

Continuous Measurements for Determination of Aerospace Coating Protective Properties

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Document History

2021-09-02: Developed by AMPP Standards Committee (SC) 07, Defense & Aerospace.

AMPP values your input. To provide feedback on this standard, please contact: standards@ampp.org

AMPP TM21449-2021

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Scope

This standard describes three Test Methods for conducting a coating evaluation for comparative performance testing, coating specification, and coating quality acceptance testing. The standard is organized to provide a general description of the Test Method (Sections 1 – 6) with three mandatory appendices that are arranged by coating protective properties and failure progression.

Appendix A (Mandatory), Barrier Properties of a Coating

Appendix B (Mandatory), Protective Corrosion Properties of a Coating at a Defect

Appendix C (Mandatory), Protective Properties of a Coating for Environmental Cracking Resistance

The Test Method describes the equipment required to conduct each type of performance test including the atmospheric corrosion test chamber, environmental monitoring, and coating performance property measurements. Materials, sensors, and test samples are detailed and guidance for materials preparation and coating application is given. The electrochemical measurements and sensors are applicable to liquid, polymer coatings applied by spray, brush, or dip processes. Atmospheric corrosion test cycles for protective property measurements are described. The method includes reporting requirements for documenting environment, materials, and sample conditions. Data collection for test records and data analysis to establish coating performance metrics are defined. The values stated in International System of Units (SI) are to be regarded as standard, although some U.S. customary units are used in this standard.

Rationale

This Test Method addresses the need for coating performance measurements that are relevant to the protection of aerospace structures.

In AMPP standards, the terms *shall* and *must* are used to state requirements and are considered mandatory. The term *should* is used to state something that is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

Section 1: General

1.1 Overview

The purpose of this standard Test Method is to provide guidance on the testing and evaluation of coatings for aerospace applications. This Test Method has been developed for use by researchers, manufacturers, and organizations responsible for the manufacture, specification, and use of corrosion protective coatings for aerospace structures. The Test Method details measurement techniques to continuously monitor the combined environmental and mechanical effects that drive coating degradation in laboratory tests. While for many industries, judgements of coating performance may be primarily aesthetic, this Test Method describes direct, continuous measurements of coating degradation processes that are important to aircraft structural integrity. The continuous measurements of coating properties and degradation allows for ranking coating system performance at any point during a test. The Test Method includes three appendices for quantifying multiple coating properties, and stages of coating system and substrate degradation. These appendices address: 1) coating barrier properties, 2) coating corrosion protection at a defect, and 3) coating protection of a structural alloy from environmental cracking. The standard Test Method references ISO⁽¹⁾ 22858¹ for use in determining coating barrier properties and free and galvanic corrosion protection. The Test Method is prescriptive and intended to produce coating performance measurements, but acceptance criteria based on these measurements are not part of the Test Method.

1.2 Limitations for Technical Use:

This Method specifies the alloys, environments, and conditions to be used to evaluate protective properties of aerospace coating systems; although, the coating property measurements are generally applicable to assessment of environments, alloys, and non-aerospace coatings.

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. The Test Method is not sufficient to ensure that coating and alloy combinations will provide satisfactory performance in service, and determinations of performance in natural and service environments should be obtained when possible. The measurement techniques and sensors covered by this standard Test Method have a wide range of uses, and therefore the Test Method is highly prescriptive to achieve consistent results for characterizing aerospace coating performance. Deviation from the Test Method is acceptable when specific sensors, measurements, environments, performance conditions, or material combinations are appropriate for development, risk mitigation, and fitness for service determinations. Performance metrics produced by this standard should be considered by user and producer in the context of the application and service environment before defining coating requirements. Coating performance determinations should not be made using sensors and samples with different geometries, excitation, and acquisition hardware and software, or from multiple manufacturers unless comparable system responses have been validated. Care must be exercised when determining the suitability of each protective property measurement type for evaluating specific classes of coatings. Electrochemical sensors used in this Test Method are not suitable for evaluating conductive coatings, such as electroplate, metalized films, or metal rich paints. The electrochemical sensors are applicable to liquid, polymer coatings applied by spray, brush, or dip processes. The electrochemical sensors are not compatible with electrocoat or powder coating. 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 Test Method is applicable to the laboratory evaluation of aerospace coating systems that are spray applied and cured at ambient temperatures. The Test Method may be used to test complete coating systems and to determine performance of any part of the system such as pretreatment, primer, and topcoat. The Test Method produces test results for protective coating properties that are useful for both comparative performance testing and as absolute measures of performance. These measurements are applicable to coating properties and degradation mechanisms that are significant to aircraft structural integrity. The Test Method is useful for coating development, selection, qualification, and quality acceptance testing.

⁽¹⁾ International Organization for Standardization (ISO), Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland. www.iso.org.

Section 2: Performance Parameters

2.1 Barrier Properties of Coating

Measurements of coating conductance (inverse of coating impedance) with gold interdigitated electrode (IDE) sensors shall be used to determine the barrier properties of a coating system ([Appendix A](#)).⁽²⁾¹ Protective coatings interact with the local environment and barrier properties are dependent on moisture, temperature, atmospheric chemistry (naturally and anthropogenic), and exposure to ultraviolet radiation.

Variation in barrier properties of a coating with temperature and humidity during a cyclic corrosion test are expected and may not indicate coating deterioration.

Loss of barrier properties due to coating degradation, as measured by increases in coating conductance, may be due to increasing diffusion of moisture and contaminants through the coating, and loss of coating adhesion and blistering between the coating and the sensor surface.

By making frequent, periodic measurements of coating conductance throughout a corrosion test, the response of an intact coating to environmental conditions can be tracked and separated from changes in conductance associated with evolution of protective properties. The coating conductance can be integrated as a function of time to obtain a cumulative metric of coating total conductance for a given atmospheric corrosion test.

For the gold IDE sensor, coating conductance is measured using low amplitude, alternating current (AC) excitation at two or more frequencies.

2.2 Protective Corrosion Properties of Coating at a Defect

The capacity of a coating system to protect an alloy substrate from free corrosion and galvanic corrosion shall be measured using electrochemical techniques and coated sensing elements with controlled coating defects ([Appendix C](#)).¹ Aerospace coating systems often include primers that contain active corrosion inhibitors that are released in the presence of moisture. Coatings with corrosion inhibitors are used to minimize the rate of corrosion over long periods of time, reducing the total amount of damage to the substrate alloy. During laboratory atmospheric corrosion testing, periodic corrosion current measurements are made to characterize the capacity of the coating to limit corrosion of substrate alloys. Two types of IDE corrosion rate sensors are used for free corrosion and galvanic corrosion measurements. Both sensors measure corrosion current and this current can be integrated with time to obtain a metric for total corrosion. For the free corrosion IDE sensor, corrosion current is measured using a low frequency, low amplitude AC excitation. The galvanic corrosion IDE sensor measures galvanic current using a zero-resistance ammeter (ZRA) technique.

2.3 Protective Properties for Resisting Environmental Cracking

Aerospace structures must resist the initiation and propagation of structural alloy cracks by processes of environmental cracking. Aerospace coating systems that contain active corrosion inhibitors may control the development of corrosion damage that can be initiation sites for cracks in stressed structural components.

The capacity of a coating system to protect an alloy substrate from environmental cracking shall be tested using an instrumented double cantilever beam (DCB) sample and load frame ([Appendix C](#)). The DCB sample will have a coating system applied to the gauge section with a small uncoated area at the high stress area of the gauge section. The aluminum alloy DCB sample has a smooth gauge section with short transverse loading similar to ASTM⁽³⁾ G139.² The DCB geometry is configured for coating and can be loaded and instrumented for testing in an environmental chamber. During laboratory atmospheric corrosion testing, periodic measurements of DCB sample displacement are made to characterize the capacity of a coating to prevent environmental crack initiation. Based on the alloy properties and finite element analysis, the change in sample displacement can be used to estimate crack length.

⁽²⁾ Impedance is typically used for quantifying coating barrier properties in ASTM G106 and ISO 22858. For this Test Method, conductance, the inverse of impedance, is used for convenience and to maintain direct relationships between environment and corrosive property measurements.

⁽³⁾ ASTM International (ASTM), 100 Barr Harbor Dr. PO Box C700, West Conshohocken, PA 19428-2959. www.astm.org.

Section 3: Test Materials

3.1 Alloys

Aerospace grade engineering alloys shall be used for sensing elements and fracture mechanics samples to characterize the protective coating properties for corrosion and environmental cracking.

3.1.1 Barrier and Protective Corrosion Properties

The IDE free corrosion sensor shall be fabricated from UNS⁽⁴⁾ A97075 (AA7075-T6, AMS4045L) aluminum alloy sheet. The galvanic corrosion sensor shall use AA7075-T6 sheet coupled to stainless steel UNS S31600 (316, AMS5524L) stainless steel sheet.

3.1.2 Environmental Cracking Protection

The DCB fracture mechanics sample shall be fabricated from AA7075-T651 (AMS4045L) aluminum alloy plate.

3.1.3 Use of Other Alloys

These alloys combinations are chosen to be susceptible to galvanic corrosion and environmental cracking in order to rapidly assess coating performance. Coating behavior and corrosion susceptibility may be specific to the material, material combinations, and environment. Actual performance of a specific material and coating system should be performed in the intended service environment. Should other alloys, coatings, and environmental conditions be used in testing, the applicability of the results should be verified.

3.2 Coatings

This Method may be used to test complete coating systems and to determine performance of any part of the system such as pretreatment, primer, and topcoat. The IDE barrier property sensor, corrosion sensor, and DCB sample shall be processed and painted according to coating manufacturer or user requirements. Application processes including cleaning, deoxidation and pretreatment should be similar to those used in production or maintenance facilities. Specific coating properties such as dry film thickness, cure, and adhesion should be tested on witness panels processed at the same time as the IDE sensors and DCB sample.³⁻⁵

3.2.1 Barrier and Protective Corrosion Properties

Coatings may be applied by spray, brush, or dip processes to the IDE barrier property and corrosion sensors. Conductive coatings, such as electroplate, metalized films, or metal rich paints shall not be used on the IDE sensors.

3.2.2 Environmental Cracking Protection

There are no application process or coating type limitations for the fracture mechanics samples and they may be used with electrocoat, powder coat, and conductive coatings.

3.3 Test Systems

3.3.1 Electrochemical Sensors for Barrier and Protective Corrosion Properties

The barrier property, free corrosion, and galvanic corrosion sensors are all interdigitated electrode sensors described in [Appendix A](#) and [Appendix C](#). These sensors may be combined in a single multi-sensor panel to perform barrier property, free corrosion, and galvanic corrosion measurements simultaneously throughout a laboratory atmospheric corrosion test.⁽⁵⁾

⁽⁴⁾ Unified Numbering System for Metals and Alloys (UNS). UNS numbers are listed in *Metals & Alloys in the Unified Numbering System*, 13th ed. (Warrendale, PA: SAE International and West Conshohocken, PA: ASTM International, 2017).

⁽⁵⁾ Known source for these sensor systems is the CorRES™ corrosion and coating evaluation system, available from Luna Innovations Incorporated.

3.3.2 Fracture Mechanics Sample for Environmental Cracking Protection

A DCB fracture sample is used to determine the capacity of a coating system to protect an alloy substrate from environmental cracking. The DCB sample, load frame and supporting instrumentation is described in [Paragraph C2.1.5](#).

Section 4: Corrosion Test Conditions and Environmental Measurements for Barrier and Protective Corrosion Properties

4.1 Corrosion Test Environment

The coating barrier properties and corrosion performance shall be determined in a cyclic corrosion test chamber according to GMW14872⁽⁶⁾ using four sprays per cycle and tested for a total of 21 cycles.⁽⁶⁾

Coating behavior and corrosion susceptibility may be specific to the environmental test conditions; should other laboratory corrosion test cycles be used, the capability of the test to distinguish performance should be verified.

4.2 Measurement of Environmental Test Conditions

Throughout barrier property and corrosion performance testing, temperature, relative humidity (RH), and surface contaminant conductance shall be measured. These measurements should be made at the same sampling rate as the coating performance measurements. Surface contaminant conductance shall be measured using a gold IDE sensor with a low voltage 20 mV peak to peak AC excitation at a frequency of 25 kHz. Independent measures of temperature, RH, and contaminant conductance sensors shall be placed as close as possible to the test articles, centered among the test articles, or at the center of the test chamber volume.⁽⁷⁾

Section 5: Corrosion Test Conditions and Environmental Measurements for Environmental Cracking

5.1 Corrosion Test Environment

Environmental cracking tests shall be done in an environmental chamber at a constant temperature of 50±2 °C and constant RH of 55±5%. The corrosive test solution applied to the sample is a simulated marine salt mixture with an initial 2.4 M chloride ion concentration.⁽⁸⁾

Coating behavior and alloy susceptibility to environmental cracking are known to be specific to the environmental parameters and salt chemistry used. If other test conditions are used, the capacity of the test to distinguish performance should be verified.

5.2 Measurement of Environmental Test Conditions

Throughout an environmental cracking test, temperature and RH shall be measured. The RH measurement shall be every five minutes or less, and the sensor shall be placed as close as possible to the test articles, centered among the test articles, or at the center of the test chamber volume. Temperature shall be measured for every individual fracture mechanics sample and the sampling rate shall be the same as that for the displacement and load measurements.

⁽⁶⁾ The GMW14872 cyclic corrosion test was selected based on capabilities of US DoD laboratories.

⁽⁷⁾ It is known that temperature, relative humidity, spray flow rates, and salt deposition may vary based on position within a chamber. Care should be taken to properly set up the chamber according to manufacturer guidelines and perform quality tests required by GMW14872.

⁽⁸⁾ Known source for marine salt mixture is Instant Ocean® Sea Salt from Spectrum Brands Holdings.