.1})$$

#### **X2.2.2 Time of Exposure, T**

$$T = 20.95 \text{ years} = 183\,648 \text{ hours} \quad (\text{X2.2})$$

#### **X2.2.3 Specimen Area, A**

$$A = 300 \text{ cm}^2 \quad (\text{X2.3})$$

#### **X2.2.4 Initial Mass, $W_1$**

$$W_1 = 79.3586 \text{ g} \quad (\text{X2.4})$$

#### **X2.2.5 Mass after exposure and removal of corrosion products according to Table A1.1, C.9.3, $W_2$**

$$W_2 = 78.7660 \text{ g} \quad (\text{X2.5})$$

#### **X2.2.6 Mass after removal of remaining coating according to Table A1.1, C.3.5, $W_3$**

<sup>8</sup> Outdoor Atmospheric Corrosion, STP 1421, H. E. Townsend, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2002, pp. 284–291.

$$W_3 = 75.0810 \text{ g} \quad (\text{X2.6})$$

X2.2.7 Aluminum content of remaining uncorroded coating by chemical analysis of the stripping solution,  $C_u$

$$C_u = 57.7\% \text{ Al} \quad (\text{X2.7})$$

### **X2.3 Calculations**

X2.3.1 Mass loss of corroded coating,  $W$

$$W = W_1 - W_2 = 79.3586 - 78.7660 = 0.5926 \text{ g} \quad (\text{X2.8})$$

X2.3.2 Mass of remaining uncorroded coating,  $W_u$

$$W_u = W_2 - W_3 = 78.7660 - 75.0810 = 3.6850 \text{ g} \quad (\text{X2.9})$$

X2.3.3 Total mass of original coating,  $W_t$

$$W_t = W + W_u = 0.5926 + 3.6850 = 4.2776 \text{ g} \quad (\text{X2.10})$$

X2.3.4 Composition of corroded coating,  $C$

$$CW + C_u W_u = C_t W_t \quad (\text{X2.11})$$

Rearranging gives

$$C = (C_t W_t - C_u W_u) / W \quad (\text{X2.12})$$

$$C = (55.0 \times 4.2776 - 57.7 \times 3.6850) / 0.5926 \quad (\text{X2.13})$$

$$C = 38.2\% \text{ Al} \quad (\text{X2.14})$$

X2.3.5 The density,  $D$ , of a 38.2 % Al-Zn alloy is  $4.32 \text{ g/cm}^{-3}$ . In cases where alloy densities are not known, they can be estimated by linear interpolation of the component densities.

X2.3.6 Calculate the average thickness loss rate,  $L$  (corrosion rate per Eq 1).

$$L = (K \times W) / (A \times T \times D) \quad (\text{X2.15})$$

where  $K$  is given in 8.1.2 as  $8.76 \times 10^7$

$$\underline{L} \equiv (8.76 \times 10^7 \times 0.5926) / (300 \times 183\,648 \times 4.32)$$

$$\underline{L} \equiv 0.218 \text{ micrometres per year}$$

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