

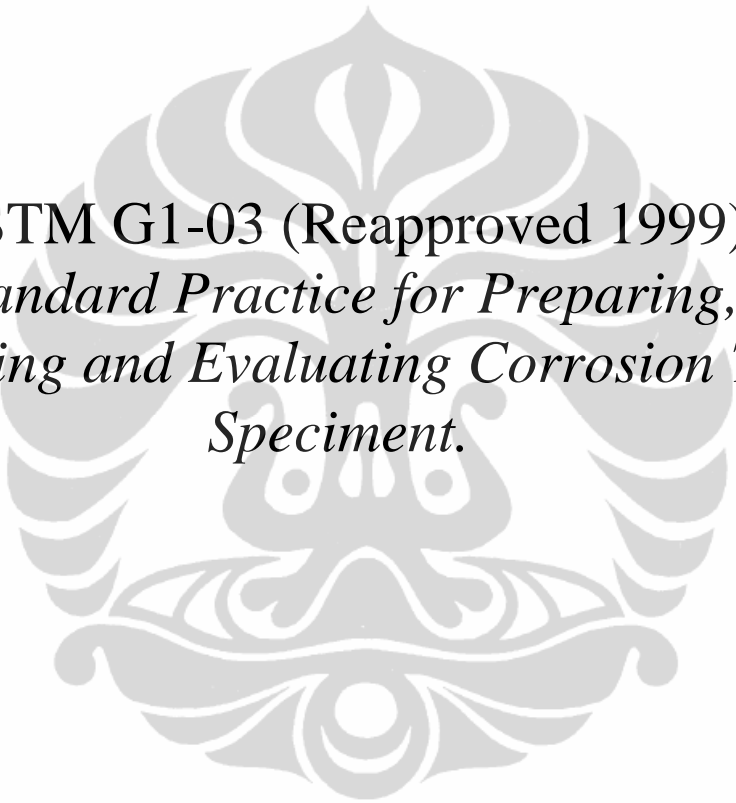
BAB VI

KESIMPULAN

6.1 KESIMPULAN

1. SUS 316L dan SUS 317L akan mengalami korosi sumuran dalam cairan *mother liquor terephthalic acid plant* dengan SUS 317L memiliki ketahanan korosi yang lebih baik. Laju korosi SUS 316L dan SUS 317L adalah sebesar 1,52 mpy dan 1,43 mpy.
2. SUS 329J tidak mengalami korosi sumuran dalam cairan *mother liquor terephthalic acid plant* dan hanya akan mengalami korosi merata dengan laju korosi sebesar 1,33 mpy
3. Hastelloy C-276 tidak mengalami korosi sumuran dalam cairan *mother liquor terephthalic acid plant* dan hanya akan mengalami korosi merata dengan laju korosi sebesar 1,00 mpy.
4. Material yang paling tahan korosi sumuran dalam *liquid mother liquor terephthalic acid plant* adalah paduan yang kandungan molibdenumnya tinggi, dalam hal ini ketahanan korosi dari yang paling baik berturut turut adalah SUS 329J(Mo=3,07%), SUS 317L(Mo=2,91%) dan SUS 316L(Mo=2,08%).
5. Hastelloy C-276 memiliki ketahanan korosi yang paling baik dibandingkan dengan SUS 329J, SUS 317L dan SUS 316L dengan laju korosi berturut turut sebesar 1,00 mpy, 1,33 mpy, 1,43 mpy dan 1,43 mpy.

Lampiran-1.



ASTM G1-03 (Reapproved 1999)
*Standard Practice for Preparing,
Cleaning and Evaluating Corrosion Test
Speciment.*



Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens¹

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.

^{ε1} NOTE—Editorial corrections were made throughout in January 1999.

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 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.

2. Referenced Documents

2.1 ASTM Standards:

- A 262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels²
- D 1193 Specification for Reagent Water³
- D 1384 Test Method for Corrosion Test for Engine Coolants in Glassware⁴
- D 2776 Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Electrical Methods)⁵
- G 15 Terminology Relating to Corrosion and Corrosion Testing⁶
- G 16 Guide for Applying Statistics to Analysis of Corrosion Data⁶

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

Current edition approved March 30, 1990. Published May 1990. Originally published as G 1 – 67. Last previous edition G 1 – 88.

² *Annual Book of ASTM Standards*, Vol 01.03.

³ *Annual Book of ASTM Standards*, Vol 11.01.

⁴ *Annual Book of ASTM Standards*, Vol 15.05.

⁵ *Discontinued*—Replaced by Guide G 96. See *1990 Annual Book of ASTM Standards*, Vol 03.02.

⁶ *Annual Book of ASTM Standards*, Vol 03.02.

G 31 Practice for Laboratory Immersion Corrosion Testing of Metals⁶

G 33 Practice for Recording Data from Atmospheric Corrosion Tests of Metallic-Coated Steel Specimens⁶

G 46 Guide for Examination and Evaluation of Pitting Corrosion⁶

G 50 Practice for Conducting Atmospheric Corrosion Tests on Metals⁶

G 78 Guide for Crevice Corrosion Testing of Iron Base and Nickel Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments⁶

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.

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.⁷ 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.

⁷ *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.

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 2—Hot alkalis and chlorinated solvents may attack some metals.

NOTE 3—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 4—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.

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 5—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

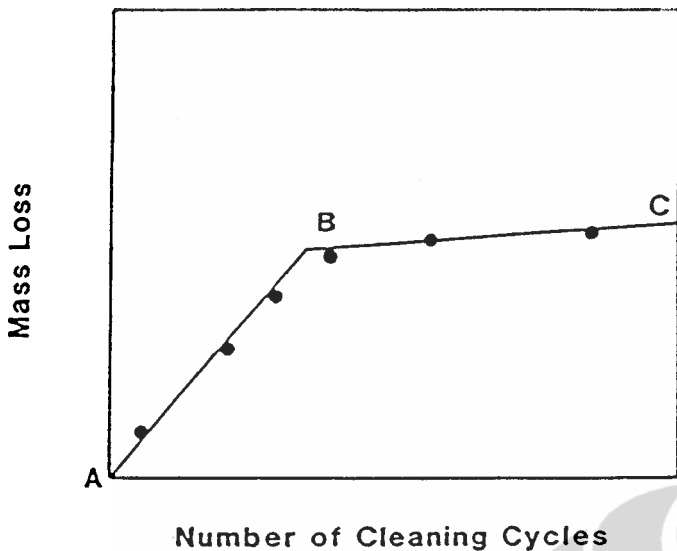


FIG. 1 Mass Loss of Corroded Specimens Resulting from Repetitive Cleaning Cycles

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 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.

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 im-

pect 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 cm²,
- W* = mass loss in grams, and
- D* = density in g/cm³ (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 (<i>K</i>) in Corrosion Rate Equation
mils per year (mpy)	3.45 × 10 ⁶
inches per year (ipy)	3.45 × 10 ³
inches per month (ipm)	2.87 × 10 ²
millimeters per year (mm/y)	8.76 × 10 ⁴
micrometers per year (um/y)	8.76 × 10 ⁷
picometers per second (pm/s)	2.78 × 10 ⁶
grams per square meter per hour (g/m ² -h)	1.00 × 10 ⁴ × <i>D</i>
milligrams per square decimeter per day (mdd)	2.40 × 10 ⁶ × <i>D</i>
micrograms per square meter per second (μg/m ² -s)	2.78 × 10 ⁶ × <i>D</i>

NOTE 7—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:

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

8.2 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 8—See Guide G 46 for guidance in evaluating depths of pitting.

NOTE 9—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 ± 0.2 mg with ease and balances are available that can obtain mass values to ± 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.
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_2SO_4 , 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_2SO_4 , sp gr 1.84) 30 g sodium dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$) Reagent water to make 1000 mL	5 to 10 s	20 to 25°C	Removes redeposited copper resulting from sulfuric acid treatment.

TABLE A1.1 *Continued*

Designation	Material	Solution	Time	Temperature	Remarks
C.2.5		54 mL sulfuric acid (H ₂ SO ₄ , 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 ₂ O ₃) 50 g stannous chloride (SnCl ₂)	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 ₄) ₂ HC ₆ H ₅ O ₇) 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 ₃ COOH) Reagent water to make 1000 mL	5 min	Boiling	...
C.4.2		50 g ammonium acetate (CH ₃ COONH ₄) Reagent water to make 1000 mL	10 min	60 to 70°C	...
C.4.3		250 g ammonium acetate (CH ₃ COONH ₄) Reagent water to make 1000 mL	5 min	60 to 70°C	...
C.5.1	Magnesium and Magnesium Alloys	150 g chromium trioxide (CrO ₃) 10 g silver chromate (Ag ₂ CrO ₄) 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 ₃) 10 g silver nitrate (AgNO ₃) 20 g barium nitrate (Ba(NO ₃) ₂) 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 ₂ SO ₄ , 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 ₃ , sp gr 1.42) Reagent water to make 1000 mL	20 min	60°C	...
C.7.2		150 g diammonium citrate (NH ₄) ₂ HC ₆ H ₅ O ₇) Reagent water to make 1000 mL	10 to 60 min	70°C	...
C.7.3		100 g citric acid (C ₆ H ₈ O ₇) 50 mL sulfuric acid (H ₂ SO ₄ , 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 ₄) Reagent water to make 1000 mL <i>followed by</i> 100 g diammonium citrate (NH ₄) ₂ HC ₆ H ₅ O ₇) Reagent water to make 1000 mL	5 min	Boiling	...
C.7.5		100 mL nitric acid (HNO ₃ , 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	...
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 ₃ PO ₄ ·12H ₂ 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	...

TABLE A1.1 *Continued*

Designation	Material	Solution	Time	Temperature	Remarks
C.9.1	Zinc and Zinc Alloys	150 mL ammonium hydroxide (NH ₄ OH, sp gr 0.90) Reagent water to make 1000 mL <i>followed by</i> 50 g chromium trioxide (CrO ₃) 10 g silver nitrate (AgNO ₃) 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 ₄ Cl) Reagent water to make 1000 mL	2 to 5 min	70°C	...
C.9.3		200 g chromium trioxide (CrO ₃) 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 ₄) ₂ S ₂ O ₈) 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 ₃ COONH ₄) 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 ₂ SO ₄) 75 g sodium carbonate (Na ₂ CO ₃) Reagent water to make 1000 mL	20 to 40 min	20 to 25°C	Cathodic treatment with 100 to 200 A/m ² current density. Use carbon, platinum or stainless steel anode.
E.1.2		28 mL sulfuric acid (H ₂ SO ₄ , sp gr 1.84) 0.5 g inhibitor (diorthotolyl thiourea or quinoline ethylidide or betanaphthol quinoline) Reagent water to make 1000 mL	3 min	75°C	Cathodic treatment with 2000 A/m ² current density. Use carbon, platinum or lead anode.
E.1.3		100 g diammonium citrate ((NH ₄) ₂ HC ₆ H ₅ O ₇) Reagent water to make 1000 mL	5 min	20 to 25°C	Cathodic treatment with 100 A/m ² current density. Use carbon or platinum anode.
E.2.1	Lead and Lead Alloys	28 mL sulfuric acid (H ₂ SO ₄ , sp gr 1.84) 0.5 g inhibitor (diorthotolyl thiourea or quinoline ethylidide or betanaphthol quinoline) Reagent water to make 1000 mL	3 min	75°C	Cathodic treatment with 2000 A/m ² 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 ² current density. Use carbon or platinum anode.
E.4.1	Zinc and Cadmium	50 g dibasic sodium phosphate (Na ₂ HPO ₄) Reagent water to make 1000 mL	5 min	70°C	Cathodic treatment with 110 A/m ² 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 ² 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 ² current density. A S31600 stainless steel anode may be used.

APPENDIX

(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 ³
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

TABLE X1.1 Continued

Aluminum Alloys		
UNS Number	Alloy	Density g/cm ³
*	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
*	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
N06625	Nickel chromium molybdenum alloy 625	8.14
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

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

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*ASTM G5-94 Standard Reference Test
Method for Making Potentiostatic and
Potentiodynamic Anodic Polarization
Measurement*





Standard Reference Test Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements¹

This standard is issued under the fixed designation G 5; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method describes an experimental procedure for checking experimental technique and instrumentation. If followed, this test method will provide repeatable potentiostatic and potentiodynamic anodic polarization measurements that will reproduce data determined by others at other times and in other laboratories provided all laboratories are testing reference samples from the same lot of Type 430 stainless steel.

1.2 Values stated in SI units are to be regarded as the standard. Inch-pound units given in parentheses are for information only.

1.3 *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.*

2. Referenced Documents

2.1 ASTM Standards:

E 1338 Guide for the Identification of Metals and Alloys in Computerized Material Property Databases²

G 3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing³

G 107 Guide for Formats for Collection and Compilation of Corrosion Data for Metals for Computerized Database Input³

3. Significance and Use

3.1 The availability of a standard procedure, standard material, and a standard plot should make it easy for an investigator to check his techniques. This should lead to polarization curves in the literature which can be compared with confidence.

3.2 Samples of a standard ferritic Type 430 stainless steel (UNS S43000) used in obtaining standard reference plot are

¹ This test method is under the jurisdiction of ASTM Committee G-1 on Corrosion of Metals and is the direct responsibility of G01.11 on Electrochemical Measurements in Corrosion Testing.

Current edition approved March 15, 1994. Published May 1994. Originally published as G 5 – 69. Last previous edition G 5 – 87.

² *Annual Book of ASTM Standards*, Vol 14.01.

³ *Annual Book of ASTM Standards*, Vol 03.02.

available for those who wish to check their own test procedure and equipment.⁴

3.3 Standard potentiostatic and potentiodynamic polarization plots are supplied with the purchase of the reference material. These reference data are based on the results from different laboratories that followed the standard procedure, using that material in 1.0 N H₂SO₄. Maximum and minimum current values are shown at each potential to indicate the acceptable range of values.

3.4 This test method may not be appropriate for polarization testing of all materials or in all environments.

3.5 This test method is intended for use in evaluating the accuracy of a given electrochemical test apparatus, not for use in evaluating materials performance. Therefore, the use of the plots in Figs. 1 and 2 or Appendix X2 is not recommended to evaluate alloys other than Type 430, or lots of Type 430 other than those available through ASTM. The use of the data in this test method in this manner is beyond the scope and intended use of this test method. Users of this test method are advised to evaluate test results relative to the scatter bands corresponding to the particular lot of Type 430 stainless steel that was tested.

4. Apparatus

4.1 The test cell should be constructed to allow the following items to be inserted into the solution chamber: the test electrode, two auxiliary electrodes, a Luggin capillary with salt-bridge connection to the reference electrode, inlet and outlet for an inert gas, and a thermometer. The test cell shall be constructed of materials that will not corrode, deteriorate, or otherwise contaminate the test solution.

NOTE 1—Borosilicate glass and TFE-fluorocarbon have been found suitable.

4.1.1 A suitable cell is shown in Fig. 3 (1).⁵ A 1-L, roundbottom flask has been modified by the addition of various necks to permit the introduction of electrodes, gas inlet and outlet tubes, and a thermometer. The Luggin probe-salt bridge separates the bulk solution from the saturated calomel reference electrode, and the probe tip can be easily adjusted to bring

⁴ These standard samples are available from ASTM Headquarters. Generally, one sample can be repolished and reused for many runs. This procedure is suggested to conserve the available material. Order PCN 12-700050-00.

⁵ The boldface numbers in parentheses refer to the list of references at the end of this test method.

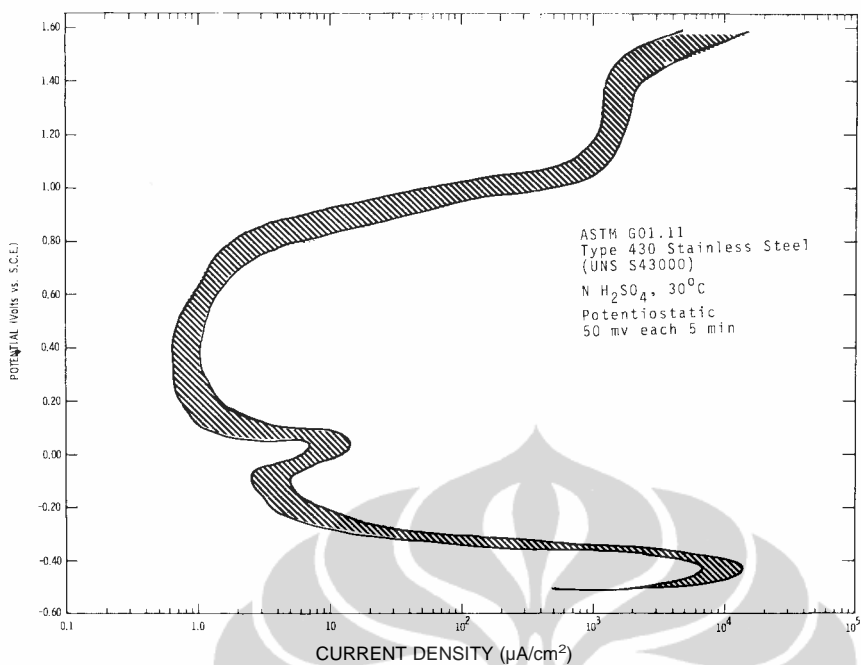


FIG. 1 Typical Standard Potentiostatic Anodic Polarization Plot

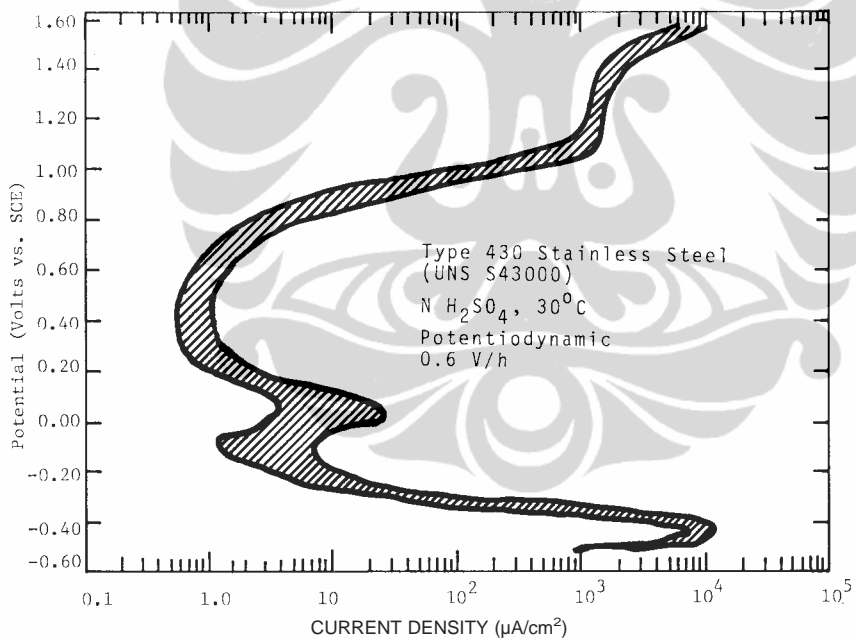


FIG. 2 Typical Standard Potentiodynamic Anodic Polarization Plot

it in close proximity with the working electrode.

4.2 Potentiostat (Note 2):

4.2.1 A potentiostat that will maintain an electrode potential within 1 mV of a preset value over a wide range of applied currents should be used. For the type and size of standard specimen supplied, the potentiostat should have a potential range from -0.6 to 1.6 V and an anodic current output range from 1.0 to 10⁵µA.

4.3 Potential-Measuring Instruments (Note 2):

4.3.1 The potential-measuring circuit should have a high input impedance on the order of 10¹¹ to 10¹⁴Ω to minimize current drawn from the system during measurements. Such

circuits are provided with most potentiostats. Instruments should have sufficient sensitivity and accuracy to detect a change of 1.0 mV over a potential range between -0.6 and 1.6 V.

4.4 Current-Measuring Instruments (Note 2):

4.4.1 An instrument that is capable of measuring a current accurately to within 1 % of the absolute value over a current range between 1.0 and 10⁵µA for a Type 430 stainless steel (UNS S43000) specimen with a surface area of approximately 5 cm².

4.5 Anodic Polarization Circuit:

4.5.1 A schematic potentiostatic anodic polarization wiring

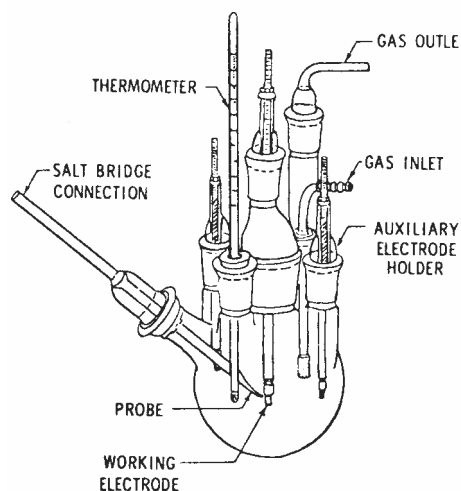


FIG. 3 Schematic Diagram of Polarization Cell (1)

diagram (2) is illustrated in Fig. 4.

4.5.2 A scanning potentiostat is used for potentiodynamic measurements. For such measurements the potentiostat shall be capable of automatically varying the potential at a constant rate between two preset potentials. A record of the potential and current is plotted continuously using such instruments as an X-Y recorder and a logarithmic converter incorporated into the circuit shown in Fig. 4. Some potentiostats have an output of the logarithm of the current as a voltage, which allows direct plotting of the potential log current curve using an X-Y recorder.

NOTE 2—The instrumental requirements are based upon values typical of the instruments in 15 laboratories.

4.6 Electrode Holder (1):

4.6.1 The auxiliary and working electrodes are mounted in the type of holder shown in Fig. 5. A longer holder is required for the working electrode than for the auxiliary electrode. A leak-proof assembly is obtained by the proper compression fit between the electrode and a TFE-fluorocarbon gasket. (Too

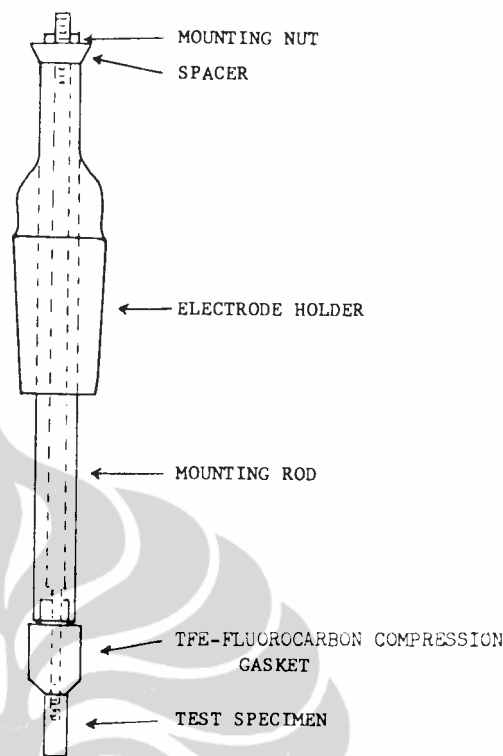


FIG. 5 Specimen Mounted on Electrode Holder

much pressure may cause shielding of the electrode or breakage of the glass holder, and too little pressure may cause leakage and subsequently crevice corrosion which may affect the test results.)

4.7 Electrodes:

4.7.1 Working Electrode, prepared from a 12.7-mm (1/2-in.) length of 9.5-mm (3/8-in.) diameter rod stock. Each electrode is drilled, tapped, and mounted in the manner discussed in 4.6.1.

NOTE 3—If specimen forms are used other than those called for by this test method, for example, flat sheet specimen, care should be taken since it was shown that crevices may be introduced which can lead to erroneous results (see Fig. X1.1).

4.7.1.1 The standard AISI Type 430 stainless steel (UNS S43000) should be used if one wishes to reproduce a standard reference plot. This material is prepared from a single heat of metal that is mill-annealed for 1/2 h at 815°C (1500°F) and air cooled. The chemical composition of the standard stainless steel is supplied with the purchase of reference material.

4.7.2 Auxiliary Electrodes:

4.7.2.1 Two platinum auxiliary electrodes are prepared from high-purity rod stock. Each electrode is drilled, tapped, and mounted with a TFE-fluorocarbon gasket in the same manner as the working electrode. A large platinum sheet sealed into a glass holder is also acceptable.

4.7.2.2 A platinized surface may be utilized because of the increased surface area. This may be accomplished by cleaning the surface in hot aqua regia (3 parts concentrated HCl and 1 part concentrated HNO₃), washing, and then drying. Both electrodes are platinized by immersing them in a solution of 3 % platinum chloride and 0.02 % lead acetate and electrolyzing at a current density of 40 to 50 mA/cm² for 4 or 5 min (1, 3). The polarity is reversed every minute. Occluded chloride is

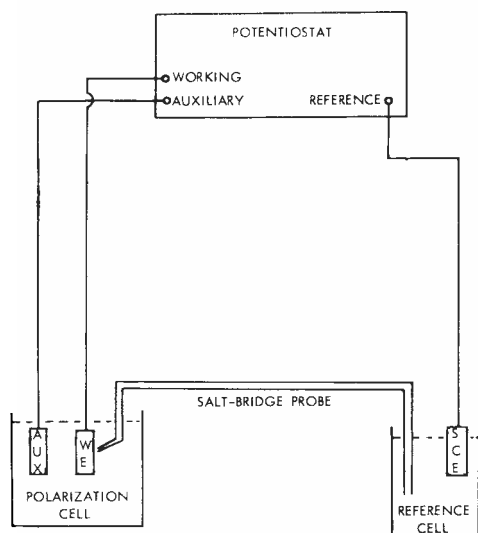


FIG. 4 Schematic Potentiostatic Anodic Polarization Wiring Diagram (2)

removed by electrolyzing in a dilute (10 %) sulfuric acid solution for several minutes with a reversal in polarity every minute. Electrodes are rinsed thoroughly and stored in distilled water until ready for use. Since certain ions can poison these electrodes, periodic checks of platinized platinum potentials against a known reference electrode should be made.

4.7.2.3 Alternatively, graphite auxiliary electrodes can be used, but material retained by the graphite may contaminate subsequent experiments. This contamination can be minimized by using high-density graphite or avoided by routinely replacing the graphite electrode.

4.7.3 Reference Electrode (4):

4.7.3.1 A saturated calomel electrode with a controlled rate of leakage (about 3 $\mu\text{L/h}$) is recommended. This type of electrode is durable, reliable, and commercially available. Precautions shall be taken to ensure that it is maintained in the proper condition. The potential of the calomel electrode should be checked at periodic intervals to ensure the accuracy of the electrode. For other alloy-electrolyte combinations a different reference electrode may be preferred in order to avoid contamination of the reference electrode or the electrolyte.

4.7.3.2 Alternatively, a saturated calomel electrode utilizing a semi-permeable membrane or porous plug tip may be used. These may require special care.

5. Experimental Procedure

5.1 Prepare 1 L of 1.0 N H_2SO_4 from A.C.S. reagent grade acid and distilled water, for example, by using 27.8 mL of 98 % $\text{H}_2\text{SO}_4/\text{L}$ of solution. Transfer 900 mL of solution to the clean polarization cell.

5.2 Place the platinized auxiliary electrodes, salt-bridge probe, and other components in the test cell and temporarily close the center opening with a glass stopper. Fill the salt bridge with test solution.

NOTE 4—When using a controlled leakage salt bridge, the levels of the solution in the reference and polarization cells should be the same to avoid siphoning. If this is impossible, a closed solution-wet (not greased) stopcock can be used in the salt bridge to eliminate siphoning, or a semi-permeable membrane or porous plug tip may be used on the salt bridge.

5.3 Bring the temperature of the solution to $30 \pm 1^\circ\text{C}$ by immersing the test cell in a controlled-temperature water bath or by other convenient means.

5.4 Reduce oxygen levels in solution prior to immersion of the test specimen. This may be accomplished by bubbling an oxygen-free gas such as hydrogen, argon, or nitrogen at a rate of 150 cm^3/min for a minimum of $\frac{1}{2}$ h.

5.5 Prepare the working electrode surface within 1 h of the experiment. Wet grind with 240-grit SiC paper, wet polish with 600-grit SiC paper until previous coarse scratches are removed, rinse, and dry. (Drilled and tapped specimens can be threaded onto an electrode holder rod and secured in a lathe or electric drill for this operation.)

5.6 Determine the surface area by measuring all dimensions to the nearest 0.01 mm, subtracting the area under the gasket (usually 0.20 to 0.25 cm^2).

5.7 Mount the specimen on the electrode holder as described in 4.6.1. Tighten the assembly by holding the upper end of the mounting rod in a vise or clamp while tightening the

mounting nut until the gasket is properly compressed.

5.8 Degrease the specimen just prior to immersion and then rinse in distilled water.

5.9 Transfer the specimen to the test cell and adjust the salt-bridge probe tip so it is about 2 mm or 2 times the tip diameter, whichever is larger from the specimen electrode.

5.10 Record the open-circuit specimen potential, that is, the corrosion potential, after 55 min immersion. If platinum counter electrodes and hydrogen gas are used, record the platinum potential 50 min after immersion of the specimen.

5.11 Potential Scan:

5.11.1 Start the potential scan or step 1 h after specimen immersion, beginning at the corrosion potential (E_{corr}) for potentiodynamic measurements and the nearest 50-mV increment above E_{corr} for the potentiostatic measurements. Proceed through +1.60 V versus saturated calomel electrode (SCE) (active to noble).

5.11.2 In the potentiostatic method, use a potentiostatic potential step rate of 50 mV every 5 min, recording the current at the end of each 5-min period at potential. These steps are repeated until a potential of +1.6 V SCE is reached.

5.11.3 In the potentiodynamic method, use a potentiodynamic potential sweep rate of 0.6 V/h ($\pm 5\%$) recording the current continuously with change in potential from the corrosion potential to +1.6 V SCE.

5.12 Plot anodic polarization data on semilogarithmic paper in accordance with Practice G 3, (potential-ordinate, current density-abcissa). If a potentiostat with a logarithmic converter is used, this plot can be produced directly during the measurement.

6. Standard Reference Plots

6.1 Standard polarization plots prepared from data obtained by following the standard procedure discussed in this test method are supplied with the purchase of reference material. Typical data are shown in Fig. 1 and Fig. 2 (5). The plots show a range of acceptable current density values at each potential. The average corrosion potential is -0.52 V, and the average platinized platinum potential is -0.26 V.

NOTE 5—The plots in Fig. 1 and Fig. 2 correspond to a lot of Type 430 stainless steel that is no longer available from ASTM (after July 1992). Figs. 1 and 2 are presented primarily for the discussion of precision and bias in Sections 6, 7, and Appendix X1. The scatter bands presented in Appendix X2 were developed from a round robin testing program on the lot of Type 430 stainless steel that is currently available from ASTM.

6.2 Typical deviations from the standard potentiostatic plot are shown and discussed in Appendix X1. Reference to this discussion may be helpful in determining the reasons for differences between an experimental curve and the standard plots.

6.3 The potentiodynamic standard curve shows good agreement with the potentiostatic standard curve determined at an equivalent overall polarization rate.

6.4 Differences in the size and placement of the scatter bands presented in Figs. 1 and 2 versus those in Appendix X2 are attributed to minor differences in the two heats of Type 430 stainless steel that were evaluated in separate round robins.

7. Precision and Bias

7.1 The repeatability of this test method is being developed. However, the repeatability on a previous interlaboratory test in which one material was run twice by one laboratory is shown in Fig. 6.

7.2 The reproducibility of this test method is being developed by interlaboratory testing.

7.3 There is no bias in this test method because the potentiodynamic curve is defined only in terms of this test method.

8. Keywords

8.1 anodic polarization; electrochemical testing; pitting; potentiodynamic; potentiostatic; sulfuric acid; Type 430 stainless steel

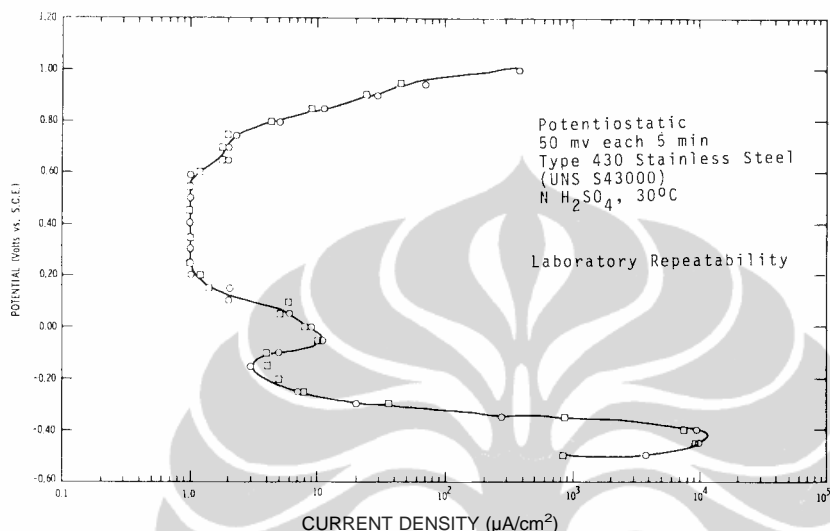


FIG. 6 Laboratory Repeatability of Potentiostatic Anodic Polarization Curve

APPENDIXES

(Nonmandatory Information)

X1. DEVIATIONS FROM STANDARD POLARIZATION PLOTS

X1.1 High Passive Current Densities (Crevice Effect)

X1.1.1 Examples of passive current densities which are greater than those for a standard potentiostatic plot are shown in Fig. X1.1. This effect is attributable to a crevice between the specimen and mounting material (6). The crevice may be the result of the mounting technique or the material used for mounting.

X1.1.2 The potential drop along the narrow path of the electrolyte within the crevice between the specimen and the mounting material prevents this area from passivating. Although the face of the specimen passivates, the high current density associated with the active crevice contributes to an increase in the measured current density. Specimen electrodes for polarization measurements must be mounted without crevice sites to avoid such erroneous passive current densities.

X1.2 Low Passive Current Densities (Instrumental Effect)

X1.2.1 The low passive current densities shown in Fig. X1.2 are undoubtedly the result of instrumental problems. This

effect can be eliminated by calibrating the current over the entire range of interest before conducting an experiment.

X1.3 Cathodic Currents During Anodic Polarization (Oxygen Effect)

X1.3.1 The “negative loop” at potentials between -0.350 V and -0.050 V, shown by dashed lines in Fig. X1.3, occurs when the total cathodic current exceeds the total anodic current. Such results are characteristic of oxygen being present in the solution (7). This effect can be anticipated if the recorded platinum potential is considerably more noble than -0.26 V. The gas purge should remove oxygen from the system, but there may be an air leak or the purge gas may be contaminated with oxygen. It is necessary to take extreme care in the design of glassware equipment and to ensure a high order of purity in the gas that is used to avoid oxygen contamination.

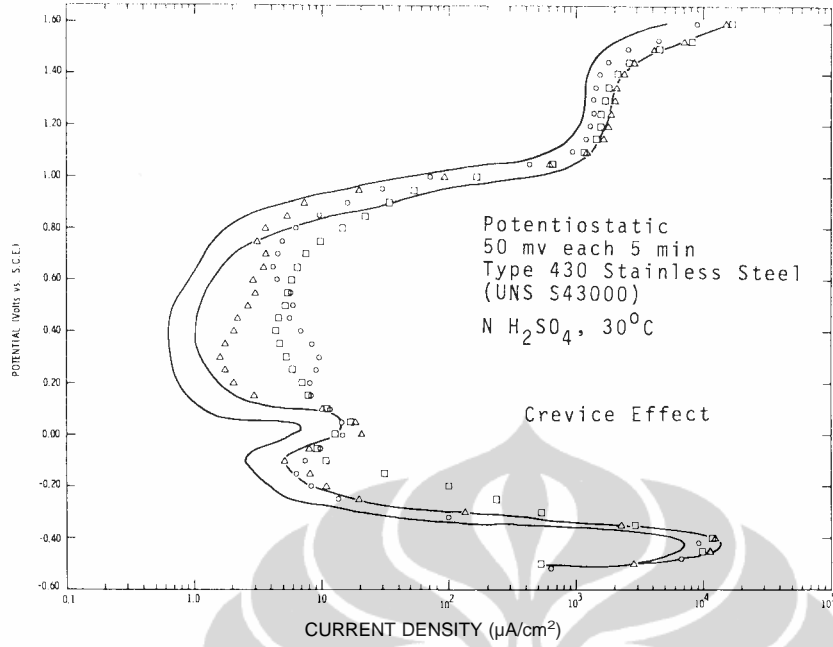


FIG. X1.1 Crevice Effect During Potentiostatic Anodic Polarization

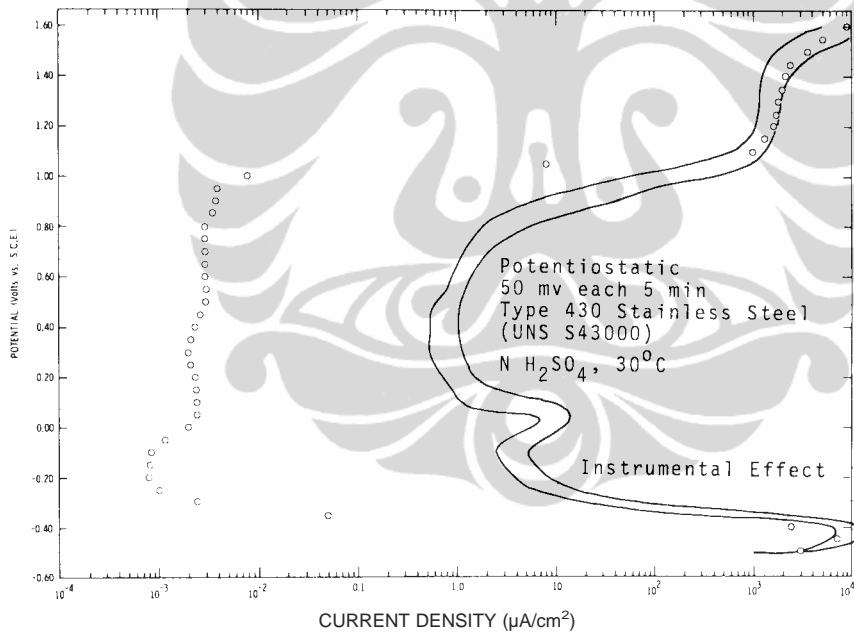


FIG. X1.2 Instrumental Effect During Potentiostatic Anodic Polarization

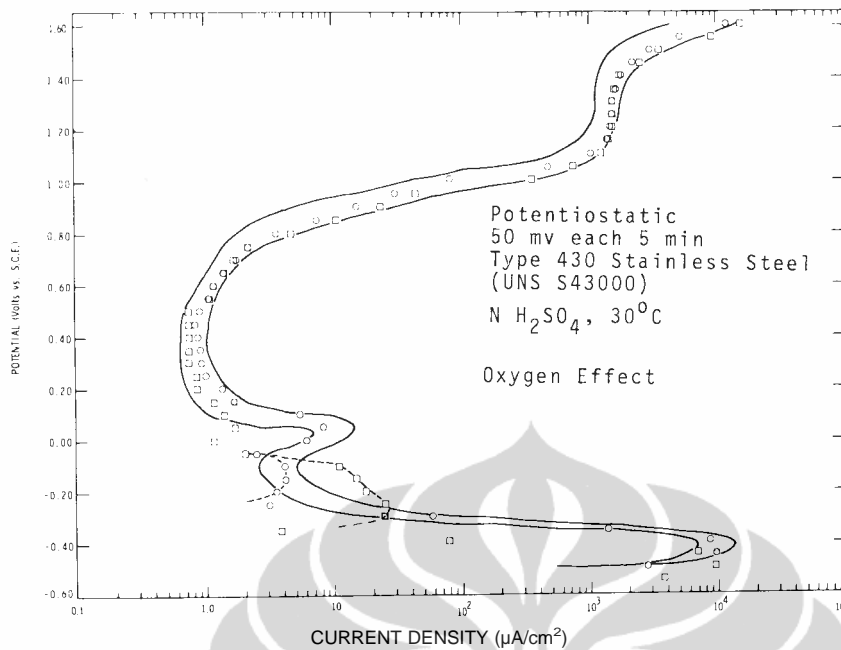


FIG. X1.3 Oxygen Effect During Potentiostatic Anodic Polarization

X2. STANDARD REFERENCE PLOTS FROM ROUND ROBIN TESTS OF THE LOT OF TYPE 430 STAINLESS STEEL

X2.1 Standard polarization plots prepared from data obtained by following the standard procedure discussed in this test method are supplied with the purchase of reference samples.⁶ All of the material available at any given time is from a lot taken from a single heat of Type 430 stainless steel bar stock. Whenever the available supply is exhausted, a new heat must be melted and the new samples qualified in a new round robin test program.

X2.2 The plots in Figs. 1 and 2 correspond to a lot of Type 430 stainless steel that is no longer available from ASTM (after

July 1992). The scatter bands presented in Fig. X2.1 and Fig. X2.2 and Table X2.1 were developed from a round robin testing program on the lot of Type 430 stainless that is currently available from ASTM.

X2.3 Fig. X2.1 and Table X2.1 summarize the round robin potentiodynamic and potentiostatic test results and define scatter bands for the new lot of Type 430 stainless steel. The plots and table show the range of current density values at each potential obtained by the laboratories that participated in the round robin to qualify the new lot of Type 430 stainless steel. Fig. X2.2 compares the scatter bands for the old and new lots of Type 430 stainless steel. The two lots are distinguished by the year of introduction, either 1987 or 1992.

⁶ Available from ASTM Headquarters. Order PCN 12-700050-00.

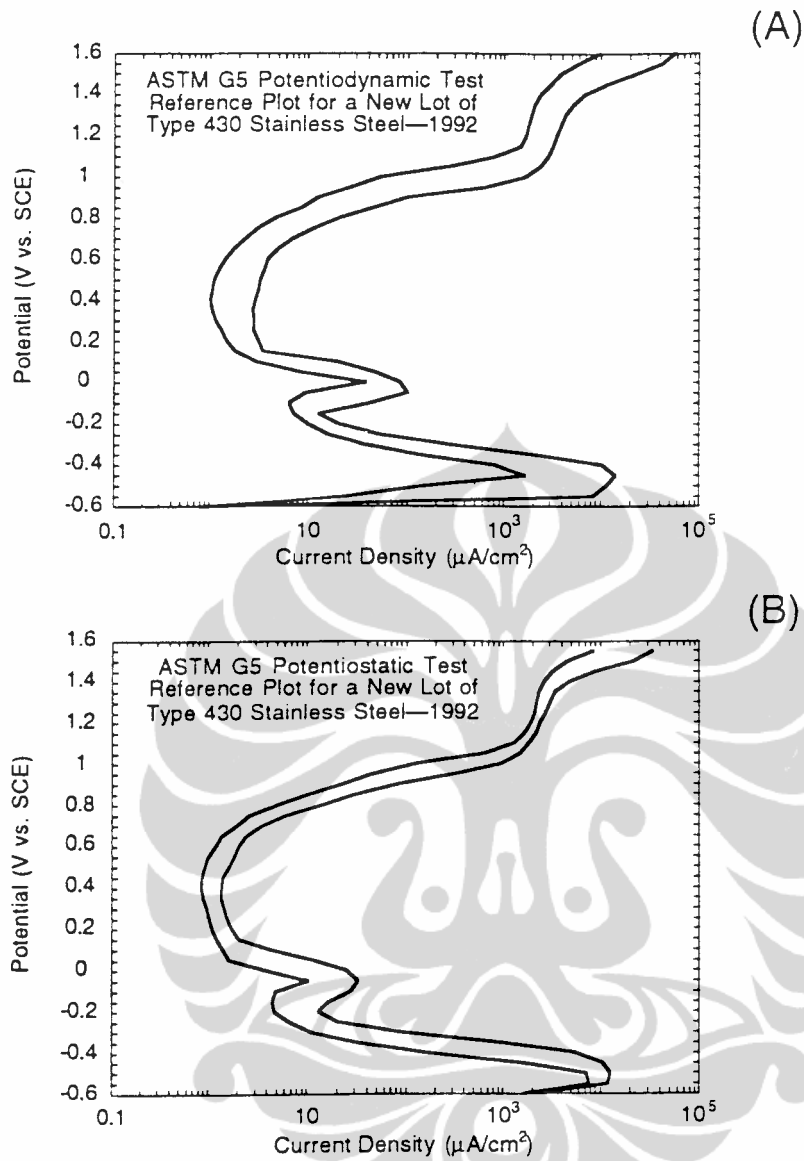


FIG. X2.1 Standard Potentiodynamic (A) and Potentiostatic (B) Polarization Plots for New Type 430 Stainless Steel Standard Introduced in 1992

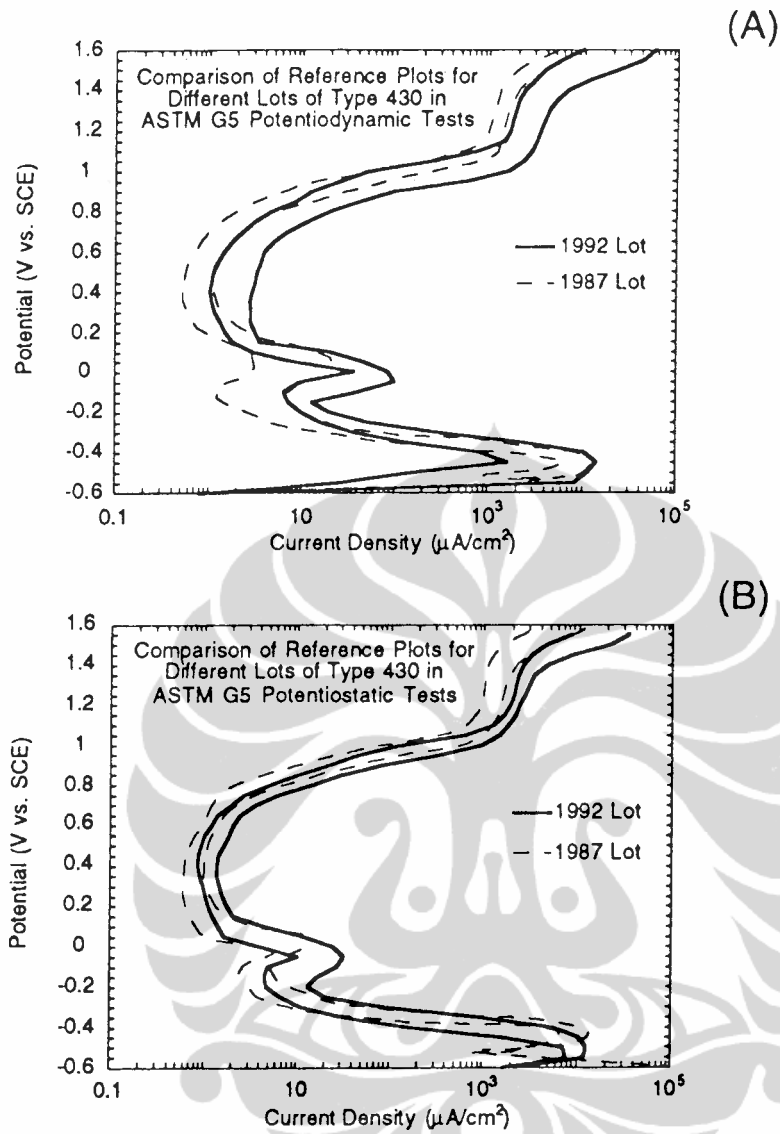


FIG. X2.2 Comparison of the Standard Reference Potentiodynamic (A) and Potentiostatic (B) Polarization Plots for the 1992 and the 1987 Lots of Type 430 Stainless Steel

TABLE X2.1 Range of Current Densities ($\mu\text{A}/\text{cm}^2$) at Cited Polarization Potentials for the 1992 Lot of Type 430 Stainless Steel in G5 Polarization Tests

Potential Volts (v. SCE)	Potentiodynamic		Potentiostatic	
	Min	Max	Min	Max
-0.600	0.76	0.76	1632	2247
-0.500	147	11451	714	12595
-0.400	810	10418	161	5453
-0.300	37.68	282	11.29	87.17
-0.200	10.02	20.23	4.77	13.09
-0.100	6.41	41.44	4.89	27.40
0.000	37.18	84.77	3.92	24.83
0.100	3.00	19.93	1.43	4.35
0.200	1.49	3.13	1.11	1.78
0.300	1.15	2.85	0.98	1.46
0.400	1.02	2.93	0.85	1.39
0.500	1.12	3.30	0.94	1.65
0.600	1.46	3.90	1.20	2.07
0.700	2.27	6.97	1.96	3.51
0.800	4.73	20.59	5.10	14.55
0.900	12.61	99.25	22.0	80.48
1.000	53.40	1628	126	954
1.100	781	2872	1300	1846
1.200	1692	3530	1923	2413
1.300	1925	4283	2176	3026
1.400	2397	6813	2619	4762
1.500	3814	22366	4570	21883
1.600	9775	57341		

X3. RECOMMENDED STANDARD DATA FIELDS FOR COMPUTERIZATION OF DATA FROM TEST METHOD G5

X3.1 In order to encourage uniformity in building computerized corrosion databases and facilitate data comparison and data interchange, it is appropriate to provide recommended standard formats for the inclusion of specific types of test data in such databases. This also has the important effect of encouraging the builders of databases to include sufficiently complete information so that comparisons among individual sources may be made with assurance that the similarities or differences, or both, in the test procedures and conditions are covered therein.

X3.2 Table X3.1 is a recommended standard format for the computerization of potentiostatic and potentiodynamic anodic polarization measurements according to Test Method G 5. There are three columns of information in Table X3.1.

X3.2.1 *Field Number*—This is a reference number for ease of dealing with the individual fields within this format guideline. It has no permanent value and does not become part of the database itself.

X3.2.2 *Field Name and Description*—This is the complete name of the field, descriptive of the element of information that would be included in this field of the database.

X3.2.3 *Category Sets, Values or Units*—This is a listing of the types of information which would be included in the field, or, in the case of properties or other numeric fields, the units in which the numbers are expressed. Category sets are closed (that is, complete) sets containing all possible (or acceptable) inputs to the field. Values are representative sets, listing sample (but not necessarily all acceptable) inputs to the field.

X3.3 The fields or elements of information included in this format are those recommended to provide sufficiently complete

information that users may be confident of their ability to compare sets of data from individual databases and to make the database useful to a relatively broad range of users.

X3.4 It is recognized that many databases are prepared for very specific applications, and individual database builders may elect to omit certain pieces of information considered to be of no value for that specific application. However, there are a certain minimum number of fields considered essential to any database, without which the user will not have sufficient information to reasonably interpret the data. In the recommended standard format, these fields are marked with asterisks.

X3.5 The presentation of this format does not represent a requirement that all of the elements of information included in the recommendation must be included in every database. Rather it is a guide as to those elements that are likely to be useful to at least some users of most databases. It is understood that not all of the elements of information recommended for inclusion will be available for all databases; that fact should not discourage database builders and users from proceeding so long as the minimum basic information is included (the items noted by the asterisks).

X3.6 It is recognized that in some individual cases, additional elements of information of value to users of a database may be available. In those cases, database builders are encouraged to include them as well as the elements in the recommended format. Guidelines for formats for additional elements are given in Guide G 107.

X3.7 This format is for potentiostatic and potentiodynamic anodic polarization measurements generated by Test Method

TABLE X3.1 Recommended Standard Data Fields for Computerization of Data from Test Method G 5

mechanical property data). These items are covered in Guide E 1338 and by separate formats developed for reporting other material property data.

Field No.	Field Name and Description	Category Sets Values or Units
Test Identification		
1*	ASTM standard test method	Test Method G 5
2	Type of test	anodic polarization
3	Date test started	yyyymmdd
4	Internal laboratory reference number	alphanumeric string
Test Apparatus		
5*	Cell similar to Fig. 1 in standard	Y/N
6*	If "No" in 5, describe	alphanumeric string
7	Potentiostat potential stability from preset value	mV, \pm
8	Potentiostat potential range	V/V
9	Impedance of potential measuring circuit	ohm
10	Accuracy of current measurement	percent of absolute value
11*	Electrode holder similar to Fig. 3 in standard	Y/N
12*	If "No" in 11, describe	alphanumeric string
13*	Working electrode	(1) 12.7 long, 9.5 mm rod (2) other
14*	If "Other" in 13, describe	alphanumeric string
15*	Auxiliary electrode	(1) platinum (2) platinized (3) graphite (4) other
16*	If "Other" in 15, describe	alphanumeric string
17*	Reference electrode	(1) saturated calomel (2) Ag/AgCl (3) Cu/CuSO ₄ (4) other
18*	If "Other" in 17, describe	alphanumeric string
Test Specimen		
19*	Standard material (UNS S43000)	Y/N
20*	If "No" in 19, give UNS No.	alphanumeric string
21	Surface area	x.xx cm ²
22	Surfaces wet ground and polished (240/600 grit SiC), degreased	Y/N
23	If "No" in 22, describe the alternate	alphanumeric string
Test Environment		
24*	Standard environment (1 N H ₂ SO ₄ , deaerated by bubbling hydrogen, argon, or nitrogen prior to specimen exposure).	Y/N
25*	If "No" in 24, describe	alphanumeric string
26	Standard cell volume (900 mL)	Y/N
27	If "No" in 26, then give volume	mL
37	Low passive current density attributed to instrumental problems	Y/N
38	Negative loop attributed to oxygen in solution	Y/N

* Denotes essential information.

G 5. It does not include the recommended material descriptors or the presentation of other specific types of test data (such as

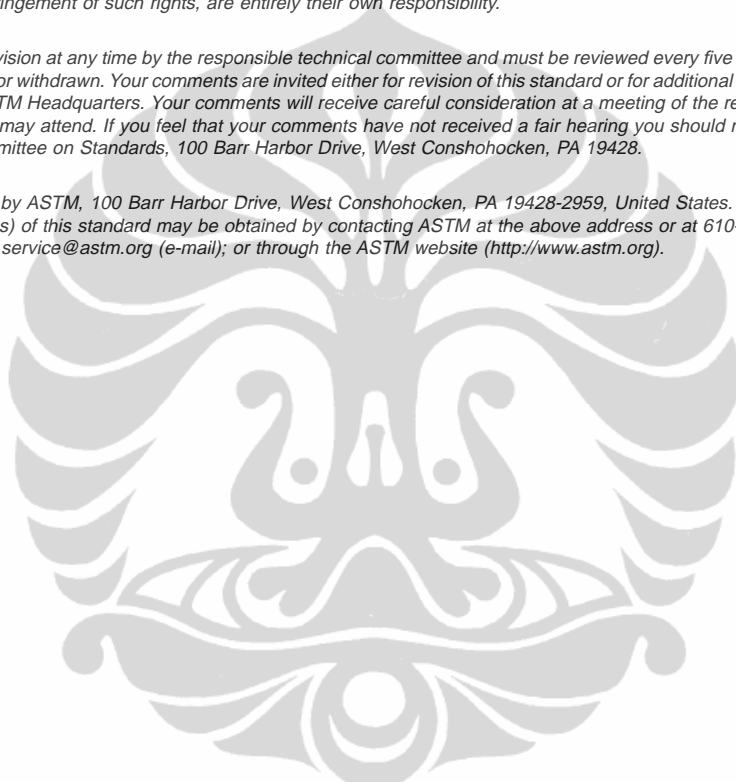
REFERENCES

- (1) Greene, N. D., *Experimental Electrode Kinetics*, Rensselaer Polytechnic Institute, Troy, NY, 1965.
- (2) France, Jr., W. D., "Controlled Potential Corrosion Tests, Their Applications and Limitations," *Materials Research and Standards*, Vol 9, No. 8, 1969, p. 21.
- (3) Mellon, M. G., *Quantitative Analysis*, Thomas Y. Crowell Co., New York, 1955.
- (4) Ives, D. J., and Janz, G. J., *Reference Electrodes, Theory and Practice*, Academic Press, New York, NY, 1961.
- (5) "The Reproducibility of Potentiostatic and Potentiodynamic Anodic Polarization Measurements," ASTM Subcommittee G-1/XI, Section I, Interlaboratory Testing Program, June, 1967. Available from ASTM Headquarters as RR: G01-1000.
- (6) Greene, N. D., France, Jr., W. D., and Wilde, B. E., "Electrode Mounting for Potentiostatic Anodic Polarization Studies," *Corrosion, CORRA*, Vol 21, 1965, p. 275.
- (7) Greene, N. D., "Effect of Oxygen on the Active-Passive Behavior of Stainless Steel," *Journal of the Electrochemical Society, JESOA*, Vol 107, 1960, p. 457.

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Lampiran-3.

*ASTM G61-86 Standard Test Method
for Conducting Cyclic Potentiodynamic
Polarization Measurement for Localized
Corrosion Susceptibility of Iron-, Nickel-
, or Cobalt Base Alloy*



Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of Iron-, Nickel-, or Cobalt-Based Alloys¹

This standard is issued under the fixed designation G 61; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method gives a procedure for conducting cyclic potentiodynamic polarization measurements to determine relative susceptibility to localized corrosion (pitting and crevice corrosion) for iron-, nickel-, or cobalt-based alloys in a chloride environment. This test method also describes an experimental procedure which can be used to check one's experimental technique and instrumentation.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water²

G 3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing³

G 5 Reference Test Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements³

3. Significance and Use

3.1 An indication of the susceptibility to initiation of localized corrosion in this test method is given by the potential at which the anodic current increases rapidly. The more noble this potential, obtained at a fixed scan rate in this test, the less susceptible is the alloy to initiation of localized corrosion. The results of this test are not intended to correlate in a quantitative manner with the rate of propagation that one might observe in service when localized corrosion occurs.

3.2 In general, once initiated, localized corrosion can propagate at some potential more electropositive than that at which the hysteresis loop is completed. In this test method, the potential at which the hysteresis loop is completed is determined at a fixed scan rate. In these cases, the more electropo-

sitive the potential at which the hysteresis loop is completed the less likely it is that localized corrosion will occur.

3.3 If followed, this test method will provide cyclic potentiodynamic anodic polarization measurements that will reproduce data developed at other times in other laboratories using this test method for the two specified alloys discussed in 3.4. The procedure is used for iron-, nickel-, or cobalt-based alloys in a chloride environment.

3.4 A standard potentiodynamic polarization plot is included. These reference data are based on the results from five different laboratories that followed the standard procedure, using specific alloys of Type 304 stainless steel, UNS S30400 and Alloy C-276, UNS N10276.⁴ Curves are included which have been constructed using statistical analysis to indicate the acceptable range of polarization curves.

3.5 The availability of a standard test method, standard material, and standard plots should make it easy for an investigator to check his techniques to evaluate susceptibility to localized corrosion.

4. Apparatus

4.1 The polarization cell should be similar to the one described in Practice G 5. Other polarization cells may be equally suitable.

4.1.1 The cell should have a capacity of about 1 L and should have suitable necks or seals to permit the introduction of electrodes, gas inlet and outlet tubes, and a thermometer. The Luggin probe-salt bridge separates the bulk solution from the saturated calomel reference electrode. The probe tip should be adjustable so that it can be brought into close proximity with the working electrode.

4.2 *Specimen Holder:*

4.2.1 Specimens should be mounted in a suitable holder designed for flat strip, exposing 1 cm² to the test solution (Fig. 1). Such specimen holders have been described in the literature.^{5,6} It is important that the circular TFE-fluorocarbon gasket be drilled and machined flat in order to minimize crevices.

¹ This test method is under the jurisdiction of ASTM Committee G-1 on Corrosion of Metals and is the direct responsibility of Subcommittee G.01.11 on Electrochemical Measurements in Corrosion Testing.

Current edition approved Nov. 28, 1986. Published January 1987.

² *Annual Book of ASTM Standards*, Vol 11.01.

³ *Annual Book of ASTM Standards*, Vol 03.02.

⁴ These standard samples are available as a set of one of each type from ASTM Headquarters at a nominal cost Order PCN 12-7006100-22

⁵ France, W. D., Jr., *Journal of the Electrochemical Society*, Vol 114, 1967, p. 818.

⁶ Myers, J. R., Gruewlar, F. G., and Smulezenski, L. A., *Corrosion*, Vol 24, 1968, p. 352.

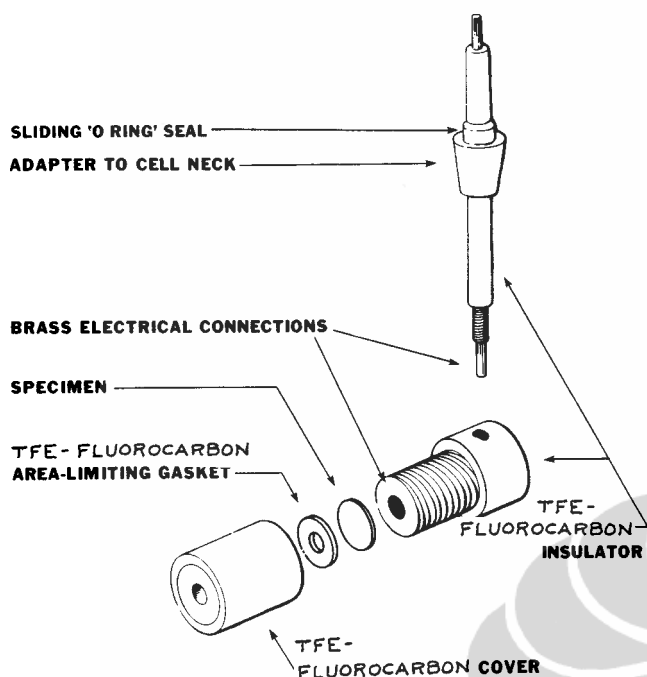


FIG. 1 Schematic Diagram of Specimen Holder^{4,5}

4.3 *Potentiostat* (Note 1)—A potentiostat that will maintain an electrode potential within 1 mV of a preset value over a wide range of applied currents should be used. For the type and size of standard specimen supplied, the potentiostat should have a potential range of - 1.0 to + 1.6 V and an anodic current output range of 1.0 to 10⁵ μA. Most commercial potentiostats meet the specific requirements for these types of measurements.

NOTE 1—These instrumental requirements are based upon values typical of the instruments in the five laboratories that have provided the data used in determining the standard polarization plot.

4.4 *Potential-Measuring Instruments* (Note 1)—The potential-measuring circuit should have a high input impedance on the order of 10¹¹ to 10¹⁴ Ω to minimize current drawn from the system during measurements. Instruments should have sufficient sensitivity and accuracy to detect a change in potential of ±1 mV, usually included in commercial potentiostats. An output as a voltage is preferred for recording purposes.

4.5 *Current-Measuring Instruments* (Note 1)—An instrument that is capable of measuring a current accurately to within 1 % of the absolute value over a current range between 1.0 and 10⁵ μA should be used. Many commercial units have a build-in instrument with an output as a voltage, which is preferred for recording purposes. For the purpose of the present test a logarithmic output is desirable.

4.6 *Anodic Polarization Circuit*—A scanning potentiostat is used for potentiodynamic measurements. Potential and current are plotted continuously using an X-Y recorder and a logarithmic converter (contained in the potentiostat or incorporated into the circuit) for the current. Commercially available units are suitable.

4.7 *Electrodes:*

4.7.1 The standard Type 304 stainless steel (UNS S30400) and Alloy C-276 (UNS N10276) should be machined into flat

0.625-in. (14-mm) diameter disks. The chemical compositions of the alloys used in the round robin are listed in Table 1.

4.7.2 *Counter Electrodes*—The counter electrodes may be prepared as described in Practice G 5 or may be prepared from high-purity platinum flat stock and wire. A suitable method would be to seal the platinum wire in glass tubing and introduce the platinum electrode assembly through a sliding seal. Counter electrodes should have an area at least twice as large as the test electrode.

4.7.3 *Reference Electrode*⁷—A saturated calomel electrode with a controlled rate of leakage (about 3 μL/h) is recommended. This type of electrode is durable, reliable, and commercially available. Precautions should be taken to ensure that it is maintained in the proper condition. The potential of the calomel electrode should be checked at periodic intervals to ensure the accuracy of the electrode.

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 shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.⁸ 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*—The water shall be distilled or deionized conforming to the purity requirements of Specification D 1193, Type IV reagent water.

5.3 Sodium Chloride (NaCl).

5.4 Samples of Standard Type 304 stainless steel (UNS S30400) and the Alloy C-276 (UNS N10276) used in obtaining the standard reference plot are available for those who wish to check their own test procedure and equipment.

⁷ Ives, D. J., and Janz, G. J., *Reference Electrodes, Theory and Practice*, Academic Press, New York, NY 1961.

⁸ *Reagent Chemicals, American Chemical Society Specifications*, Am. Chemical Soc., 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."

TABLE 1 Chemical Composition of Alloys Used in the Round Robin, Weight %

Element	Alloy C-276 (UNS N10276)	Type 304 Stainless Steel (UNS S30400)
Carbon	0.003	0.060
Chromium	15.29	18.46
Cobalt	2.05	...
Columbium	...	0.11
Copper	...	0.17
Iron	5.78	balance
Manganese	0.48	1.43
Molybdenum	16.03	0.17
Nickel	balance	8.74
Phosphorus	0.018	0.029
Silicon	0.05	0.60
Sulfur	0.006	0.014
Vanadium	0.20	...
Tungsten	3.62	...

6. Procedure

6.1 Test Specimen Preparation:

6.1.1 Wet grind with 240-grit SiC paper, wet polish with 600-grit SiC paper until previous coarse scratches are removed, rinse, and dry.

6.1.2 Prior to assembly of the specimen holder, ultrasonically degrease the specimen for 5 min in detergent and water, rinse thoroughly in distilled water, and dry.

6.1.3 Mount the specimen in the electrode holder. Tighten the assembly until the TFE-fluorocarbon gasket is sufficiently compressed to avoid leakage in the gasket.

6.2 Prepare a 3.56 % (by weight) sodium chloride solution by dissolving 34 g of reagent grade NaCl in 920 mL of distilled water.

6.3 Assemble the electrode holder and place in the polarization cell. Transfer 900 mL of test solution to the polarization cell, ensuring that the specimen remains above the solution level.

6.4 Bring the temperature of the solution of $25 \pm 1^\circ\text{C}$ by immersing the test cell in a controlled-temperature water bath or by other convenient means.

6.5 Place the platinum auxiliary electrodes, salt-bridge probe, and other components in the test cell. Fill the salt bridge with test solution and locate the probe tip approximately 1 mm from the working electrode.

NOTE 2—The levels of the solution in the reference and polarization cells should be the same. If this is impossible, a closed solution-wet (not greased) stopcock can be used in the salt bridge to eliminate siphoning.

6.6 Purge the solution sufficiently with an appropriate gas to remove oxygen before specimen immersion (minimum of 1 h).

6.7 Immerse the specimen for 1 h before initiating polarization. A sliding seal can be used to ensure that an oxygen-free environment is maintained while the specimen is lowered. It is important that all oxygen be removed by purging prior to polarization, otherwise, more noble initial corrosion potential values will be observed.

6.8 Record the platinum potential 50 min after immersion of the specimen. Record the open-circuit specimen potential, that is, the corrosion potential, the instant before beginning polarization.

6.9 *Potential Scan*—Start the potential scan 1 h after specimen immersion, beginning at the corrosion potential (E_{corr}), and scan in the more noble direction at a scan rate of 0.6 V/h ($\pm 5\%$). Record the current continuously with change in potential on an X-Y recorder using semilogarithmic paper.

6.9.1 The onset of localized corrosion is usually marked by a rapid increase of the anodic current at potentials below the oxygen-evolution potential. When the current reaches 5 mA ($5 \times 10^3 \mu\text{A}$), reverse the scanning direction (toward more active potentials).

6.9.2 Continue the reverse scan until the hysteresis loop closes or until the corrosion potential is reached.

6.10 Plot anodic polarization data on semilogarithmic paper in accordance with Practice G 3 (potential-ordinate, current density-abscissa). A plot of representative polarization curves generated by the practice is shown in Fig. 2.

7. Interpretation of Results

7.1 The polarization curves shown in Fig. 2, Fig. 3, and Fig. 4 indicate that initiation and propagation of localized corrosion occurs at potentials more electronegative than the oxygen evolution potential on Type 304 stainless steel (UNS S30400) in the chloride environment. The curve for Alloy C-276 (UNS N10276) is not a result of localized corrosion but of uniform corrosion in the transpassive or oxygen evolution region. Since the corrosion potentials (E_{corr} values) for Alloy C-276 (UNS N10276) and Type 304 stainless steel (UNS S30400) are usually similar, these curves indicate that Alloy C-276 is more resistant to initiation and propagation of localized corrosion than Type 304 stainless steel.

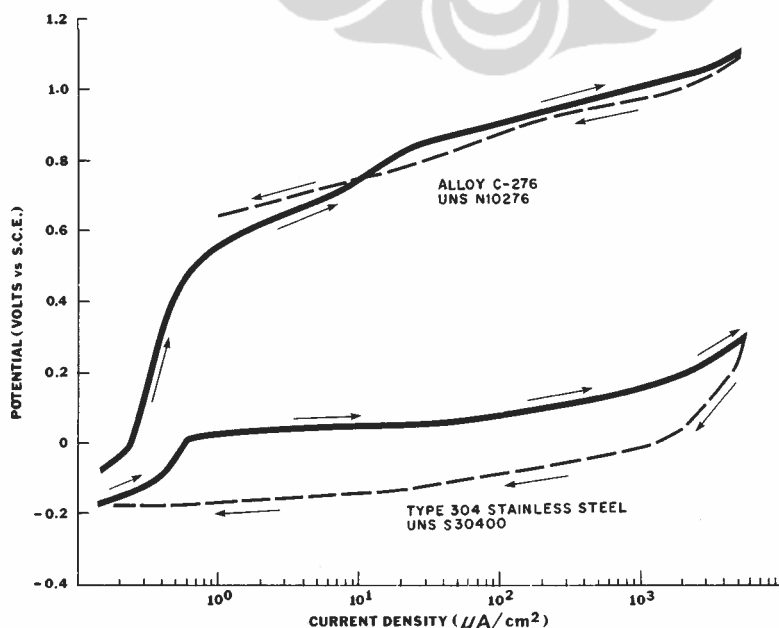


FIG. 2 Representative Cyclic Potentiodynamic Polarization Curves

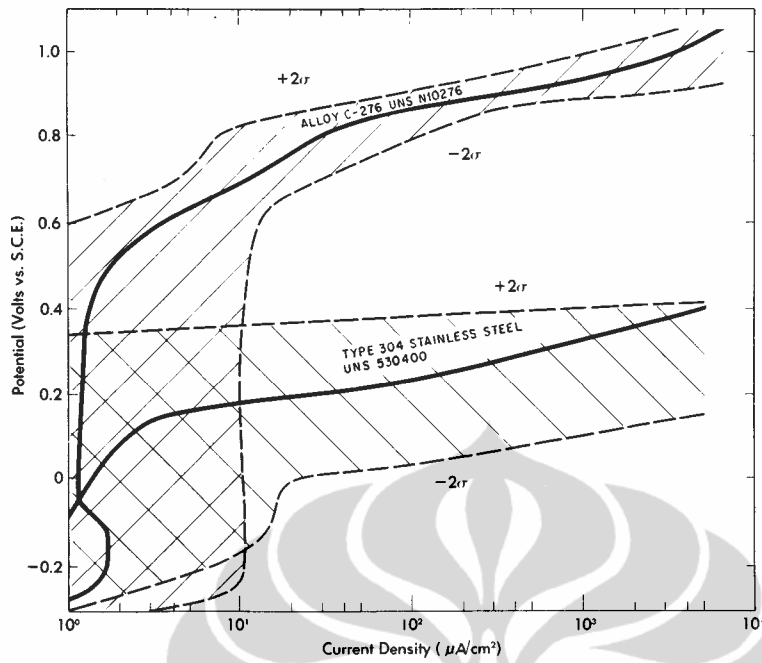


FIG. 3 Standard Potentiodynamic Polarization Plot (Forward Scan)

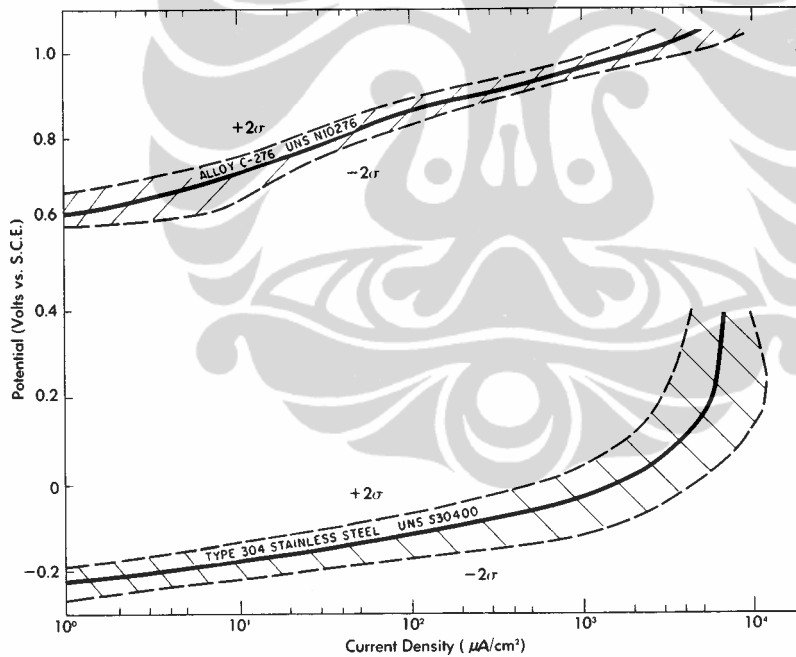


FIG. 4 Standard Potentiodynamic Polarization Plot (Reverse Scan)

8. Precision and Bias

8.1 A standard polarization plot, based on the potentiodynamic data from five different laboratories, has been prepared. The plot has been separated into the forward (Fig. 3) and reverse (Fig. 4) scans for clarity. These plots show the mean values and a range of ± 2 standard deviations.

8.2 The spread in data obtained from a number of laboratories and used in the preparation of the standard plot (Fig. 3 and Fig. 4) demonstrates the reproducibility that is possible when a standard procedure is followed. An investigator's data should fall within the range of ± 2 standard deviations since

this includes 95 % of all data provided random variations are the only source of error. No information is available on the repeatability when one laboratory conducts several identical tests. Crevice corrosion under gaskets may lead to erroneous results.

8.3 When testing iron-, nickel-, and cobalt-based alloys according to this test method, the repeatability and reproducibility would be expected to be similar to the standard material. However, no data is currently available on other alloys.

8.4 This test method, when conducted in accordance with the procedures described herein, ranks some iron-, nickel-, and

cobalt-based alloys relative to their resistance to crevice and pitting corrosion in chloride-containing environments, such as seawater. The test method will not necessarily rank materials properly in environments which are significantly different from

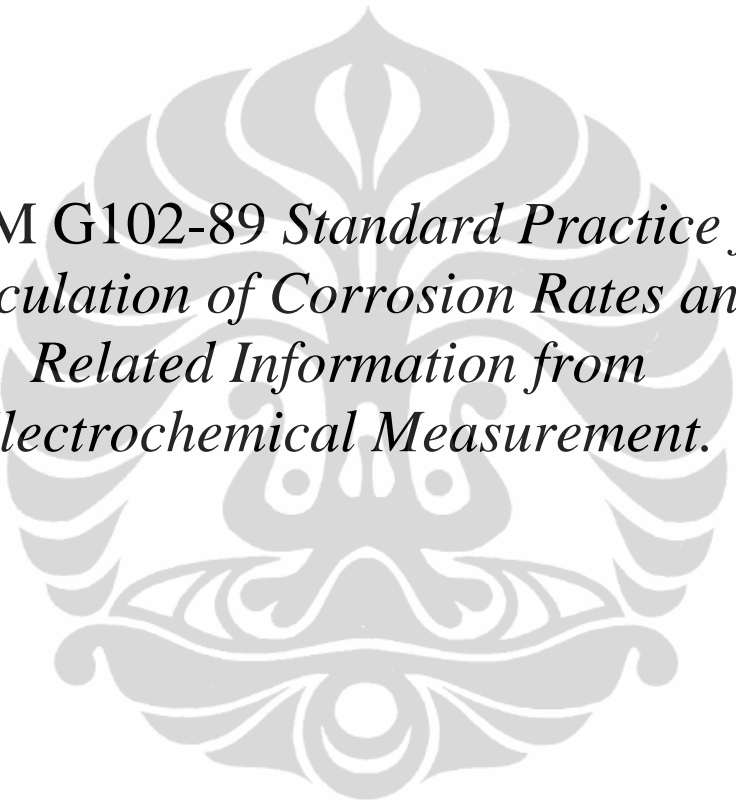
aqueous, ambient temperature aerated sodium chloride. For other alloys tested in other electrolytes, there is currently no information.

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Lampiran-4.



*ASTM G102-89 Standard Practice for
Calculation of Corrosion Rates and
Related Information from
Electrochemical Measurement.*



Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements¹

This standard is issued under the fixed designation G 102; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice is intended to provide guidance in converting the results of electrochemical measurements to rates of uniform corrosion. Calculation methods for converting corrosion current density values to either mass loss rates or average penetration rates are given for most engineering alloys. In addition, some guidelines for converting polarization resistance values to corrosion rates are provided.

2. Referenced Documents

2.1 ASTM Standards:

- D 2776 Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Electrical Methods)²
- G 1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens³
- G 5 Reference Test Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements³
- G 59 Practice for Conducting Potentiodynamic Polarization Resistance Measurements³

3. Significance and Use

3.1 Electrochemical corrosion rate measurements often provide results in terms of electrical current. Although the conversion of these current values into mass loss rates or penetration rates is based on Faraday's Law, the calculations can be complicated for alloys and metals with elements having multiple valence values. This practice is intended to provide guidance in calculating mass loss and penetration rates for such alloys. Some typical values of equivalent weights for a variety of metals and alloys are provided.

3.2 Electrochemical corrosion rate measurements may provide results in terms of electrical resistance. The conversion of these results to either mass loss or penetration rates requires additional electrochemical information. Some approaches for estimating this information are given.

3.3 Use of this practice will aid in producing more consistent corrosion rate data from electrochemical results. This will

make results from different studies more comparable and minimize calculation errors that may occur in transforming electrochemical results to corrosion rate values.

4. Corrosion Current Density

4.1 Corrosion current values may be obtained from galvanic cells and polarization measurements, including Tafel extrapolations or polarization resistance measurements. (See Reference Test Method G 5 and Practice G 59 for examples.) The first step is to convert the measured or estimated current value to current density. This is accomplished by dividing the total current by the geometric area of the electrode exposed to the solution. It is assumed that the current distributes uniformly across the area used in this calculation. In the case of galvanic couples, the exposed area of the anodic specimen should be used. This calculation may be expressed as follows:

$$i_{\text{cor}} = \frac{I_{\text{cor}}}{A} \quad (1)$$

where:

- i_{cor} = corrosion current density, $\mu\text{A}/\text{cm}^2$,
- I_{cor} = total anodic current, μA , and
- A = exposed specimen area, cm^2 .

Other units may be used in this calculation. In some computerized polarization equipment, this calculation is made automatically after the specimen area is programmed into the computer. A sample calculation is given in Appendix X1.

4.2 *Equivalent Weight*—Equivalent weight, EW, may be thought of as the mass of metal in grams that will be oxidized by the passage of one Faraday ($96\,489 \pm 2 \text{ C (amp-sec)}$) of electric charge.

NOTE 1—The value of EW is not dependent on the unit system chosen and so may be considered dimensionless.

For pure elements, the equivalent weight is given by:

$$EW = \frac{W}{n} \quad (2)$$

where:

- W = the atomic weight of the element, and
- n = the number of electrons required to oxidize an atom of the element in the corrosion process, that is, the valence of the element.

4.3 For alloys, the equivalent weight is more complex. It is usually assumed that the process of oxidation is uniform and

¹ This practice is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.11 on Electrochemical Measurements in Corrosion Testing.

Current edition approved Feb. 24, 1989. Published May 1989. Originally published as G 102–89. Last previous edition G 102–89 (1994)^{ε1}.

² Discontinued—See 1990 Annual Book of ASTM Standards, Vol 03.02.

³ Annual Book of ASTM Standards, Vol 03.02.

does not occur selectively to any component of the alloy. If this is not true, then the calculation approach will need to be adjusted to reflect the observed mechanism. In addition, some rationale must be adopted for assigning values of n to the elements in the alloy because many elements exhibit more than one valence value.

4.4 To calculate the alloy equivalent weight, the following approach may be used. Consider a unit mass of alloy oxidized. The electron equivalent for 1 g of an alloy, Q is then:

$$Q = \frac{\sum n_i f_i}{W_i} \quad (3)$$

where:

- f_i = the mass fraction of the i^{th} element in the alloy,
- W_i = the atomic weight of the i^{th} element in the alloy, and
- n_i = the valence of the i^{th} element of the alloy.

Therefore, the alloy equivalent weight, EW , is the reciprocal of this quantity:

$$EW = \frac{1}{\sum \frac{n_i f_i}{W_i}} \quad (4)$$

Normally only elements above 1 mass percent in the alloy are included in the calculation. In cases where the actual analysis of an alloy is not available, it is conventional to use the mid-range of the composition specification for each element,

unless a better basis is available. A sample calculation is given in Appendix X2 (1).⁴

4.5 Valence assignments for elements that exhibit multiple valences can create uncertainty. It is best if an independent technique can be used to establish the proper valence for each alloying element. Sometimes it is possible to analyze the corrosion products and use those results to establish the proper valence. Another approach is to measure or estimate the electrode potential of the corroding surface. Equilibrium diagrams showing regions of stability of various phases as a function of potential and pH may be created from thermodynamic data. These diagrams are known as Potential-pH (Pourbaix) diagrams and have been published by several authors (2, 3). The appropriate diagrams for the various alloying elements can be consulted to estimate the stable valence of each element at the temperature, potential, and pH of the contacting electrolyte that existed during the test.

NOTE 2—Some of the older publications used inaccurate thermodynamic data to construct the diagrams and consequently they are in error.

4.6 Some typical values of EW for a variety of metals and alloys are given in Table 1.

⁴ The boldface numbers in parentheses refer to the list of references at the end of this standard.

TABLE 1 Equivalent Weight Values for a Variety of Metals and Alloys

Common Designation	UNS	Elements w/Constant Valence	Lowest		Second		Third		Fourth	
			Variable Valence	Equivalent Weight	Variable Valence	Equivalent Weight	Element/Valence	Equivalent Weight	Element/Valence	Equivalent Weight
<i>Aluminum Alloys:</i>										
AA1100 ⁴	A91100	Al/3		8.99						
AA2024	A92024	Al/3, Mg/2	Cu/1	9.38	Cu/2	9.32				
AA2219	A92219	Al/3	Cu/1	9.51	Cu/2	9.42				
AA3003	A93003	Al/3	Mn/2	9.07	Mn/4	9.03	Mn 7	8.98		
AA3004	A93004	Al/3, Mg/2	Mn/2	9.09	Mn/4	9.06	Mn 7	9.00		
AA5005	A95005	Al/3, Mg/2		9.01						
AA5050	A95050	Al/3, Mg/2		9.03						
AA5052	A95052	Al/3, Mg/2		9.05						
AA5083	A95083	Al/3, Mg/2		9.09						
AA5086	A95086	Al/3, Mg/2		9.09						
AA5154	A95154	Al/3, Mg/2		9.08						
AA5454	A95454	Al/3, Mg/2		9.06						
AA5456	A95456	Al/3, Mg/2		9.11						
AA6061	A96061	Al/3, Mg/2		9.01						
AA6070	A96070	Al/3, Mg/2, Si/4		8.98						
AA6101	A96161	Al/3		8.99						
AA7072	A97072	Al/3, Zn/2		9.06						
AA7075	A97075	Al/3, Zn/2, Mg/2	Cu/1	9.58	Cu/2	9.55				
AA7079	A97079	Al/3, Zn/2, Mg/2		9.37						
AA7178	A97178	Al/3, Zn/2, Mg/2	Cu/1	9.71	Cu/2	9.68				
<i>Copper Alloys:</i>										
CDA110	C11000		Cu/1	63.55	Cu/2	31.77				
CDA220	C22000	Zn/2	Cu/1	58.07	Cu/2	31.86				
CDA230	C23000	Zn/2	Cu/1	55.65	Cu/2	31.91				
CDA260	C26000	Zn/2	Cu/1	49.51	Cu/2	32.04				
CDA280	C28000	Zn/2	Cu/1	46.44	Cu/2	32.11				
CDA444	C44300	Zn/2	Cu/1, Sn/2	50.42	Cu/1, Sn/4	50.00	Cu/2, Sn/4	32.00		
CDA687	C68700	Zn/2, Al/3	Cu/1	48.03	Cu/2	30.29				
CDA608	C60800	Al/3	Cu/1	47.114	Cu/2	27.76				
CDA510	C51000		Cu/1, Sn/2	63.32	Cu/1, Sn/4	60.11	Cu/2, Sn/4	31.66		
CDA524	C52400		Cu/1, Sn/2	63.10	Cu/1, Sn/4	57.04	Cu/2, Sn/4	31.55		

TABLE 1 Continued

Common Designation	UNS	Elements w/Constant Valence	Lowest		Second		Third		Fourth	
			Variable Valence	Equivalent Weight	Variable Valence	Equivalent Weight	Element/Valence	Equivalent Weight	Element/Valence	Equivalent Weight
CDA655	C65500	Si/4	Cu/1	50.21	Cu/2	28.51				
CDA706	C70600	Ni/2	Cu/1	56.92	Cu/2	31.51				
CDA715	C71500	Ni/2	Cu/1	46.69	Cu/2	30.98				
CDA752	C75200	Ni/2, Zn/2	Cu/1	46.38	Cu/2	31.46				
<i>Stainless Steels:</i>										
304	S30400	Ni/2	Fe/2, Cr/3	25.12	Fe/3, Cr/3	18.99	Fe/3, Cr/6	15.72		
321	S32100	Ni/2	Fe/2, Cr/3	25.13	Fe/3, Cr/3	19.08	Fe/3, Cr/6	15.78		
309	S30900	Ni/2	Fe/2, Cr/3	24.62	Fe/3, Cr/3	19.24	Fe/3, Cr/6	15.33		
310	S31000	Ni/2	Fe/2, Cr/3	24.44	Fe/3, Cr/3	19.73	Fe/3, Cr/6	15.36		
316	S31600	Ni/2	Fe/2, Cr/3, Mo/3	25.50	Fe/2, Cr/3, Mo/4	25.33	Fe/3, Cr/6, Mo/6	19.14	Fe/3, Cr/6, Mo/6	16.11
317	S31700	Ni/2	Fe/2, Cr/3, Mo/3	25.26	Fe/2, Cr/3, Mo/4	25.03	Fe/3, Cr/3, Mo/6	19.15	Fe/3, Cr/6, Mo/6	15.82
410	S41000		Fe/2, Cr/3	25.94	Fe/3, Cr/3	18.45	Fe/3, Cr/6	16.28		
430	S43000		Fe/2, Cr/3	25.30	Fe/3, Cr/3	18.38	Fe/3, Cr/6	15.58		
446	S44600		Fe/2, Cr/3	24.22	Fe/3, Cr/3	18.28	Fe/3, Cr/6	14.46		
20CB3 ^A	N08020	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	23.98	Fe/2, Cr/3, Mo/4, Cu/1	23.83	Fe/3, Cr/3, Mo/6, Cu/2	18.88	Fe/3, Cr/6, Mo/6, Cu/2	15.50
<i>Nickel Alloys:</i>										
200	N02200		Ni/2	29.36	Ni/3	19.57				
400	N04400	Ni/2	Cu/1	35.82	Cu/2	30.12				
600	N06600	Ni/2	Fe/2, Cr/3	26.41	Fe/3, Cr/3	25.44	Fe/3, Cr/6	20.73		
800	N08800	Ni/2	Fe/2, Cr/3	25.10	Fe/3, Cr/3	20.76	Fe/3, Cr/6	16.59		
825	N08825	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	25.52	Fe/2, Cr/3, Mo/4, Cu/1	25.32	Fe/3, Cr/3, Mo/6, Cu/2	21.70	Fe/3, Cr/6, Mo/6, Cu/2	17.10
B	N10001	Ni/2	Mo/3, Fe/2	30.05	Mo/4, Fe/2	27.50	Mo/6, Fe/2	23.52	Mo/6, Fe/3	23.23
C-22 ^B	N06022	Ni/2	Fe/2, Cr/3, Mo/3, W/4	26.04	Fe/2, Cr/3, Mo/4, W/4	25.12	Fe/2, Cr/3, Mo/6, W/6	23.28	Fe/3, Cr/6, Mo/6, W/6	17.88
C-276	N10276	Ni/2	Fe/2, Cr/3, Mo/3, W/4	27.09	Cr/3, Mo/4	25.90	Fe/2, Cr/3, Mo/6, W/6	23.63	Fe/3, Cr/6, Mo/6, W/6	19.14
G	N06007	Ni/2	(1)	25.46	(2)	22.22	(3)	22.04	(4)	17.03
<i>Carbon Steel:</i>										
			Fe/2	27.92	Fe/3	18.62				
(1) = Fe/2, Cr/3, Mo/3, Cu/1, Nb/4, Mn/2			(3) = Fe/3, Cr/3, Mo/6, Cu/2, Nb/5, Mn/2							
(2) = Fe/2, Cr/3, Mo/4, Cu/2, Nb/5, Mn/2			(4) = Fe/3, Cr/6, Mo/6, Cu/2, Nb/5, Mn/4							
<i>Other Metals:</i>										
Mg	M14142	Mg/2		12.15						
Mo	R03600		Mo/3	31.98	Mo/4	23.98	Mo/6	15.99		
Ag	P07016		Ag/1	107.87	Ag/2	53.93				
Ta	R05210	Ta/5		36.19						
Sn	L13002		Sn/2	59.34	Sn/4	29.67				
Ti	R50400		Ti/2	23.95	Ti/3	15.97	Ti/4	11.98		
Zn	Z19001	Zn/2		32.68						
Zr	R60701	Zr/4		22.80						
Pb	L50045		Pb/2	103.59	Pb/4	51.80				

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^BRegistered trademark Haynes International.

NOTE 1—Alloying elements at concentrations below 1 % by mass were not included in the calculation, for example, they were considered part of the basis metal.

NOTE 2—Mid-range values were assumed for concentrations of alloying elements.

NOTE 3—Only consistent valence groupings were used.

NOTE 4—(Eq 4) was used to make these calculations.

4.7 Calculation of Corrosion Rate—Faraday's Law can be used to calculate the corrosion rate, either in terms of penetration rate (CR) or mass loss rate (MR) (4):

$$CR = K_1 \frac{i_{cor}}{\rho} EW \quad (5)$$

$$MR = K_2 i_{cor} EW \quad (6)$$

where:

CR is given in mm/yr, i_{cor} in $\mu A/cm^2$,

$K_1 = 3.27 \times 10^{-3}$, mm g/ μA cm yr (Note 3),

ρ = density in g/cm^3 , (see Practice G 1 for density values for many metals and alloys used in corrosion testing),

$MR = g/m^2d$, and

$K_2 = 8.954 \times 10^{-3}$, g $cm^2/\mu A$ m² d (Note 3).

NOTE 3—EW is considered dimensionless in these calculations.

Other values for K_1 and K_2 for different unit systems are given in Table 2.

4.8 Errors that may arise from this procedure are discussed below.

4.8.1 Assignment of incorrect valence values may cause serious errors (5).

4.8.2 The calculation of penetration or mass loss from electrochemical measurements, as described in this standard, assumes that uniform corrosion is occurring. In cases where non-uniform corrosion processes are occurring, the use of these

TABLE 2 Values of Constants for Use in Faraday's Equation Rate

A				
Penetration Rate Unit (CR)	i_{cor} Unit	ρ Unit	K_1	Units of K_1^A
mpy	$\mu\text{A}/\text{cm}^2$	g/cm^3	0.1288	mpy $\text{g}/\mu\text{A cm}$
mm/yr^B	A/m^2^B	kg/m^3^B	327.2	$\text{mm kg}/\text{A m y}$
mm/yr^B	$\mu\text{A}/\text{cm}^2$	g/cm^3	3.27×10^{-3}	$\text{mm g}/\mu\text{A cm y}$
B				
Mass Loss Rate Unit	i_{cor} Unit	K_2	Units of K_2^A	
$\text{g}/\text{m}^2\text{d}^B$	A/m^2^B	0.8953	g/Ad	
$\text{mg}/\text{dm}^2\text{d}$ (mdd)	$\mu\text{A}/\text{cm}^2$	0.0895	$\text{mg cm}^2/\mu\text{A dm}^2 \text{d}$	
$\text{mg}/\text{dm}^2\text{d}$ (mdd)	A/m^2^B	8.953×10^{-3}	$\text{mg m}^2/\text{A dm}^2 \text{d}$	

^AEW is assumed to be dimensionless.
^BSI unit.

methods may result in a substantial underestimation of the true values.

4.8.3 Alloys that include large quantities of metalloids or oxidized materials may not be able to be treated by the above procedure.

4.8.4 Corrosion rates calculated by the method above where abrasion or erosion is a significant contributor to the metal loss process may yield significant underestimation of the metal loss rate.

5. Polarization Resistance

5.1 Polarization resistance values may be approximated from either potentiodynamic measurements near the corrosion potential (see Practice G 59) or stepwise potentiostatic polarization using a single small potential step, ΔE , usually either 10 mV or - 10 mV, (see Test Method D 2776). Values of ± 5 and ± 20 mV are also commonly used. In this case, the specimen current, ΔI , is measured after steady state occurs, and $\Delta E/\Delta I$ is calculated. Potentiodynamic measurements yield curves of I versus E and the reciprocal of the slope of the curve (dE/dI) at the corrosion potential is measured. In most programmable potentiodynamic polarization equipment, the current is converted to current density automatically and the resulting plot is of i versus E . In this case, the polarization resistance is given by dE/di at the corrosion potential and 5.2 is not applicable.

5.2 It is necessary to multiply the dE/dI or $\Delta E/\Delta I$ value calculated above by the exposed specimen geometric area to obtain the polarization resistance. This is equivalent to the calculation shown in 4.1 for current density.

5.3 The Stern-Geary constant B must be estimated or calculated to convert polarization resistance values to corrosion current density (6, 8).

5.3.1 Calculate Stern-Geary constants from known Tafel slopes where both cathodic and anodic reactions are activation controlled, that is, there are distinct linear regions near the corrosion potential on an $E \log i$ plot:

$$B = \frac{ba \ bc}{2.303 (ba + bc)} \tag{7}$$

where:

ba = slope of the anodic Tafel reaction, when plotted on base 10 logarithmic paper in V/decade,

bc = slope of the cathodic Tafel reaction when plotted on base 10 logarithmic paper in V/decade, and

B = Stern-Geary constant, V.

5.3.2 In cases where one of the reactions is purely diffusion controlled, the Stern-Geary constant may be calculated:

$$B = \frac{b}{2.303} \tag{8}$$

where:

b = the activation controlled Tafel slope in V/decade.

5.3.3 It should be noted in this case that the corrosion current density will be equal to the diffusion limited current density. A sample calculation is given in Appendix X4.

5.3.4 Cases where both activation and diffusion effects are similar in magnitude are known as mixed control. The reaction under mixed control will have an apparently larger b value than predicted for an activation control, and a plot of E versus $\log I$ will tend to curve to an asymptote parallel to the potential axis. The estimation of a B value for situations involving mixed control requires more information in general and is beyond the scope of this standard. In general, Eq 7 and Eq 8 may be used, and the corrosion rate calculated by these two approximations may be used as lower and upper limits of the true rate.

NOTE 4—Electrodes exhibiting stable passivity will behave as if the anodic reaction were diffusion limited, except that the passive current density is not affected by agitation.

5.3.5 It is possible to estimate b_a and b_c from the deviation from linearity of polarization curves in the 20–50 mV region around the corrosion potential. Several approaches have been proposed based on analyses of electrode kinetic models. See Refs (9-11) for more information.

5.3.6 In cases where the reaction mechanism is known in detail, the Tafel slopes may be estimated from the rate controlling step in the mechanism of the reaction. In general, Tafel slopes are given by (12):

$$b = \frac{KRT}{nF} \tag{9}$$

where:

K = a constant,

R = the perfect gas constant,

T = the absolute temperature,

n = the number of electrons involved in the reaction step, and

F = Faraday's constant.

At 25°C, ($\frac{RT}{2.303 F}$) is 59.2 mV/decade. For simple one electron reactions, K is usually found to be 2.0.

5.3.7 In cases where the Tafel slopes cannot be obtained from any of the methods described above, it may be necessary to determine the Stern-Geary constant experimentally by measuring mass loss and polarization resistance values.

5.4 The corrosion current density may be calculated from the polarization resistance and the Stern-Geary constant as follows:

$$i_{cor} = \frac{B}{R_p} \tag{10}$$

The corrosion rate may then be calculated from the corrosion current, as described in Section 4. A sample calculation is given in Appendix X5.

5.5 There are several sources of errors in polarization resistance measurements:

5.5.1 Solution resistivity effects increase the apparent polarization resistance, whether measured by the potentiostatic or potentiodynamic methods (13). The effect of solution resistance is a function of the cell geometry, but the following expression may be used to approximate its magnitude.

$$R_p = R_a - \rho l \quad (11)$$

where:

R_a = the apparent polarization resistance, ohm cm²,

ρ = the electrolyte resistivity in ohm cm,

l = the distance between the specimen electrode and the Luggin probe tip, or the reference electrode in cm, and

R_p = the true polarization resistance in ohm cm².

Significant solution resistivity effects cause the corrosion rate to be underestimated. A sample calculation is given in Appendix X6.

5.5.2 Potentiodynamic techniques introduce an additional error from capacitive charging effects. In this case, the magnitude of the error is proportional to scan rate. The error is illustrated by (Eq 12):

$$I_{\text{total}} = I_f + c \left(\frac{dV}{dt} \right) \quad (12)$$

where:

I_{total} = the cell current,

I_f = the Faradaic current associated with anodic and cathodic processes,

c = the electrode capacitance, and

dV/dt = the scan rate.

The capacitance charging effect will cause the calculated polarization resistance to be in error. Generally, this error is small with modest scan rates (14).

5.5.3 Corroding electrodes may be the site for other electrochemical reactions. In cases where the corrosion potential is within 50 to 100 mV of the reversible potential of the corroding electrode, the electrochemical reactions will occur simultaneously on the electrode surface. This will cause either the anodic or cathodic b value to appear smaller than the corrosion reaction above. Consequently, the Stern-Geary constant B will be inflated and the predicted corrosion current will be overestimated (15). In this case, the concentration of the corroding electrode ions is generally of the same magnitude or higher than other ions participating in the corrosion process in the electrolyte surrounding the electrode. Other redox couples that do not necessarily participate in the corrosion reaction may have similar effects. This is especially true for metals exhibiting passive behavior.

6. Keywords

6.1 corrosion current; corrosion rate; electrochemical; equivalent weight; polarization resistance; Tafel slopes

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE CALCULATION—CORROSION CURRENT DENSITY

X1.1 Data:

X1.1.1 Corrosion Current—27.0 μA .

X1.1.2 Specimen Size—round anode area exposed.

X1.1.3 Diameter—1.30 cm.

X1.2 Calculation—See (Eq 1) in text:

$$i_{\text{cor}} = \frac{27.0}{(1.30)^2 \frac{\pi}{4}} = \frac{27.0}{1.32} = 20.3 \mu\text{A}/\text{cm}^2 \quad (\text{X1.1})$$

X2. SAMPLE CALCULATION—ALLOY EQUIVALENT WEIGHT

X2.1 Data:

X2.1.1 Alloy—UNS S31600, actual composition not available.

X2.1.2 Corrosion Potential—300 mV versus SCE 1N sulfuric acid.

X2.2 Assumptions:

X2.2.1 Composition:

X2.2.1.1 Chromium—16–18 %—mid range 17 %.

X2.2.1.2 Nickel—10–14 %—mid range 12 %.

X2.2.1.3 Molybdenum—2–3 %—mid range 2.5 %.

X2.2.1.4 Iron—Balance (ignore minor elements).

$$17 + 12 + 2.5 = 31.5 \quad (\text{X2.1})$$

X2.2.1.5 Iron = 100 – 31.5 = 68.5 %.

X2.2.2 Valence values from Ref (2).

Chromium—+3
Nickel—+2
Molybdenum—+3
Iron—+2

X2.3 Calculations—For simplicity, assume 100 g of alloy dissolved. Therefore, the gram equivalents of the dissolved components are given by (Eq 3).

$$Q = \frac{17}{51.996} \times 3 + \frac{12}{58.71} \times 2 + \frac{2.5}{95.94} \times 3 + \frac{68.5}{55.847} \times 2 \quad (\text{X2.2})$$

$$= 0.981 + 0.409 + 0.078 + 2.453 = 3.921 \text{ g equivalents}$$

The alloy equivalent weight is therefore $100/3.921 = 25.50$.

X3. SAMPLE CALCULATION FOR CORROSION RATE FROM CORROSION CURRENT

X3.1 Data and requirements—See X1 and X2.

X3.1.1 Corrosion rate in mm/yr.

X3.1.2 Density 8.02 g/cm³.

X3.2 Calculations—See (Eq 5).

$$K_1 = 3.27 \times 10^{-3} \quad (\text{X3.1})$$

$$CR = \frac{3.27 \times 10^{-3} \times 20.3 \times 25.50}{8.02} = 0.211 \text{ mm/yr}$$

X4. SAMPLE CALCULATION FOR STERN-GEARY CONSTANT

X4.1 Case 1 Data—Tafel slopes polarization diagram,

$$ba = 58.2 \text{ mV/decade, and} \quad (\text{X4.1})$$

$$bc = 114.3 \text{ mV/decade.} \quad (\text{X4.1})$$

X4.2 Calculation in accordance with (Eq 7).

$$B = \frac{58.2 \times 114.3}{2.303 (58.2 + 114.3)} = 16.74 \text{ mV or } 0.01674 \text{ V} \quad (\text{X4.2})$$

X4.3 Case 2—Cathodic reaction is diffusion controlled

$$ba = 58.2 \text{ mV/decade} \quad (\text{X4.3})$$

X4.4 Calculation—(Eq 8):

$$B = \frac{58.2}{2.303} = 25.31 \text{ mV} \quad (\text{X4.4})$$

X5. SAMPLE CALCULATION—CORROSION CURRENT FROM POLARIZATION RESISTANCE DATA

X5.1 Data—Polarization: 10 mV from corrosion potential.

X5.1.1 Current measured—17.1 μA.

X5.1.2 Specimen Size—14.2 mm diameter masked circular area.

X5.1.3 Tafel slope values given in X4.

X5.2 Calculations:

X5.2.1 Current density (see X4):

$$\frac{17.1}{(1.42)^2 \frac{\pi}{4}} = 10.80 \mu\text{A/cm}^2 \quad (\text{X5.1})$$

X5.2.2 Polarization resistance calculation:

$$Rp = \frac{Ep}{i} = \frac{10 \text{ mV}}{10.80 \mu\text{A/cm}^2} = 926 \text{ ohm cm}^2 \quad (\text{X5.2})$$

X5.2.3 Corrosion current—(Eq 10)

$$i_{\text{cor}} = \frac{B}{Rp} = \frac{25.31 \text{ mV}}{926 \text{ ohm cm}^2} = 27.33 \mu\text{A/cm}^2 \quad (\text{X5.3})$$

X6. SAMPLE CALCULATION—SOLUTION RESISTIVITY EFFECTS

X6.1 Data:

X6.1.1 Solution Resistivity—4000 ohm cm.

X6.1.2 Distance Between Luggin Tip and Specimen—5 mm.

X6.1.3 Measured Polarization Resistance—9926 ohm cm².

X6.2 Calculation from (Eq 11):

$$Rp = Ra - \rho l \quad (\text{X6.1})$$

$$Rp = 9926 - 0.5 \times 4000$$

$$Rp = 9926 - 2000 = 7926 \text{ ohm cm}^2$$

NOTE X6.1—The solution resistivity effect causes the corrosion rate to be underestimated by about 25 % in this case.

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