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FOR SPACE STANDARDIZATION

Space product assurance

Corrosion

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Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards. Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

This Standard has been prepared by the ECSS-Q-ST-70-14C Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Introduction

This standard is aimed primarily at flight hardware including launchers but the principles can also be applied to ground support equipment.

Materials and processes used in ground support equipment, test equipment, hardware processing equipment, hardware packaging, hardware shipment and interfacing with flight hardware are to be controlled to prevent damage to or contamination of flight hardware.

This standard describes the requirements necessary to show that hardware is adequately protected from corrosion.

The purpose of this document is to:

- assess the risk of each form of corrosion,
- describe the corrosion protection requirements needed to mitigate the risks of corrosion, and
- define the acceptance criteria for the protected metal or alloy system that shows fitness for purpose over the life of the mission.

1
Scope

This document specifies the minimum requirements to qualify the materials and processes selected to provide corrosion protection. Additional testing can be performed to satisfy the requirements for materials and processes used in specific flight applications.

This standard specifies the behaviour of metals and alloys but it does not remove the responsibility for the degradation of other materials such as polymers or ceramics to be considered. This standard refers only to metallic materials.

This document does not cover the requirements for protection against stress corrosion cracking (SCC) which has its own dedicated standard ECSS-Q-ST-70-36.

It covers typical spacecraft and launcher programmes on ground for a period of no more than 10 years.

This standard may be tailored for the specific characteristic and constraints of a space project in conformance with ECSS-S-ST-00.

2
Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-S-ST-00-01	ECSS System - Glossary of terms
ECSS-Q-ST-70	Space product assurance - Materials, mechanical parts and processes
ASTM D 5894-10 (2010)	Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
ISO 9227:2012	Corrosion tests in artificial atmospheres – Salt spray tests
ISO 9588:2007	Metallic and other inorganic coatings - Post-coating treatments of iron or steel to reduce the risk of hydrogen embrittlement
ISO 11130:2010	Corrosion of metals and alloys - Alternate immersion test in salt solution
MIL-STD-1501F (2011)	Chromium Plating, Low Embrittlement, Electrodeposition

3
Terms, definitions and abbreviated terms

3.1 Terms from other standards

a. For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.

b. For the purpose of this Standard, the terms and definitions from ECSS-Q-70-50 apply, in particular for the following terms:

    1. representative sample

3.2 Terms specific to the present standard

3.2.1 corrosion

gradual degradation of materials produced by chemical reaction with the environment or with fluids in contact with materials

3.2.2 corrosion resistant alloys

alloys showing acceptable corrosion performance in most environments seen by space hardware

NOTE The use of corrosion resistant alloys does not mean that corrosion cannot occur in all environments.

3.2.3 corrosion-resistant aluminium alloys

1000, 3000, 5000, and 6000 series alloys and all clad alloys

3.2.4 corrosion-Resistant Steel (CRES)

steel having 12 % in weight or more chromium content

3.2.5 exterior surfaces

surface in contact with or exposed to direct action of the environment

NOTE All other surfaces are considered interior surfaces.

3.2.6 non-corrosion-resistant aluminium alloys

all other aluminium alloys not considered to be corrosion-resistant alloys

3.2.7 non-corrosion-resistant steel

steel having less than 12 % in weight chromium

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	**Meaning**
AD	applicable document
AMS	aerospace material specification
ASTM	American Society for Testing and Materials
CRES	corrosion-resistant steel
CVD	chemical vapour deposition
°C	degree Celsius
DML	declared materials list
DMPL	declared mechanical parts list
DPL	declared process list
DRD	document requirements definition
EN	European Norm
H/W	hardware
ISO	International Standardisation Organisation
MIL-STD	military standard
MPa	Megapascal
NSST	Neutral Salt Spray Test
PVD	physical vapour deposition
RD	reference document
RH	relative humidity
SAE	Society of Automotive Engineers
SCC	stress-corrosion cracking
SST	salt spray test
UTS	ultimate tensile strength
UV	ultraviolet

3.4 Nomenclature

The following nomenclature applies throughout this document:

a. The word "shall" is used in this Standard to express requirements. All the requirements are expressed with the word "shall".

b. The word "should" is used in this Standard to express recommendations. All the recommendations are expressed with the word "should".

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

c. The words "may" and "need not" are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word "may". All the negative permissions are expressed with the words "need not".

d. The word "can" is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS "may" and "can" have completely different meanings: "may" is normative (permission), and "can" is descriptive.

e. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

4
Principles

4.1 General

Corrosion is the degradation of a material when exposed to an environment. Although corrosion usually refers to the degradation of metals and alloys. polymeric and ceramic materials can also degrade when exposed to an environment.

Clause 5.1.9 of ECSS-Q-ST-70 states that:

a. *"For all materials that come into contact with atmospheric gases, cleaning fluids or other chemicals, it shall be demonstrated that the degradation of properties during their anticipated service life does not prevent to meet the performance and integrity requirements"*.

b. *"All mechanical parts, assemblies and equipment including spares, shall be finished to provide protection from corrosion.*

NOTE *This applies equally to fasteners and other fixing devices, such as insert systems."*

4.2 Eight forms of corrosion

Corrosion is classified according to eight forms:

1) general,

2) galvanic,

3) pitting,

4) crevice,

5) erosion corrosion,

6) intergranular,

7) stress corrosion cracking,

8) dealloying or selective leaching.

A full explanation of eight forms of corrosion is given in Annex A.

Although some corrosion processes can be considered benign or even advantageous, the by-products of such reactions should also be considered. For example, hydrogen is generated as a by-product of many corrosion reactions.

The original corrosion can be superficial but the hydrogen generated can result in delayed fracture in titanium, high strength steels and martensitic alloys.

In the European Space Industry most corrosion problems experienced are associated with general corrosion, galvanic corrosion and pitting. Stress corrosion is covered by ECSS-Q-ST-70-36.

4.3 Corrosion protection

It is possible to protect materials from corrosion. Corrosion protection systems compatible with the space environment are available and some examples are described in clauses 5.6, 5.7 and 5.8.

NOTE Selection of a corrosion protection system needs to ensure it complies with local environmental regulations.

5
Requirements

5.1 Classification of corrosive environments

a. The supplier shall identify, the applicable classes of environments from the list specified in the Table 5-1 to which space flight hardware materials are exposed during hardware life cycle on ground or during mission.

NOTE A non-exhaustive list of standards that can be agreed between customer and supplier is given in the bibliography of this standard.

b. The supplier shall select corrosion protection systems for each space flight hardware material.

c. The selection of the relevant class of corrosive environment shall be based on the worst-case hardware exposure.

NOTE 1 The exterior surfaces are typically the worst-case exposure. However it is necessary to evaluate each hardware individually.

NOTE 2 The manufacturer can decide to put (or not) surface protection on materials or parts inside a hermetically sealed enclosure, containing a non-corrosive atmosphere.

d. Degree of severity increases from Class 6 to Class 1, except for Class 4 that shall be considered apart from other classes.

Table 5-1: Definition of corrosive environment classes

Class	Definition
1	Exposure to seawater (immersion)
2	Exposure to marine (atmospheric) environments
3	Exposure to inland outdoor environments. (See note 1).
4	Exposure to potentially corrosive chemical systems or microbial induced corrosion.
5	Exposure to indoor and uncontrolled humidity environments.
6	Continuous and exclusive exposure to temperature and humidity controlled (non-condensing) environment, dry air, and nitrogen- purged environments (maximum 65 % RH). (See note 2).
Note 1:	The weather conditions and prevailing winds mean that most of Europe is considered a marine environment. Use of this class in Europe need dedicated justification showing a chloride deposition rate of less than 5 mg.m2/day (mean annual value).
Note 2:	Examples of temperature and humidity controlled environments are clean room, flight hardware controlled storage areas

5.2 Performance requirements

a. It shall be shown that all environmentally exposed surfaces are protected from corrosion or resistant to corrosion in accordance with the test methods specified in the Table 5-2.

b. All corrosion tests shall be conducted using alloys with the heat treatment specified in the design documentation of the hardware.

c. For alloys in the same family, the most corrosion-susceptible alloy may be agreed between a customer and supplier and tested in lieu of the testing of all alloys in that family.

NOTE Sometimes it is not possible to select a single alloy to represent a family.

d. The supplier shall perform corrosion tests for the most severe environmental conditions anticipated.

e. In case the tests specified in Table 5-2 cannot be performed or are not representative, alternative justified corrosion test regimes for specific applications shall be submitted for customer approval.

f. Test acceptance criteria shall be specified by the supplier and agreed with the customer.

NOTE 1 A typical acceptance criteria can be “no visible signs of corrosion at 5X magnification and no material removed when tape tested in accordance with ISO 2409 standard without cuts”.

NOTE 2 See Tape Test method in Annex B.

g. At the conclusion of testing, the test samples shall be evaluated in accordance with acceptance criteria specified in the requirement 5.2f.

5.3 Test samples definition

a. Test samples shall be representative of the material listed in DML and DMPL specified in DRDs Annex A and Annex B from ECSS-Q-ST-70.

b. Test samples specified in the requirement 5.3a shall be manufactured with the same materials as the flight hardware and representative of the material form, finish, thermal treatment and size.

NOTE 1 Examples of material form are cast, forged or extruded.

NOTE 2 A typical sample has a minimum area of 1 dm^2. In the case of small flight hardware, a smaller sample size can be acceptable.

c. A minimum number of test samples shall be subject to the customer approval.

5.4 Test methods

5.4.1 Overview

The following clauses provide additional information on test methods versus environmental classes listed in Table 5-2.

Table 5-2– Matrix of test methods versus environments

Test Method	**Applicable Test Standard**	**Environment Class**					
		1	**2**	**3**	**4**	**5**	**6**
		Seawater Immersion	**Seacoast, Outdoor**	**Inland, Outdoor**	**Chemical or Microbial**	**Indoor uncontrolled**	**Indoor controlled**
Neutral Salt Spray Test (NSST)	**ISO 9227**			500 h alternating with UV test		168 h	
Chemical Resistance	**See Note 1**				Specific test in accordance with corrosive agents		
Damp Heat Test	**Damp Heat Test (see Annex C)** **(93 % RH 40 °C)**						240 h
UV	**ASTM D5894**			7 days alternating with NSST			
Alternate immersion	**ISO 11130**	2x maximum allowed exposure	30 days				
Note 1 Because for the environment class 4 there are no applicable test standards, the specific test in accordance with corrosive agents is performed.							

5.4.2 Class 1: Seawater Immersion

a. In Class 1 environments, the protective finish shall withstand two times the maximum defined duration of immersion in seawater, when tested in accordance with ISO 11130.

5.4.3 Class 2: Seacoast, Outdoor

a. In Class 2 environments, the protective finish shall withstand 30 days when tested in accordance with ISO 11130.

5.4.4 Class 3: Inland, Outdoor

a. In Class 3 environments, the protective finish shall be tested by a combination of UV and NSST.

b. In Class 3 environments, the protective finish shall be tested alternating NSST and UV test, starting with UV testing.

c. In Class 3 environments, the total duration of test specified in the requirement 5.4.4b shall be seven days for UV and 500 h for NSST.

5.4.5 Class 4: Chemical or Microbial-Induced Corrosion

a. In Class 4 environments, specific tests shall be performed to confirm that the hardware is protected against corrosion during the anticipated chemical exposure or during exposure to microorganisms that induce corrosion.

5.4.6 Class 5: Indoor, Uncontrolled

a. In Class 5 environments, the hardware or representative samples shall be tested for 168 h in accordance with Neutral Salt Spray Test from ISO 9227.

5.4.7 Class 6: Indoor, Controlled

a. In Class 6 environments, all exposed surfaces shall be maintained in a continuous exposure to temperature- and humidity-controlled non-condensing environments.

NOTE Examples of non-condensing environments include clean room, flight hardware controlled storage areas.

b. In Class 6 environments, the corrosion resistance shall be tested for 240 h in accordance with Damp Heat Test at (93 ±3)% RH and (40 ±3)°C.

NOTE The Damp Heat Test method is described in Annex C.

5.5 Corrosion protection

5.5.1 Process verification

a. For processes used for corrosion protection the supplier shall implement a verification programme.

b. The verification program shall be defined in accordance with the test methods specified in 5.4.

c. The process verification shall indicate the test methods used for process verification and the requirements to be met.

NOTE Depending on process and application additional testing can be performed. For example dry film thickness, coating adhesion, flexibility, abrasion resistance, and impact resistance testing can be performed if appropriate.

d. Process maturity and sensitivity studies shall be performed to establish processing parameters for protective finishes being qualified.

e. The process parameters specified in the requirement 5.5.1d shall be defined in the process specification.

5.5.2 Cleaning and surface preparation

a. Cleaning and surface preparation requirements shall be included in the surface treatment technical specification.

b. At the time of application of any finish, all surfaces shall be clean and free from dirt, grease, oil, or any contamination that can interfere with the performance of the finish of the part.

c. Cleaning methods or solutions used shall not affect the functioning of the part or application of the finish.

d. Steel and aluminium wools shall not be used.

e. The use of wire brushes shall be restricted to the same alloy type.

NOTE Carbon steel brushes on carbon or low-alloy steel structures are examples of wire brushes.

f. Austenitic stainless steel brushes may be used on other alloy classes provided that:

1. use of the brush is restricted to a single alloy, or

2. the brush is cleaned, rinsed, and dried before use on a different alloy.

g. All cleaning fluids and other chemicals used during manufacturing and processing of hardware shall be verified to be compatible with the hardware.

NOTE 1 Hydrochloric acid, chlorinated solvents, chlorinated cutting fluids, fluorinated hydrocarbons, and anhydrous methyl alcohol can all produce stress corrosion cracking. Silver, and gold have been shown to cause embrittlement in titanium and its alloys.

NOTE 2 For aluminium and alloys the use of a non-etch cleaner is preferred. This is particularly important when using an alkaline etch as the aluminium tends to be more soluble than its alloying elements and existing intermetallics, such as copper, which can be further exposed.

h. In case an etch is used, pitting or intergranular attack shall be prevented.

i. Alkaline etching of aluminium alloys should be avoided.

NOTE Particularly when cleaning assembled structures.

j. In case an alkaline etch is used, it shall be followed by an acid neutralization step.

k. Cleanliness shall be maintained and corrosion prevented between the various cleaning and finishing steps.

l. Cleaning and surface preparation shall be performed by trained personnel.

5.6 Metallic finishes

5.6.1 Verification of metallic finishes

a. All metallic finishes shall be verified in compliance with requirements from clause 5.5.

NOTE This list of requirements specified in clause 5.5 is not exhaustive.

5.6.2 Nickel plating

a. Electrodeposited nickel plating shall be applied in accordance with specification identified in the DPL specified in the DRD in Annex C from ECSS-Q-ST-70.

NOTE ISO 1456, SAE AMS2403 or SAE AMS2423 are internationally recognised standards describing electrodeposited nickel plating.

b. Electroless nickel plate shall be applied in accordance with specification identified in the DPL specified in the DRD in Annex C from ECSS-Q-ST-70.

NOTE 1 ISO 4527 or ASTM B733 are internationally recognized standards describing electroless nickel plate.

NOTE 2 Electroless nickel is preferred for irregularly shaped parts when a uniform thickness is required and for applications requiring a hard surface.

NOTE 3 Electroless nickel plating with low (<3 %) phosphorous content provides superior corrosion resistance in alkaline environments.

NOTE 4 Electroless nickel plating with high (>9 %) phosphorous content provides superior corrosion resistance in acidic environments.

c. The nickel-aluminium interface in nickel-plated aluminium shall be protected from exposure to corrosive environments.

NOTE Nickel and aluminium form a strong galvanic cell at the nickel-aluminium interface, and exposure of the aluminium alloy to a corrosive environment can produce rapid debonding of the nickel plate.

d. Nickel plating may be used for applications up to 538 °C.

e. Nickel plating on steel heat treated to a UTS over 1000 MPa shall receive a post-plating bake cycle.

f. For steels above a UTS of 1240 MPa, post-plating heat treatment shall conform to ISO 9588 to avoid hydrogen embrittlement.

NOTE ASTM B733 contains guidance on post-plating bake cycles for electroless nickel plating.

5.6.3 Chromium plating

a. Chromium plating shall be applied in accordance with specification identified in the DPL specified in the DRD from Annex C from ECSS-Q-ST-70.

NOTE ISO 6158 or SAE AMS2460 are internationally recognised standards describing chromium plating.

b. Chromium plating may be used for applications up to 538 °C or when an abrasion-resistant surface is needed.

c. Chromium plating on steel heat treated to a UTS of 1100 MPa to 1240 MPa shall receive a post-plating bake cycle in accordance with ISO 9588.

d. For steels above a UTS of 1240 MPa, chromium plating and post-plating heat treatment shall conform to MIL-STD-1501.

5.6.4 Zinc-Nickel plating

a. Zinc-nickel alloy shall be applied in accordance with specification identified in the DPL specified in DRD in Annex C from ECSS-Q-ST-70.

NOTE ISO 15726 or SAE AMS2417 are internationally recognised standards describing zinc-nickel plating.

5.6.5 Copper plating

a. Copper plating shall be applied in accordance with specification identified in the DPL specified in the DRD of Annex C from ECSS-Q-ST-70.

NOTE SAE AMS2418 or ASTM B734 are internationally recognised standards describing copper plating.

5.6.6 Silver plating

a. Silver plating shall be applied in accordance with specification identified in the DPL specified in DRD Annex C from ECSS-Q-ST-70.

NOTE 1 ISO 4521 or ASTM B700 are internationally recognized standards describing silver plating.

NOTE 2 Silver plating is susceptible to attack by atomic oxygen in low Earth orbit applications.

NOTE 3 Silver plating is also susceptible to forming dendrites when exposed to sulfur-/sulfide-containing environments.

b. Silver plating over copper shall be >2 μm.

NOTE Silver plating on copper can cause the formation of cuprous oxide (red plague corrosion) when stored in a high humidity environment.

5.6.7 Tin plating

a. Pure Tin plating coating shall not be used in space applications.

NOTE 1 The reason is the risk of whiskers formation and of allotropic transformation (called tin pest) when exposed to low temperatures in space environment.

NOTE 2 Alloying tin with at least 3 % of other metal is to prevent these problems.

5.6.8 Gold plating

a. Gold plating shall be applied in accordance with specification identified in the DPL specified in DRD of Annex C from ECSS-Q-ST-70.

NOTE ISO 27874 or ASTM B488 are internationally recognised standards describing gold plating.

5.6.9 Vapour deposited coatings (CVD and PVD)

a. CVD and PVD coatings may be used to protect high-strength steels, aluminium alloys and other alloys.

5.7 Inorganic finishes

5.7.1 Verification of inorganic finishes

a. All inorganic finishes shall be verified in compliance with requirements from clause 5.5.

5.7.2 Anodic oxidations on aluminium and its alloys and titanium and its alloys

a. Anodic oxidation dyed or not, Plasma electrolytic Oxidations (PEO) micro-arc oxidation (MAO) shall be applied in accordance with specification identified in the DPL specified in DRD of Annex C from ECSS-Q-ST-70.

NOTE 1 ISO 10074 ISO 7599, ECSS-Q-ST-70-03, SAE AMS2487, MIL-A-8625F are internationally recognised standards describing anodic oxidations on aluminium and its alloys and titanium and its alloys.

NOTE 2 Examples of anodic oxidation are sulphuric, sulpho-tartaric and phosphoric oxidation.

b. Anodic coating shall be sealed.

c. Chemical conversion coatings shall be applied in accordance with specification identified in the DPL specified in DRD in Annex C from ECSS-Q-ST-70.

NOTE 1 Examples of chemical conversion coatings are TCP-Trivalent Chromium Products- based, Zirconium, Molybdenum, Cerium.

NOTE 2 The use of hexavalent chromium can be restricted in some geographical regions.

NOTE 3 MIL-DTL-5541 and MIL-DTL-81706 are internationally recognized standard describing chemical conversion on aluminium and its alloys.

d. When organic post-treatments are applied over chemical conversion coatings to improve corrosion resistance the thermal and radiation stability shall be verified.

NOTE Example of radiation stability include heavy ions, proton, electron.

5.8 Organic finishes

a. All organic finishes shall be verified in compliance with requirements from Clause 5.5.

5.9 Design considerations for corrosion control

5.9.1 Surface treatments processes

a. All design and verification shall include the surface treatments or features on a flight hardware.

NOTE A flight hardware can have regions with difficult geometries for coating systems. For example holes through or blind, abrupt change of geometry, sharp edges and crevices.

5.9.2 Cut edges

a. The edges of all metals in exterior locations shall be rounded or chamfered to permit adhesion of an adequate thickness of protective coatings.

5.9.3 Drainage and airflow

a. Drainage shall be provided to prevent collection and entrapment of rain, seawater, or other unwanted fluids and allow air to flow.

b. All designs including fixtures and masking shall prevent of entrapment of water or fluid and ensure drain holes are located for drainage of accumulated fluids.

NOTE Restricting airflow can lead condensation becoming trapped on internal surfaces.

5.9.4 Galvanic compatibility

a. Dissimilar metal assemblies, bimetallic contact, shall be in compliance with requirements from clause 5.1.12 of ECSS-Q-ST-70.

b. Galvanic couples shall be in conformance with values from Table 5-1 of ECSS-Q-ST-70.

c. All contacts between graphite-based or graphite containing composites and metallic materials shall be treated as dissimilar metal couples.

d. Galvanic corrosion of incompatible assemblies shall be evaluated at the assembly level in accordance with the requirements from clause 5.2 of this standard and requirements from clause 5.1.12 from ECSS-Q-ST-70.

Annex A (informative) Corrosion

A.1 Overview

The majority of corrosion reactions involve a metal in the presence of water and oxygen. Consider the corrosion of iron or steel in a natural water. The reaction proceeds as follows:

$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2$	(1)

Equation (1) summarises the overall reaction but it is made up from two independent half-reactions (the oxidation of iron, anodic reaction (1a), and the reduction of oxygen and water, cathodic reaction (1b)) i.e.

$2Fe \rightarrow 2Fe^{2+} + 4\,e^-$	(1a)
$O_2 + 2H_2O + 4e^- \rightarrow 4OH$	(1b)

In a real system the iron hydroxide usually oxidises further to form either magnetite (Fe_3O_4) or a hydrated ferric oxide (FeOOH), but if the initial oxidation of the iron can be stopped or reduced then a steel structure can be protected. The principles behind many corrosion protection methods depend on interfering with this reaction.

A.2 The eight forms of corrosion

A.2.1 General corrosion

General corrosion, or uniform attack, is one of the most common causes of corrosion. It is characterised by its relatively uniform progress through a structure usually over a large area.

A.2.2 Galvanic corrosion

Galvanic, sometimes referred to as bimetallic, corrosion can occur when two metals are in contact both electrically and via an electrolyte. Two metals placed into the same solution achieve different potentials. If the metals are electrically connected to each other then they are at the same potential, somewhere between the two unconnected potentials. This change in potential is referred to as polarisation, and results in the corrosion of the more active metal being driven harder whilst the more noble metal is protected. This phenomenon can be taken advantage of in corrosion protection, when a more active metal is used to coat a structural material such as zinc galvanising on steel, with the zinc corroding preferentially and protecting the underlying steel.

The amount of corrosion experienced by the active, anodic, metal depends on the corrosion current being provided by the non-corroding cathode. This leads to the effect that galvanic corrosion can be reduced by coating the cathodic, non-corroding, material. In many cases, if the area of the cathode is small relative to the anode the additional corrosion is negligible. For example: stainless steel screws in an aluminium structure that can be considered a problem according to ECSS-Q-ST-70. In practice stainless steel screws are commonly used without any problems because the small area of steel relative to the large area of aluminium structure means that the current density driving corrosion is low and the effects are negligible.

A.2.3 Crevice corrosion

Localised corrosion frequently occurs within crevices or other shielded features where small quantities of an electrolyte can stagnate. Restricted access means that any oxygen in the crevice is used up relatively quickly, stifling the local cathodic reactions. The cathodic reaction continues outside the crevice, and so provides a balance to the anodic reaction continuing within the crevice and putting metal ions into solution. Without the cathodic reaction within the crevice producing hydroxyl ions there is soon an excess of positively charged metal ions. These ions attract negatively charged ions, particularly the very mobile chlorides, into the crevice and form metal chlorides. In aqueous solutions most metal chlorides dissociate producing insoluble metal hydroxides and hydrochloric acid, which then goes on to further attack the remaining metal in the crevice.

A.2.4 Pitting

Pitting is one of the most destructive forms of corrosion. When a metal is placed in an environment there are three possible results. Occasionally no reactions occur and the metal does not corrode. If it does react then corrosion products form. If the corrosion products do not protect the metal then general corrosion continues until all the metal has been oxidised. If the corrosion products do protect the metal then a film forms over the surface. This is referred to as *passivation*. In general the protection of the metal is not complete and the corrosion continues at a reduced rate, but problems can occur if the film breaks down locally for any reason. If the local breakdown becomes large enough a pit is formed and draws current from the surrounding area. Any smaller pits are stifled whilst the larger ones continue to grow.

Once formed the mechanism of pit growth is very similar to crevice corrosion. A semi-permeable membrane forms over top of the pit and caps it. This restricts the flow of some species in and out of the pit and allows the pH within the pit to decrease, become more acidic.

As the pit becomes more acidic, the rate of attack can increase.

A.2.5 Intergranular corrosion

Localised attack of grain boundaries in preference to the bulk of the grains is referred to as intergranular corrosion. Grain boundaries are the planes of atomic mismatch between the lattices of adjacent grains. They are slightly more energetic than the surrounding grains and tend to corrode a little faster. Usually this effect is minimal and is swamped by general corrosion, but occasionally the boundaries are very reactive and corrode very quickly. As the boundary corrodes then the grain it surrounds is undermined until it falls out and a great deal of material can be lost from the structure.

A.2.6 Dealloying or Selective leaching

Selective leaching or dealloying occurs when one element in an alloy is removed preferentially by a corrosion process. The most common example of this form of attack is dezincification where zinc is selectively removed from brass. The exact mechanism by which this occurs is still being debated but it is generally believed to be one or both of two. In the first it is suggested that both alloying elements are removed during the corrosion process and that the more noble is then redeposited. In the second, one metal is selectively dissolved leaving the second metal in a porous structure. Selective leaching can sometimes be advantageous, for instance it has been known for the enrichment of silicon to occur in the oxide films on stainless steel, increasing their resistance to pitting.

A.2.7 Erosion corrosion

Erosion corrosion occurs when the corrosion processes are accelerated because of the relative movement between a corrodent and a metal surface. The metal can be removed either as dissolved ions or as corrosion products which are broken away from the surface. The resistance of a metal to erosion corrosion depends on the nature of the films developed on its surface.

A.2.8 Stress corrosion

Stress corrosion cracking (SCC) is a delayed failure mechanism in which cracks initiate and propagate though a material until the stresses in the remaining ligament exceed the material’s strength. It occurs when a susceptible metal is stressed and exposed to a specific corrosive environment. The stresses can either be imposed from the outside or be residual, internal, stresses. There are almost as many proposed mechanisms for SCC as there are susceptible metal-environment combinations, however there are certain common themes. The breaking of the bonds between atoms at the crack tip can be either by chemical solvation followed by dissolution or by mechanical fracture. If mechanical fracture is the mechanism then it is probably stimulated at the crack tip because of the adsorption of environmental species, reactions at the surface, reactions in the metal ahead of the crack tip or the development of surface films.

A.3 Hydrogen damage

Although it is not one of the eight forms of corrosion, it is worth noting the effects of hydrogen damage which can occur as a result of some corrosion reactions. One of the products of many corrosion reactions is atomic hydrogen. Once generated the hydrogen atom can do one of two things. It can either combine with another hydrogen atom and be released as a gas, H_2, or it can dissolve in the metal surface on which it was generated. The hydrogen evolved as a gas is usually of little worry but if it dissolves it can produce embrittlement, delamination or blistering in the structure, all of which can be detrimental to the performance of an alloy. If sulphur is present then it can poison the hydrogen recombination reaction, increasing the probability of atomic hydrogen dissolving in the metals lattice. Titanium alloys, high strength steels and martensitic alloys are particularly sensitive to embrittlement by adsorbed hydrogen.

A.4 Corrosion in clean rooms

The humidity in clean rooms is controlled to 55%RH ± 10%RH meaning that corrosion is not expected. In reality a small but significant number of corrosion issues are reported in clean rooms each year.

A small number of the failures have been associated with failure of the clean room controls but this is relatively rare.

Most of the failures seen are associated with poor air flow. In the bulk of a clean room the air circulation maintains the environment but low flow or dead spots can be found near walls or corners. Poor circulation can also be deliberately introduced, for instance by a baffle to provide additional protection to a sensitive part such as a mirror. The generation of microclimates can result in the adsorption of monolayers of water onto surfaces which then initiates corrosion. Once corrosion has initiated the corrosion products are often hydroscopic drawing in more water and exacerbating the corrosion.

Annex B (informative)
Tape test method

The adhesion tape test is described in the standard ISO 2409 without application of cuts.

For this test a pressure-sensitive tape with peel adhesion strength of 440 g/cm (with a tolerance of ±10 %) is used.

NOTE It is important to take special attention when using alternative standards where differing results classification systems can be defined.

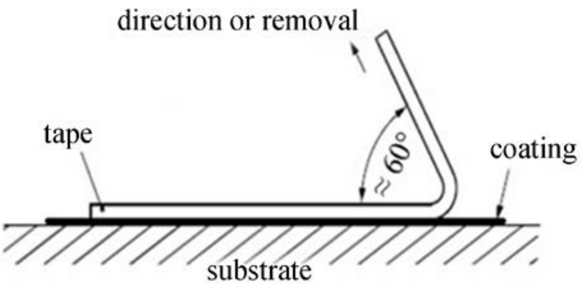

Figure B-1: Tape test method

Annex C (informative) Damp heat test method

C.1 Introduction

This procedure covers the basic principles and operating procedures for testing corrosion resistance of coatings by exposing coated specimens in an atmosphere maintained nominally between 80 % RH and 95 % RH and temperature between 35 °C and 50 °C (other RH and T range can be used in function of materials characteristics or specific requirements).

For these tests, condensation over test specimens is avoided.

This procedure does not describe the type of test specimen or exposure periods to be used for a specific product.

C.2 Significance and use

This test provides a controlled and soft corrosive environment to produce relative corrosion resistance information for specimens of materials (e.g. metals and coated metals) and relative information concerning materials degradation and ageing.

Damp heat tests are used for specification and qualification acceptance, quality control, and research and development for substrates and coatings.

Acceptance criteria levels and test parameters (e.g. duration, temperature and humidity) are typically set in other documents (e.g. material specification and qualification plan).

C.3 Apparatus and test specimens

C.3.1 Test chambers

The test chamber is constructed of corrosion-resistant materials with supports for test specimens and the ability to control temperature and humidity.

C.3.2 Test specimens

The type, preparation and number of test specimens used as well as the criteria for the evaluation of test results, is defined in the specification covering the material or product being exposed.

The design of experimental programmes needs to take account of the probable dispersion in results. It is important to consider the number of specimens needed to give statistically significant results.

C.4 Position of test specimens during exposure

The specimens (for corrosion resistance samples) are not in contact with each other, with any unprotected metallic material or any material capable of acting as a wick; they are supported or suspended between 15° and 30° from the vertical and preferably parallel to the principal direction of flow through the chamber, based upon the dominant surface being tested.

Specimens are arranged to avoid any condensation from one specimen to another.

Each specimen is placed to permit unencumbered exposure of the active surface being tested.

If more than one specimen is exposed, place the replicates in different locations in the exposure area.

C.5 Conditions in the chamber

Temperature and relative humidity defined in the relevant document (e.g. material specification: qualification plan) are set and maintained during the duration of the test.

Tolerances for temperature are usually between -3 °C and +3 °C. Humidity tolerances are typically ±3 % RH.

C.6 Procedure

Heating and generation of water vapour uses appropriate profiles to avoid or minimise condensation.

In case of non-homogeneous environment inside the chamber, and to control and compensate the variability within the apparatus, the specimens are repositioned on a regular basis so that all specimens spend equivalent amounts of time in the various areas of the apparatus (front, back, left, right and centre).

Conclude the test after the specified period of time or after effects from exposure to damp heat exposure are observed.

Wipe the test specimen dry.

C.7 Evaluations of results

A careful and immediate examination is made as required by the specification and qualification plan covering the material or product being tested.

C.8 Records and report

The following information is typically recorded:

- Sample identification
- Test parameters sets (test duration, temperature and humidity)
- Pictures of samples installed in the chamber
- All readings of temperature and humidity within the exposure zone of the chamber
- Daily temperature and humidity records
- Special conditions of test or any deviation from the test procedure
- Results of the inspections or test evaluations

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