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Test Method for Monitoring Atmospheric Corrosion Rate by Electrochemical Measurements

ABSTRACT

This standard test method provides guidance on the specification, selection, and use of sensors for monitoring atmospheric corrosion that are based on electrochemical techniques. The sensors may be used like more traditional mass loss coupons or painted test panels, but these sensors provide continuous records of contaminants, corrosion rates, or coating condition over time as opposed to singular cumulative measurements of mass loss or coating degradation. This method permits instantaneous evaluation of corrosion rates so that situations where changes in environmental conditions cause changes in the corrosion rate can be detected in real time. It addresses the use of electrochemical sensors in a bare metal condition or with protective coatings. It encompasses sensor elements for measurement of free corrosion, galvanic corrosion, and conductance for assessing atmospheric corrosion.

KEYWORDS

Atmospheric corrosion, galvanic, electrochemical, corrosion rate, conductance, sensor, TG 530.

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Foreword

In NACE standards, the terms shall, must, should, and may are used in accordance with the definitions of these terms in the NACE Publications Style Manual, 4th ed., Paragraph 7.4.1.9. Shall and must are used to state mandatory requirements. The term should is used to state something considered good and is recommended but is not mandatory. The term may is used to state something considered optional.

The purpose of this standard test method is to provide guidance on the specification, selection, and use of sensors for monitoring atmospheric corrosion that are based on electrochemical techniques. The sensors may be used like more traditional mass loss coupons or painted test panels, but these sensors provide continuous records of contaminants, corrosion rates, or coating condition over time as opposed to singular cumulative measurements of mass loss or coating degradation. This method permits instantaneous evaluation of corrosion rates so that situations where changes in environmental conditions cause changes in the corrosion rate can be detected in real time. This is considered a substantive benefit as compared with mass loss methods. These continuous records of material condition are broadly applicable to studying atmospheric corrosion, evaluating materials, or managing assets. The method addresses the use of electrochemical sensors in a bare metal condition or with protective coatings. It encompasses sensor elements for measurement of free corrosion, galvanic corrosion, and conductance for assessing atmospheric corrosion. Atmospheric corrosivity measurements, using electrochemical-based sensors, provide a means to obtain instantaneous corrosion rate, surface contaminant, and coating property estimates over long exposure periods. The electrochemical-based sensors may be used to estimate free corrosion rate of specific alloys, galvanic corrosion rate of coupled materials, conductance of surface moisture layers, or the barrier properties of coatings. These sensors may be included in instrumentation used in accelerated test chambers, outdoor exposure sites, or service environments.

This standard test method for measuring atmospheric corrosion may be useful for material selection, establishing maintenance requirements, characterization of test chambers, site surveys, environmental severity mapping, asset monitoring, and investigating interactions between the environment, materials, and protection systems. These sensors and measurement techniques enable atmospheric corrosion monitoring systems for better design and management of mobile and fixed assets and infrastructure. These corrosion rate measurements may be used to characterize temporal and spatial variations of corrosivity throughout a given structure or for surveying different geographic locations.

The test method has the advantage of producing direct measures that are dependent on electrochemical reaction rates, conductance of thin film electrolytes, and coating performance over long periods, under atmospheric conditions. These instantaneous corrosion rate measurements are not readily accessible using electrical resistance and microbalance mass loss techniques. The technology described in the test method compliments other standard techniques for assessing atmospheric corrosion such as mass loss coupons, electrical resistance, and microbalance methods.[1-3] The electrochemical sensor techniques, described in this test method, have the benefit of providing continuous measures of instantaneous performance properties.

This NACE standard test method was prepared in 2016 by Task Group (TG) 530, "Test Method for Monitoring Atmospheric Corrosion Rate by Electrochemical Measurements." TG 530 is administered by Specific Technology Group (STG) 62, Corrosion Monitoring and Measurement—Science and Engineering Applications," and sponsored by STG 40, "Military and Aerospace Systems and Facilities," and STG 41, "Electric Utility Generation, Transmission, and Distribution." This standard is issued by NACE under the auspices of STG 62.

Test Method for Monitoring Atmospheric Corrosion Rate by Electrochemical Measurements

1. General 4
2. Summary of Sensors 5
3. Free Corrosion Sensors 5
4. Galvanic Corrosion Sensors 10
5. Surface Conductance Sensors 14
6. Atmospheric Testing 17
7. Reporting 18
8. Precision and Bias 18
References 19
Appendix A Example Images of Electrochemical Sensors (Nonmandatory) 21

Figures

Table 1: Sensor Uses and Types of Measurement Techniques 5
Figure A1: Schematic Isometric and Top View of Laminated Interdigitated Two-Electrode Sensor 21
Figure A2 Schematic of Laminated Thin Film Interdigitated Two-Electrode Sensor 21
Figure A3 Electrochemical Sensors for Free Corrosion, Galvanic Corrosion, and Conductance in a Single Panel 21
Figure B1 Equivalent Circuit for Two-Electrode Corrosion Measurement 22

Section 1: General

1.1 **Scope**: This test method for making atmospheric corrosion measurements encompasses: 1) two-electrode electrochemical impedance, 2) zero resistance ammeter (ZRA), and 3) precision resistor current measurement techniques. The measurements can be used to quantify free corrosion, galvanic corrosion, conductance of surface contaminants (electrolyte layers), and properties of protective coatings. Factors important in specifying and selecting sensing elements and electrochemical measurement methods are provided. Sensing element types are described, along with excitation methods and data collection considerations. Methods are given to convert electrical responses to corrosion rate and cumulative corrosion measurements. Guidance is given for quality assurance practices, sensor preparation, and atmospheric corrosion testing. The test method also provides instruction for the preparation and testing of coatings using electrochemical sensors. Use and limitations of this method for determining the performance of materials and predicting corrosion behavior are described. Guidance is given for reporting sensor information, results, and environmental test parameters.

1.2 **Limitations for Technical Use**: The electrochemical measurements can be used for comparative assessment of environments, alloys, and coatings. These sensors provide electrochemical measurements for estimating corrosion rate, but correlation and calibration may be required to establish absolute measures of corrosion for given environments and corrosion mechanisms. Caution should be exercised when making claims about expected performance for environments other than those tested, or when extrapolating data to predict service life based on accelerated or short duration performance testing. Electrochemical measurements used to estimate area averaged corrosion rates do not inherently provide a means to quantify localized corrosion damage and depth of penetration associated with localized corrosion mechanisms such as pitting and intergranular corrosion. Performance of electrochemical sensors and measurement systems will be dependent on the specific sensing elements, preparation process, and supporting electronics. Electrical measurements are described in this test method to establish measurement system specifications. The sensors covered by this standard have a wide range of uses, and therefore the method is not intended to be highly prescriptive for a given sensor technology or application. Parameters identified, but not specified should be considered by user and supplier in the design and use of these sensors for a given application. Prescriptive descriptions for verifying and validating measurement system performance for particular environments, sensor alloys, electrode geometries, and applications are beyond the scope of this test method. Comparative performance determinations should not be made using sensors with different geometries, excitation and acquisition hardware and software, or from different manufactures, unless comparable system responses have been validated. Use of electrochemical sensors to evaluate conductive coatings, such as electroplate, hot dip coatings, metalized films, or metal rich paints is outside the scope of this test method. Specific safety, durability, and regulatory requirements for the use and operation of the systems described in this document for any given application are outside the scope of the test method.

1.3 **Applicability**: The electrochemical sensors are useful for comparative testing of materials in atmospheric corrosion tests including accelerated laboratory, outdoor exposure sites, and service environments. The electrochemical sensors provide continuous measures indicative of current environmental and material conditions. The test method can be used to assess the relative severity of corrosive environments using standard materials, or to assess material performance in specific environments. The electrochemical sensors can be used to quantify and track corrosion rate and estimate cumulative corrosion. The protective properties of coatings on metals and alloys can be continuously measured over long periods using the electrochemical sensors.

Section 2: Summary of Sensors

2.1 The atmospheric corrosion measurements included in this test method are: 1) two-electrode electrochemical impedance, 2) ZRA, and 3) precision resistor current measurement techniques. These measurement techniques and associated sensing elements can be used to measure free corrosion, galvanic corrosion, surface conductance, and coating properties (Table 1).

2.2 Atmospheric corrosion sensors have a nominally planar geometry and are composed of two electrodes separated by dielectric materials that protect and electrically isolate the electrode surfaces other than the sensing areas (Appendix A [nonmandatory], Figures A1 and A2). The two electrodes have interleaved geometries with a defined separation distance. These interleaved electrodes are referred to as interdigitated electrodes and they can be produced using laminates or thin films. Two-electrode composite laminate sensors can be fabricated using potted alloy materials to form interdigitated electrodes (IDE). Thin film or foil electrode sensors can also be produced by depositing or adhesively bonding metals and alloys onto dielectric substrates such as polymers, ceramics, or fiber reinforced polymers. Materials of construction are selected to be chemically resistant and durable in the exposure environment. The sensor gage area is defined as the area of the electrodes exposed to the environment.

2.3 The electrochemical sensors can be used individually or in combination to evaluate coatings in accelerated tests, outdoor exposures, or service environments (Figure A3). These measurement techniques and associated sensing elements can be used to measure the capability of coatings to control free corrosion, galvanic corrosion, and maintain barrier properties.

Table 1
Sensor Uses and Types of Measurement Techniques

Electrochemical Sensors	Measurement Method		
	Two-electrode impedance	Zero resistance ammeter	Precision resistor
Free corrosion	Yes	No	No
Galvanic corrosion	No	Yes	Yes
Surface conductance	Yes	No	No

Section 3: Free Corrosion Sensors

3.1 Free corrosion measurements are obtained using two-electrode sensors that may have a range of geometries and excitation techniques.[4-6]

3.2 Two-electrode sensors for measurement of free corrosion can be fabricated from any alloy of interest for a given application, or a reference alloy for determining the relative severity of a given environment. Both electrodes of the two-electrode free corrosion sensor shall be constructed of the same alloy.

3.3 The separation distance between the electrodes should be uniform and no more than 300 µm. A high electrode digit length to width ratio may minimize contribution of edge effects that distort current and potential distributions, and small width electrodes support more uniform active measurement area under varying environmental conditions. An example length to width ratio is 10, and an example electrode digit width is 2 mm. Geometry and sensing areas for each electrode should be the same.