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Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance¹

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1. Scope

1.1 This guide covers the development of a galvanic series and its subsequent use as a method of predicting the effect that one metal can have upon another metal when they are in electrical contact while immersed in an electrolyte. Suggestions for avoiding known pitfalls are included.

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.* Specific precautionary statements are given in Section 5.

2. Referenced Documents

2.1 *ASTM Standards:*

G 3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing²

G 15 Terminology Relating to Corrosion and Corrosion Testing²

G 16 Guide for Applying Statistics to Analysis of Corrosion Data²

G 71 Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes²

3. Terminology

3.1 Definitions of terms used in this guide are from Terminology **G 15**.

3.2 *active*—the negative (decreasingly oxidizing) direction of electrode potential.

3.3 *corrosion potential*—the potential of a corroding surface in an electrolyte relative to a reference electrode measured under open-circuit conditions.

3.4 *galvanic corrosion*—accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.

3.5 *galvanic series*—a list of metals and alloys arranged according to their relative corrosion potentials in a given environment.

3.6 *noble*—the positive (increasingly oxidizing) direction of electrode potential.

3.7 *passive*—the state of the metal surface characterized by low corrosion rates in a potential region that is strongly oxidizing for the metal.

3.8 *polarization*—the change from the open-circuit electrode potential as the result of the passage of current.

4. Significance and Use

4.1 When two dissimilar metals in electrical contact are exposed to a common electrolyte, one of the metals can undergo increased corrosion while the other can show decreased corrosion. This type of accelerated corrosion is referred to as galvanic corrosion. Because galvanic corrosion can occur at a high rate, it is important that a means be available to alert the user of products or equipment that involve the use of dissimilar metal combinations in an electrolyte of the possible effects of galvanic corrosion.

4.2 One method that is used to predict the effects of galvanic corrosion is to develop a galvanic series by arranging a list of the materials of interest in order of observed corrosion potentials in the environment and conditions of interest. The metal that will suffer increased corrosion in a galvanic couple in that environment can then be predicted from the relative position of the two metals in the series.

4.3 *Types of Galvanic Series:*

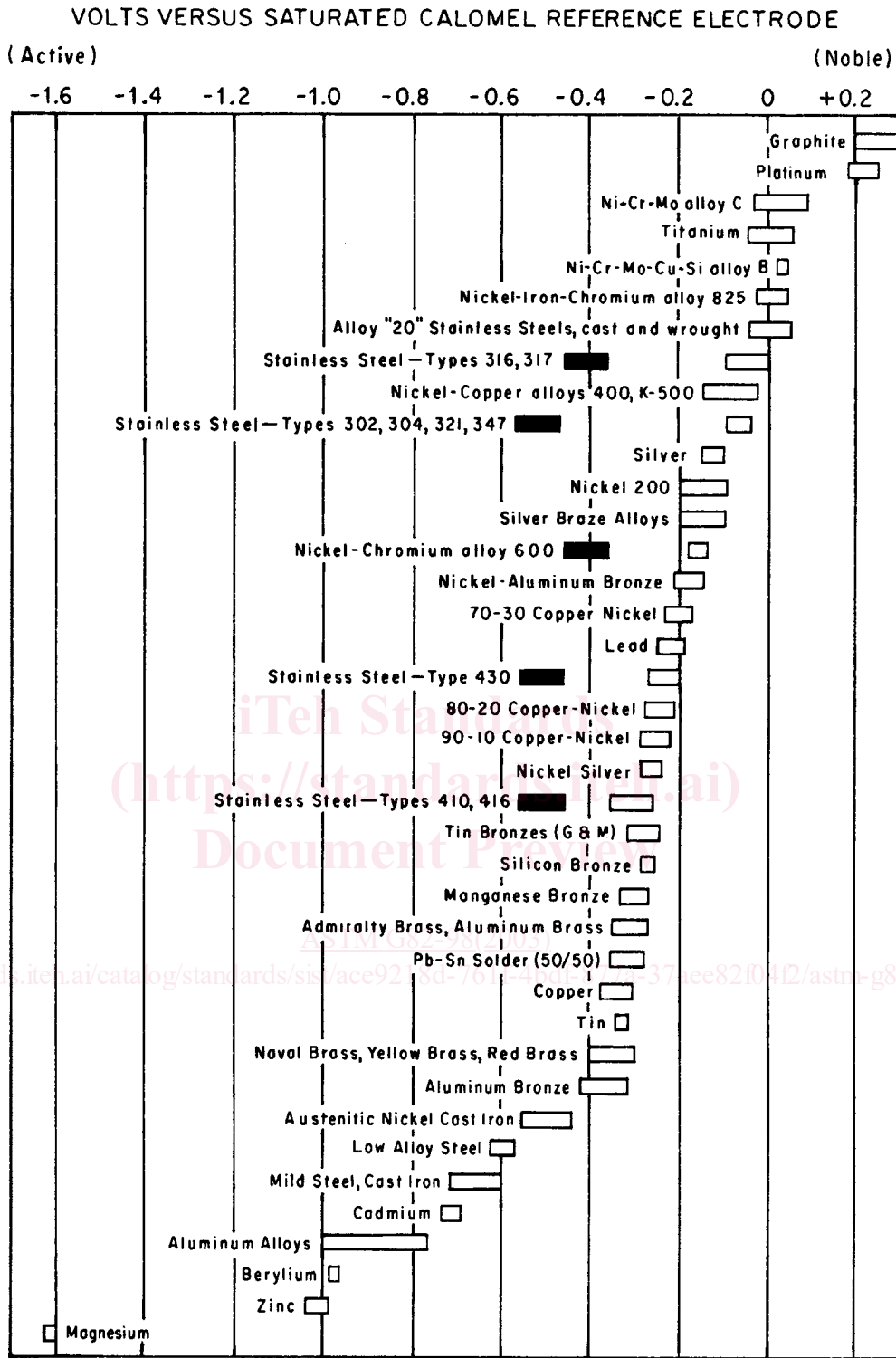
4.3.1 One type of Galvanic Series lists the metals of interest in order of their corrosion potentials, starting with the most active (electronegative) and proceeding in order to the most noble (electropositive). The potentials themselves (versus an appropriate reference half-cell) are listed so that the potential difference between metals in the series can be determined. This type of Galvanic Series has been put in graphical form as a series of bars displaying the range of potentials exhibited by the metal listed opposite each bar. Such a series is illustrated in **Fig. 1**.

4.3.2 The second type of galvanic series is similar to the first in that it lists the metals of interest in order of their corrosion potentials. The actual potentials themselves are not specified,

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² *Annual Book of ASTM Standards*, Vol 03.02.



NOTE—Dark boxes indicate active behavior of active-passive alloys.

FIG. 1 Galvanic Series of Various Metals in Flowing Seawater at 2.4 to 4.0 m/s for 5 to 15 Days at 5 to 30°C (Redrawn from Original)⁵

however. Thus, only the relative position of materials in the series is known and not the magnitude of their potential difference. Such a series is shown in Fig. 2.

4.4 Use of a Galvanic Series:

4.4.1 Generally, upon coupling two metals in the Galvanic Series, the more active (electronegative) metal will have a

tendency to undergo increased corrosion while the more noble (electropositive) metal will have a tendency to undergo reduced corrosion.

4.4.2 Usually, the further apart two metals are in the series, and thus the greater the potential difference between them, the greater is the driving force for galvanic corrosion. All other

ACTIVE END	Magnesium
(-)	Magnesium Alloys
↑	Zinc
	Galvanized Steel
	Aluminum 1100
	Aluminum 6053
	Alclad
	Cadmium
	Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn)
	Mild Steel
	Wrought Iron
	Cast Iron
	13 % Chromium Stainless Steel
	Type 410 (Active)
	18-8 Stainless Steel
	Type 304 (Active)
	18-12-3 Stainless Steel
	Type 316 (Active)
	Lead-Tin Solders
	Lead
	Tin
	Muntz Metal
	Manganese Bronze
	Naval Brass
	Nickel (Active)
	76 Ni-16 Cr-7 Fe alloy (Active)
	60 Ni-30 Mo-6 Fe-1 Mn
	Yellow Brass
	Admiralty Brass
	Aluminum Brass
	Red Brass
	Copper
	Silicon Bronze
	70:30 Cupro Nickel
	G-Bronze
	M-Bronze
	Silver Solder
	Nickel (Passive)
	76 Ni-16 Cr-7 Fe
	Alloy (Passive)
	67 Ni-33 Cu Alloy (Monel)
	13 % Chromium Stainless Steel
	Type 410 (Passive)
	Titanium
	18-8 Stainless Steel
	Type 304 (Passive)
	18-12-3 Stainless Steel
	Type 316 (Passive)
↓	Silver
(+)	Graphite
NOBLE or	Gold
PASSIVE END	Platinum

FIG. 2 Galvanic Series of Various Metals Exposed to Sea Water³

factors being equal, and subject to the precautions in Section 5, this increased driving force frequently, although not always, results in a greater degree of galvanic corrosion.

5. Precautions in the Use of a Galvanic Series

5.1 The galvanic series should not be confused with the electromotive force series, which, although of a similar appearance to the galvanic series, is based on standard electrode potentials of elements and not on corrosion potentials of metals. The electromotive force series should not be used for galvanic corrosion prediction.

5.2 Each series is specific to the environment for which it was compiled. For example, a series developed in a flowing ambient temperature seawater should not be used to predict the performance of galvanic couples in fresh water or in heated seawater.

5.3 Corrosion potentials can change with time and the environment. These changes can affect the potential difference between the metals of interest and, in some cases, can reverse relative positions. It is thus imperative that the series used for the prediction be obtained under similar conditions of exposure duration and electrolyte composition as the situation being predicted.

5.4 Galvanic corrosion can occur between two identical materials in different environments. The galvanic series generated herein cannot be applied to this situation.

5.5 Use of a galvanic series provides qualitative prediction of galvanic corrosion. It should not be used for quantitative predictions of galvanic corrosion rate. A more precise determination of the effect of galvanic coupling can be obtained by the measurement of the corrosion currents involved as outlined in Guide G 71.^{3,4}

5.6 Some published Galvanic Series, such as those in Fig. 1⁵ and 2, consider the possibility of there being more than one potential range for the same material, depending on whether the material is in the active or the passive state. Knowledge of conditions affecting passivity of these materials is necessary to determine which potential range to use in a particular application.

5.7 Galvanic corrosion behavior is affected by many factors besides corrosion potentials. These factors must also be considered in judging the performance of a galvanic couple. They include, but are not limited to, the following:

5.7.1 Anode-to-cathode area ratio,

5.7.2 Electrolyte conductivity,

5.7.3 Distance between coupled metals,

5.7.4 Shielding of metal surfaces by marine growth, sediments, and so forth,

5.7.5 Localized electrolyte concentration changes in shielded areas, and

5.7.6 Polarization characteristics of the metals involved.

5.8 Some materials that are subject to chemical attack in alkaline solutions may suffer increased attack when made the cathode in a galvanic couple due to generation of hydroxyl ions by the cathodic reaction. Use of a galvanic series will not predict this behavior.

5.9 A more detailed discussion of the theory of galvanic corrosion prediction is presented in Appendix X1 and in ASTM STP 576.⁴

6. Development of a Galvanic Series

6.1 The development of a Galvanic Series may be divided into several steps. First is the selection of the environment and conditions of interest. During the exposures, the environment and conditions should be as close as possible to service conditions. A list of environmental factors and conditions that

³ Brasunas, A., Editor, *NACE Basic Corrosion Course*, Chapter 3, NACE, Houston, TX, 1970.

⁴ Baboian, R., "Electrochemical Techniques for Predicting Galvanic Corrosion," *Galvanic and Pitting Corrosion-Field and Laboratory Studies*, ASTM STP 576, Am. Soc. Testing Mats., 1976, pp. 5-19.

⁵ LaQue, F. L., *Marine Corrosion, Causes and Prevention*, John Wiley and Sons, New York, NY, 1975.