Guideline for selection of accelerated corrosion test for product qualification

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Title: Guideline for selection of accelerated corrosion test for product qualification

Abstract:
In corrosion engineering large efforts have been made to develop quantitative accelerated corrosion tests for the purpose of product qualification. As a result of this work a broad spectrum of methods now exists of which some are also available as international standards. The new kind of accelerated corrosion tests offer many new possibilities. However, to identify the most relevant method for one specific application requires knowledge that usually goes beyond what you can get from a single standard.

The Guideline in this report has therefore been prepared as a framework for comparing existing accelerated corrosion tests and should be applicable in the choice of best method and procedure for qualification testing of a product with respect to corrosion resistance.

The Guideline has recently been submitted to the International Organization for Standardization ISO together with a new work item proposal for ISO TC 156 Corrosion of metals and alloys, WG 7 Accelerated corrosion tests

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**Building**

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Foreword

This report is the result of project NIC 04129, which has been financed jointly by Nordic Innovation Centre (NIC), SP Swedish National Testing and Research Institute, Danish Technical Institute, Ericsson Microway System, Norwegian University of Science and Technology, Swedish Corrosion Institute, Volvo Car Corporation, and VTT Industrial Systems.

The project members have been

- Prof. Bo Carlsson, SP Swedish National Testing and Research Institute
- MSc Göran Engström, Swedish Corrosion Institute
- MSc Mikael Johansson, Ericsson Microway System
- Prof. Roy Johnsen, Norwegian University of Science and Technology
- BSc Anne-Lise Hög Lejre, Danish Technical Institute
- MSc Reima Lahtinen, VTT Industrial Systems
- MSc Mats Ström, Volvo Car Corporation

The project members have all large experience of corrosion testing and have also a deep insight into the industrial needs to which this Guideline is addressed. The Guideline is unique in that it represents the first attempt to set up a framework for comparing both well established and novel accelerated corrosion tests so that the various aspects in the choice of best method and procedure for product qualification with respect to corrosion testing can properly be taken into account.

The report has been prepared partly in the form of an ISO template document and shall be considered as a contribution to the work in ISO TC 156 Corrosion of metals and alloys, WG 7 Accelerated corrosion tests.

Bo Carlsson
Project Leader
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B.2 Functional and service life requirements on product and functional units
B.3 Potential failure modes and associated material degradation mechanisms
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0. Introduction

In corrosion testing there has been a development from qualitative to more quantitative methods and the prerequisites for corrosion testing in product qualification are changing. Modern technologies for control and regulation of climatic test parameters are adopted in test equipment so that the reproducibility of tests increases. To make possible a better translation of laboratory test results into in-service performance, quantitative methods for characterization of corrosivity have been introduced during recent years. To evaluate the effect of corrosion attack on product functional performance, quantitative methods are adopted for assessing changes in the functional properties as well as in the associated chemical changes resulting from corrosion of the materials of the component.

Field site exposure testing was and still is the traditional way to verify the corrosion resistance of new materials and products, especially for testing new surface treatment systems or coatings for corrosion protection. Field test sites can be selected at places of high corrosivity as in marine or industrial areas. The field test sites therefore often represent worst cases of environments and as such the tests at those sites can be considered as accelerated tests. The degree of acceleration is, however, mostly moderate and it generally takes a long time to get an answer whether a tested material or product should be considered qualified with respect to its corrosion resistance.

For qualification of new materials and products with respect to corrosion resistance therefore accelerated corrosion tests generally need to be adopted during product design work. The higher the degree of acceleration of a corrosion test the more favourable the accelerated corrosion test will be in keeping the required testing time short. On the other hand, the higher the acceleration of the corrosion process needs to be during testing the harder there is to simulate properly the natural occurring corrosion processes. This is pointing at the main problem in designing meaningful accelerated corrosion tests for product qualification.

Large efforts have been made to develop accelerated corrosion tests for the purpose of product qualification. As a result of this work a broad spectrum of methods now exists of which some are also available as international standards. However, some of those tests are intended only for checking the comparative quality of a metallic material with or without corrosion protection while others may even be useful for predicting or estimating the long-term performance of a product with metallic materials when exposed to corrosive stress representing in-service conditions.

To identify the most relevant method for one specific application requires knowledge that usually goes beyond what you can get from a single standard. This guideline therefore presents a framework for comparing existing accelerated corrosion tests so that the various aspects in the choice of best method and procedure can properly be taken into account.
Corrosion of metals and alloys — Corrosion tests in artificial atmospheres — Guideline for selection of accelerated corrosion test for product qualification

1 Scope

This Technical Guideline is applicable for the selection of suitable accelerated atmospheric corrosion tests for qualification of products with metallic materials without or with permanent corrosion protection or temporary corrosion protection. The characteristics of a number of standardised accelerated corrosion tests are also given to serve as guide in preparation of test specifications.

In the Technical Guideline the following aspects are taken into account

- Categories of accelerated atmospheric corrosion tests
- Recommended fields of application for the different kinds of tests and their suitability
- Corrosivity of tests and relative corrosion rates of standard metals
- Requirement on test equipment, criteria for reproducibility and correlation with in-service performance
- Recommended procedures for product qualification

The main purpose of the Technical Guideline is to present a framework for comparing the different accelerated corrosion test methods, which presently are available as international standards. The suitability of a test method varies with the requirements set by the intended application of the product.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9227, Corrosion tests in artificial atmospheres – Salt spray tests
ISO 10062, Corrosion tests in artificial atmosphere at very low concentrations of polluting gas(es)
ISO 11130, Corrosion of metals and alloys – Alternate immersion test in salt solution
ISO 11474, Corrosion of metals and alloys – Corrosion tests in artificial atmosphere – Accelerated outdoor test by intermittent spraying of a salt solution (Scab test)
ISO 11997-1, Paints and varnishes – Determination of resistance to cyclic corrosion conditions – Part 1: Wet (salt fog)/dry/humidity
ISO 11997-2, Paints and varnishes – Determination of resistance to cyclic corrosion conditions – Part 2: Wet (salt fog)/dry/humidity/UV-light
ISO 14993, Corrosion of metals and alloys – Accelerated testing involving cyclic exposure to salt mist, "dry" and "wet" conditions
ISO 16151, Corrosion of metals and alloys – Accelerated cyclic tests with exposure to acidified salt spray, 'dry' and 'wet' conditions
ISO 16701, Corrosion of metals and alloys – Corrosion in artificial atmosphere – Accelerated corrosion test involving exposure under controlled conditions of humidity cycling and intermittent spraying of a salt solution
ISO 20340, Paints and varnishes - Performance requirements for protective paint systems for offshore and related structures

ISO 21207, Corrosion tests in artificial atmospheres – Accelerated corrosion tests involving alternate exposure to corrosion promoting gases, neutral salt spray and drying

IEC 60068-2-11, Environmental testing - Part 2: Tests. Test Ka: Salt mist

IEC 60068-2-30, Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)

IEC 60068-2-52, Environmental testing - Part 2: Tests - Test Kb: Salt mist, cyclic (sodium, chloride solution)

IEC 60068-2-60, Environmental testing - Part 2: Tests - Test Ke: Flowing mixed gas corrosion test

IEC 60068-2-78, Environmental testing - Part 2-78: Tests - Test Cab: Damp heat, steady state

ISO 9223 Corrosion of metals and alloys - Corrosivity of atmospheres – Classification

ISO 9226 Corrosion of metals and alloys - Corrosivity of atmospheres - Determination of corrosion rate of standard specimens for the evaluation of corrosivity

ISO 9224 Corrosion of metals and alloys - Corrosivity of atmospheres - Guiding values for the corrosivity categories

ISO 9225 Corrosion of metals and alloys - Corrosivity of atmospheres - Measurement of pollution

### 3 Categories and characteristics of accelerated corrosion tests

The oldest and most widely used method for laboratory accelerated corrosion testing is maybe the continuous neutral salt spray test (category A in Table 1). The continuous salt spray test is particularly useful for detecting discontinuities such as pores and other defects in certain metallic, anodic oxide and conversion coatings as well as in organic coatings. However, although used extensively for the purposes of qualification testing, results from continuous salt spray testing seldom correlate well with in-service performance.

<table>
<thead>
<tr>
<th>Category of test</th>
<th>Examples of standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Continuous salt spray tests</td>
</tr>
<tr>
<td>B</td>
<td>Tests with alternating immersion of test objects in a salt solution followed by drying or intermittent salt spraying and drying</td>
</tr>
<tr>
<td>C</td>
<td>Tests with cyclic variation of humidity (dry/wet) and including also steps of salt spraying</td>
</tr>
<tr>
<td>D</td>
<td>Tests with continuous exposure to atmospheres with low concentrations of corrosion promoting gases and at moderately high humidity</td>
</tr>
<tr>
<td>E</td>
<td>Tests with continuous exposure to atmospheres with higher concentrations of corrosion promoting gases and at higher humidity including also steps of drying and short period of salt spraying</td>
</tr>
<tr>
<td>F</td>
<td>High humidity tests</td>
</tr>
</tbody>
</table>

¹ See reference [1] in Annex C
One way to increase this ability is to introduce a step of drying after salt spray exposure (category B in Table 1). Even better, however is to combine salt spray exposure with humidity cycling between a high humidity level and a low humidity level (category C in Table 1) and, thus, introducing both wetting and drying in the corrosion test cycle.

Results from such tests turn out to correlate reasonably well with in-service performance at normal outdoor conditions. A number of cyclic accelerated corrosion tests based on this principle have been developed and standardised. The complexity of such tests, however, varies and so the requirements on test equipment. To get better control of the factors determining the rate of corrosion and relevance to in-service corrosion performance advanced systems have come into use.

Certain air pollutants as sulphur dioxide $\text{SO}_2$, nitrogen dioxide $\text{NO}_2$, hydrogen sulphide $\text{H}_2\text{S}$, and chlorine $\text{Cl}_2$ present in air as trace substances promote corrosion of metals under high humidity conditions and need to be taken into consideration in the evaluation of corrosion resistance of products that are especially sensitive to corrosion failures such as electronic devices. High humidity exposure tests in the presence of such air pollutants are therefore frequently used in the qualification of electronic products with respect to corrosion resistance (category D in Table 1).

Corrosion effects may appear at air volume fractions of pollutants less than of $10^{-6}$. The conduct of air pollutant corrosion tests, therefore, requires very special kind of test equipment. Moreover mixtures of polluting gases are often used to simulate synergistic effects.

To assess corrosion resistance of certain products, tests combining intermittent salt spraying with exposure to corrosion promoting gases have also been introduced (category E in Table 1). Additional synergistic effects may be tested by such methods. The tests are also recommended for qualification of products designed for use in relative corrosive environments.

Sometimes tests involving exposure of test specimens to high humidity and to condensing water are considered as corrosion tests (category F in Table 1). Such test may produce corrosion effects on metallic parts of products if surface contaminants in the form of salts are present. Condensation tests are also used for the testing of organic coatings because they may induce damage caused by swelling and out-leakage of additives. For testing of electronic devices high humidity tests are used for control of air-tightness and in-leakage of water in the equipment. A special case of that is testing the corrosion protection capability of a semi permeable enclosure with electric device by initiating rapid cooling of the enclosure. This will cause the pumping of damp air into the enclosure and there result in condensation of water vapour if the cooling effect is sufficiently high.

### 4 Recommended fields of application for different kinds of tests and their suitability

During recent years methods for quantitative assessment and classification of atmospheric corrosivity have been developed and some of those exist also as international standards. Atmospheric corrosivity for a specific location may either be estimated from meteorological data as described in ISO 9223 or assessed by measuring the corrosion rate of standard metal specimens at this location as described in ISO 9226.

The suitability of the different categories of corrosion tests for product qualification is given in Table 2 for four different fields of applications and at varying corrosivity of an intended in-service environment in those applications.

The corrosivity categories C1 = very low corrosivity, C2 = low corrosivity, C3 = medium corrosivity, C4 = high corrosivity, and C5 = very high corrosivity given in Table 2 are defined quantitatively in the standard ISO 9223. The severity classes G1 = mild, G2 = moderate, G3 = harsh, and GX = severe appearing in Table 2 also are quantitatively defined in ISA S71.04 (Reference [2] in Annex C).

For expressing the suitability of a specific category of corrosion test the following classes are used:
Table 2 Suitability of corrosion test methods for different fields of application

(P = Preferred kind of method, U = Useful for comparative testing of similar products, and N = Not useful unless for quality control of the same product)

<table>
<thead>
<tr>
<th>Field of application</th>
<th>Suitability of different categories of corrosion tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A (constant salt spray)</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td><strong>Descriptive</strong></td>
<td></td>
</tr>
<tr>
<td>Marine constructions</td>
<td>Top site (C4-C5)</td>
</tr>
<tr>
<td></td>
<td>Splash (C5)</td>
</tr>
<tr>
<td></td>
<td>Sub-sea</td>
</tr>
<tr>
<td>Automotive</td>
<td>Chassis (C4-C5)</td>
</tr>
<tr>
<td></td>
<td>Engine compartment (C2-C4)</td>
</tr>
<tr>
<td></td>
<td>Passenger compartment (C1)</td>
</tr>
<tr>
<td>Building constructions</td>
<td>Open (C3-C5)</td>
</tr>
<tr>
<td></td>
<td>Sheltered (C2-C4)</td>
</tr>
<tr>
<td></td>
<td>Indoor (C1-C2)</td>
</tr>
<tr>
<td>Electric devices</td>
<td>Severe (G1)</td>
</tr>
<tr>
<td></td>
<td>Harsh (G3)</td>
</tr>
<tr>
<td></td>
<td>Mild to Moderate (G1-G2)</td>
</tr>
</tbody>
</table>

1) Total immersion test should be used,

2) Is the preferred kind of method for electric devices but is also of more general applicability

3) For the testing of tightness,

4) Preferred kind of method when the effect of inner salt contaminants dominates

General statements on the suitability of the different categories of tests for assessing the corrosion resistance of specific metallic materials are given in Table 3 by making use of the same classes of suitability as used in Table 2.
Table 3 Suitability of the different tests for assessing corrosion resistance of specific metallic materials with or without corrosion protection

(P = Preferred kind of method, U = Useful for comparative testing of similar products, N = Not useful unless for quality control of the same product)

<table>
<thead>
<tr>
<th>Metallic material</th>
<th>A (constant salt spray)</th>
<th>B (alternate immersion)</th>
<th>C (humidity cycling with salt spraying)</th>
<th>D (air pollutant exposure)</th>
<th>E (air pollutant exposure, drying and salt spray)</th>
<th>F (condensation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals and alloys</td>
<td>N</td>
<td>U</td>
<td>P</td>
<td>4)</td>
<td>P5)</td>
<td>7)</td>
</tr>
<tr>
<td>Metals protected by cathodic coatings</td>
<td>U</td>
<td>U</td>
<td>P</td>
<td>4)</td>
<td>P5)</td>
<td>7)</td>
</tr>
<tr>
<td>Metals protected by anodic coatings</td>
<td>N</td>
<td>N</td>
<td>P1)</td>
<td>4)</td>
<td>P5)</td>
<td>7)</td>
</tr>
<tr>
<td>Metals protected by conversion coatings on an anodic coating</td>
<td>N</td>
<td>U</td>
<td>P</td>
<td>4)</td>
<td>P5)</td>
<td>7)</td>
</tr>
<tr>
<td>Metals protected by organic coatings</td>
<td>N</td>
<td>U</td>
<td>P2), 3)</td>
<td>4)</td>
<td>P5)</td>
<td>P6), 7)</td>
</tr>
<tr>
<td>Metals with temporary corrosion protection</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>P8)</td>
</tr>
</tbody>
</table>

1) Consideration should be paid to the fact that some test methods enhance the corrosion of zinc relative to that of carbon steel, see Table 5.
2) Consideration should be paid to the fact that for some methods the drying times are too short and the salt load too high to avoid locking of paint under-creep corrosion for many coating systems. Crevice corrosion may be hampered by the same reason. In the selection of corrosion test method and specification of test severity consideration should be paid to the fact whether open air or crevice corrosion is the most critical.
3) Most methods are not capable to simulate all type of failure modes for painted aluminium.
4) Kind of test method mainly intended for testing of electric devices from mild to harsh corrosive environments.
5) Preferable kind of test method in connection with testing of electric devices but is also more generally applicable.
6) Condensation testing of value for checking wet adhesion of coatings.
7) Preferred kind of method for testing electric devices when the effect of inner salt contaminants dominates.
8) Temporary corrosion protection includes in this case surface treatment with waxes or other agents to protect metal surface from moisture.

In the table some considerations needed to be taken into account when selecting the most appropriate test method within a certain category of corrosion tests are also stated.
5 Corrosivity of tests and relative corrosion rates of standard metals

The use of standard metal specimen exposure to assess corrosivity or corrosion load should preferably be adopted for characterizing the corrosive stress in a specific accelerated corrosion test. Data on corrosivity with respect to corrosion of standard metal specimens are available for many standard tests and such data can be used to compare different tests. To illustrate how the corrosive stress varies between some standard tests, estimated mean testing times to reach a metallic mass loss of carbon steel corresponding to 10 years of outdoor exposure in corrosivity category C3 mean, according to ISO 9224 are presented in Table 4. Data on the corrosivity of the different tests are found in the respective standards but are also available in Annex A of this Technical Guideline.

Table 4 Testing time to reach a metallic mass loss of carbon steel corresponding to 10 years of outdoor exposure in corrosivity category C3 mean according to ISO 9224

<table>
<thead>
<tr>
<th>Test method</th>
<th>Mean testing time (^1) to reach a metallic mass loss of carbon steel = 670 g/m(^2) due to corrosion (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor exposure under mean C3 atmospheric corrosivity conditions according to ISO 9224</td>
<td>3650</td>
</tr>
<tr>
<td>Outdoor exposure under mean C4 atmospheric corrosivity conditions according to ISO 9224</td>
<td>639</td>
</tr>
<tr>
<td>Outdoor exposure under mean C5 atmospheric corrosivity conditions according to ISO 9224</td>
<td>222</td>
</tr>
<tr>
<td>ISO 9227</td>
<td>19</td>
</tr>
<tr>
<td>ISO 14993</td>
<td>7</td>
</tr>
<tr>
<td>ISO 16151A</td>
<td>12</td>
</tr>
<tr>
<td>ISO 16151B</td>
<td>15</td>
</tr>
<tr>
<td>ISO 16701</td>
<td>19</td>
</tr>
<tr>
<td>ISO 21207B</td>
<td>24</td>
</tr>
<tr>
<td>ISO 11997-1 C2</td>
<td>32</td>
</tr>
<tr>
<td>ISO 11474</td>
<td>120 (^2)</td>
</tr>
</tbody>
</table>

\(^1\) Mean testing times have been estimated from metallic mass loss data found in the respective standards and it has further been assumed that metallic mass loss versus exposure time for the accelerated tests is linear

\(^2\) Data representative for testing during winter season at SP Swedish National Testing and Research Institute

The corrosion rate of one standard metal in relation to the corrosion rate of another standard metal in an accelerated corrosion test should be considered in the choice of the most suitable test for a given application. The relative corrosion rate of the two standard metals in the test compared to the relative corrosion rate of the same metals under in-service conditions is a measure on how well the test reproduces in-service corrosion behaviour. To illustrate this, corrosion load data for carbon steel and for zinc in some standard accelerated corrosion tests are shown in Table 5. In this table estimated allowed range of metallic mass loss of carbon steel and of zinc with reference to a mean metallic mass loss of carbon steel equal to 670 g/m\(^2\) are shown in comparison with data from outdoor exposure during 10 years in atmospheric corrosivity category C3 according to ISO 9224.
Table 5 Allowed range of metallic mass loss of carbon steel and of zinc with reference to a mean metallic mass loss of carbon steel equal to 670 g/m²

<table>
<thead>
<tr>
<th>Test method / exposure time</th>
<th>Metallic mass loss of carbon steel (g/m²)</th>
<th>Metallic mass loss of zinc (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric corrosivity category C3 for 10 years</td>
<td>400 - 940</td>
<td>40-140</td>
</tr>
<tr>
<td>ISO 9227 for 19 days</td>
<td>480 - 860</td>
<td>240 - 710</td>
</tr>
<tr>
<td>ISO 14993 for 7 days</td>
<td>530 - 800</td>
<td>100 -170</td>
</tr>
<tr>
<td>ISO 16151 A for 12 days</td>
<td>460 - 880</td>
<td>140 -250</td>
</tr>
<tr>
<td>ISO 16151 B for 15 days</td>
<td>470 - 870</td>
<td>15 - 50</td>
</tr>
<tr>
<td>ISO 16701 for 19 days</td>
<td>630 - 710</td>
<td>25 -35</td>
</tr>
<tr>
<td>ISO 21207 B for 24 days</td>
<td>670 (^{2})</td>
<td>104 (^{2})</td>
</tr>
<tr>
<td>ISO 11997-1:C2 for 32 days</td>
<td>670 (^{2})</td>
<td>241 (^{2})</td>
</tr>
<tr>
<td>ISO 11474 for 4 months</td>
<td>670 (^{2})</td>
<td>63 (^{2})</td>
</tr>
</tbody>
</table>

\(^{1)} Mean testing times have been estimated from metallic mass loss data found in the respective standards and it has further been assumed that metallic mass loss versus exposure time for the accelerated tests is linear
\(^{2)} Available data is limited so that it is not possible to give an allowed range of metallic mass loss in those cases

In Table 6 corresponding data for the corrosion of zinc and copper are shown for just one test because data of this kind for the other accelerated tests are not presently available.

Table 6 allowed range of metallic mass loss of zinc and of copper with reference to a mean metallic mass loss of carbon steel equal to 670 g/m²

<table>
<thead>
<tr>
<th>Test method / exposure time</th>
<th>Metallic mass loss of zinc (g/m²)</th>
<th>Metallic mass loss of copper (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric corrosivity category C3 for 10 years</td>
<td>40 - 140</td>
<td>9 -130</td>
</tr>
<tr>
<td>ISO 21207 B for 24 days</td>
<td>103 (^{2})</td>
<td>46 (^{2})</td>
</tr>
</tbody>
</table>

\(^{1)} Mean testing times have been estimated from metallic mass loss data found in the respective standards and it has further been assumed that metallic mass loss versus exposure time for the accelerated tests is linear
\(^{2)} Available data is limited so that it is not possible to give an allowed range of metallic mass loss in those cases

For the purpose of product qualification, results from standard metal specimen exposure under in-service conditions should be used to estimate the most likely lifetime corrosion load a product may be exposed to during its designed service lifetime. This estimated in-service corrosion load may thereafter be used to estimate the necessary exposure time for a product qualification test. How relevant this equivalent corrosion load approach is for the product to be tested and qualified depends on many factors as the corrosion properties of the materials of the product, the standard metal used for corrosion load estimations, the available in-service corrosion data, and the accelerated test selected for product qualification. But, the better the accelerated test is in simulating in-service corrosion behaviour the more reliable predictions can be made from the results of the test of course.

6 Requirement on test equipment and reproducibility of test results

The requirements on test equipment may vary considerably between different standardized accelerated corrosion tests as are shown in Annex A, where important characteristics of some standardized accelerated corrosion tests are given.

In the choice of test equipment, the requirements set by the test method considered the most suitable and that on reproducibility of test results should be first considered. Of importance in the selection of test equipment is, of course, also the availability of test equipment required for the various tests that can come into question and the cost of test.
NOTE When using simple test methods, it is important to check the test conditions very carefully for obtaining a reasonably high reproducibility. The corrosivity of the test should be checked by standard metal coupon exposure and adjusted so that it falls within the prescribed interval as described in most of the newer standards. However, it is also important to take into account that the correlation between test results and in-service corrosive performance is generally much poorer when a simple highly accelerated test is used than when a more advanced accelerated corrosion test is utilized for the same purpose.

7 Recommended procedures for product qualification

For qualification testing of products or functional units with respect to corrosion resistance the following general procedure is recommended.

1) Use the results of an initial risk analysis of potential failure modes of the product or functional unit to be qualified, as described in Annex B, to identify a critical failure mode and associated corrosion process that needs to be evaluated by way of accelerated corrosion testing.

2) Select appropriate accelerated corrosion test; see clauses 3,4,5,6 and Annex A.

3) Select suitable attribute of the functional unit for use as degradation indicator. From the performance requirement evaluate the lowest tolerable level of this degradation indicator to define failure of the functional unit; see clause B.2.

4) Specify in-service corrosivity and design lifetime corrosion load for the functional unit to be tested. The exposure of metal coupons and determination of the rate of corrosion of those is the preferred method for determining severity classes or classes of atmospheric corrosivity in specific in-service environments; see clause B.3 and clause 5.

5) Estimate acceptable failure time in the accelerated test from the design lifetime corrosion load for the functional unit. Adopt the principle of equivalent corrosion load as described in clause 5.

6) Perform the test and conclude whether the tested functional unit has a failure time higher than the acceptable. Analyse test specimens also with respect to expected degradation mechanism.

7) From the results obtained conclude whether the functional unit shall be considered qualified or not in respect of its corrosion resistance.
Annex A

Characteristics of standardized accelerated atmospheric corrosion tests

Warning: In this annex general characteristics of some standardized accelerated corrosion tests are presented for the purpose of comparing the tests. To conduct the tests, the full text of the standards is needed.

A.1 ISO 9227, Corrosion tests in artificial atmospheres – Salt spray tests

The oldest and most widely used method for laboratory accelerated corrosion testing is the continuous neutral salt spray test as described in e.g. ASTM B 117, ISO 9227 and IEC 60068-2-11.

A.1.1. Recommended fields of applications

The salt spray methods are all suitable for checking that the comparative quality of a metallic material with or without corrosion protection is maintained. They should not be used for comparative testing to rank different materials relative to each other with respect to corrosion resistance.

The salt spray tests are particularly useful for detecting discontinuities such as pores and other defects in certain metallic, organic, anodic oxide and conversion coatings.

The neutral salt spray test applies to metals and their alloys, metallic coatings (anodic and cathodic), conversion coatings, anodic oxide coatings, and organic coatings on metallic materials.

The acetic acid salt spray test is especially useful for testing decorative coatings of copper + nickel + chromium or nickel + chromium.

The copper-accelerated acetic acid salt spray test is useful for testing decorative coatings of copper + nickel + chromium or nickel + chromium; it has also been found suitable for testing anodic coatings on aluminium. However, it should be mentioned that no satisfactory basis for comparison can be derived from this test with regard to the respective quality of nickel + chromium coatings and copper + nickel + chromium coatings, because the reagent used contain copper ions which promote corrosion in the presence of nickel but is without influence on copper.

A.1.2 Test conditions

In the continuous salt spray test, the test objects are continuously exposed to a salt containing mist or fog under constant temperature conditions. Depending on the composition of the salt mist there are three different salt spray test methods; the neutral salt spray test (NSS), the acetic acid salt spray test (AASS), and the copper acetic acid salt spray test (CASS). In the NSS test, the salt solution is an aqueous sodium chloride solution of a concentration of 50 g/litre. In the AASS test, glacial acetic acid is added to the 50 g/litre sodium chloride salt solution so that the pH of the salt mist solution will become around 3.2. In the CASS test, copper(II) chloride dihydrate (CuCl₂·2H₂O) is added to the AASS solution to produce a solution with a CuCl₂ concentration of 0.26 g/litre. The characteristics of the three salt spray tests are summerized in Table A.1.1.
Table A.1.1 Operating condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Test method</th>
<th>NSS</th>
<th>AASS</th>
<th>CASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td>35 °C ± 2 °C</td>
<td>35 °C ± 2 °C</td>
<td>50 °C ± 2 °C</td>
</tr>
<tr>
<td>Average collection rate for a horizontal collecting area of 80 cm²</td>
<td></td>
<td></td>
<td>1,5 ml/h ± 0,5 ml/h</td>
<td></td>
</tr>
<tr>
<td>Concentration of sodium chloride (collected solution)</td>
<td></td>
<td></td>
<td>50 g/l ± 5 g/l</td>
<td></td>
</tr>
<tr>
<td>pH (collected solution)</td>
<td></td>
<td>6,5 – 7,2</td>
<td>3,1 – 3,3</td>
<td>3,1 – 3,3</td>
</tr>
</tbody>
</table>

A.1.3 Corrosivity of tests

In terms of mass loss of carbon steel and zinc after testing, the corrosivity of the different salt spray tests may be expressed as shown in Table A.1.2.

Table A.1.2 Corrosivity of the different tests with respect to corrosion of carbon steel and zinc

<table>
<thead>
<tr>
<th>Test method</th>
<th>Test duration (h)</th>
<th>Mass loss of the steel reference specimens (g/m²)</th>
<th>Mass loss of the zinc reference specimens (g/m²)</th>
<th>Mass loss based relative corrosion rate steel to zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSS</td>
<td>48</td>
<td>70 ± 20</td>
<td>50 ± 25</td>
<td></td>
</tr>
<tr>
<td>AASS</td>
<td>24</td>
<td>40 ± 10</td>
<td>30 ± 15</td>
<td></td>
</tr>
<tr>
<td>CASS</td>
<td>24</td>
<td>55 ± 15</td>
<td>50 ± 20</td>
<td></td>
</tr>
</tbody>
</table>

A.1.4 Requirement on test equipment

1) The cabinet shall have a capacity of not less than 0,4 m³ since, with smaller volumes, there will be difficulties in ensuring the even distribution of spray. The upper parts of the cabinet shall be designed so that drops of sprayed solution formed on its surface do not fall on the specimens being tested.

2) It is preferred that the apparatus has a means to properly treat the fog after test prior to releasing it from the building for environmental conservation and also drain water prior to discharging it to the drainage.

3) The compressed air supplied to the atomizers shall be passed through a filter to remove all traces of oil or solid matter and the atomizing pressure shall be at an overpressure of 70 kPa to 170 kPa.

4) The atomizers shall be made of inert material. The level of the salt solution in the salt reservoir shall be maintained automatically to ensure uniform spray delivery throughout the test.

5) At least two suitable collecting devices shall be available, consisting of funnels made of glass or other chemically inert material, with the stems inserted into graduated cylinders or other similar containers.

6) If the cabinet has been once used for AASS or CASS test or has been used for any other purpose with a solution differing from that specified for the NSS test it shall be not used for NSS test.

NOTE It is nearly impossible to clean a cabinet once used for AASS or CASS test so it can be used for NSS test. If it is necessary for an NSS test to use a cabinet used for AASS or CASS test the equipment shall be thoroughly...
cleaned, and then checked; particularly ensure the pH of the collected solution is correct throughout the entire spraying period.

A.1.5 Reproducibility and correlation with in-service exposures with respect to observed damage

There is seldom a direct relation between resistance to the action of continuous salt spray and resistance to corrosion in other media, because several factors influencing the progress of corrosion, such as the formation of protective films, vary greatly with the conditions encountered. Therefore, the test results should not be regarded as a direct guide to the corrosion resistance of the tested metallic materials. Nevertheless, the method described gives a means of checking that the comparative quality of a metallic material, with or without corrosion protection, is maintained.

Salt spray tests are generally suitable as corrosion protection tests for rapid analysis for discontinuities, pores and damages in organic and inorganic coatings. In addition, for quality control purposes, comparison can be made between specimens coated with the same coating. As comparative tests however, salt spray tests are only suitable if the coatings are sufficiently similar in nature.

It is often not possible to use results gained from salt spray testing as a comparative guide to the long-term behaviour of different coating systems as the corrosion stress during these tests differs significantly from the corrosion stresses encountered in practice.
A.2 ISO 10062, Corrosion tests in artificial atmosphere at very low concentrations of polluting gas(es)

Products with e.g. sensitive electrical functions, may during storage or operation in indoor locations be affected by atmospheric corrosion dependent on climatic factors as temperature, relative humidity, air velocity and rate of change by temperature and humidity. Additionally, gaseous pollutants may seriously affect the rate of corrosion as well as the occurrence of different corrosion mechanisms. Contaminants on the surface, such as salt, dust, oil and compounds liberated from plastics may also affect the rate and mechanism of corrosion.

Different corrosion promoting gaseous pollutants dominate in different field environments:
- sulphur dioxide and nitrogen oxides in atmospheres influenced by combustion of fossil fuels and in traffic environments,
- hydrogen sulphide in atmospheres in the vicinity of petrochemical and steel industry, decaying organic matter, stagnant waters and animals shelters, and
- hydrogen sulphide and chlorine compounds in the vicinity of pulp and paper industry; if chlorine is used for bleaching

Those gaseous pollutants are known to act as single corrosion promoting factors. But, in atmospheres where more than one gaseous pollutant is present synergistic effects may be initiated. As a result a considerable increase in the corrosion rate may occur compared to the case when the different gaseous pollutants act as single corrosion promoting factors.

A.2.1 Recommended fields of applications

This standard specifies tests which are intended to determine the influence of one or more of those flowing polluting gas(es) under determined conditions of temperature and relative humidity.

The tests apply to (a) metals and their alloys, (b) metallic coatings (anodic and cathodic), (c) metals with conversion coatings, (d) metals with anodic oxide coatings, and metals with organic coatings.

A.2.2 Test conditions

In the corrosion tests test objects are exposed to a flow of air containing corrosion promoting polluting gases under constant conditions of temperature and relative humidity. The standard specifies six alternative mixtures of polluting gases as shown in Table A.2.1 and two test options regarding choice of temperature and relative humidity as given in Table A.2.2.

Table A.2.1 Mixtures of polluting gases

<table>
<thead>
<tr>
<th>Test method</th>
<th>Sulphur dioxide (volume fraction)</th>
<th>Hydrogen sulphide (volume fraction)</th>
<th>Nitrogen dioxide (volume fraction)</th>
<th>Chlorine (volume fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$(0.5 \pm 0.1) \cdot 10^{-6}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
<td>$(0.10 \pm 0.02) \cdot 10^{-6}$</td>
<td>-</td>
<td>$(0.02 \pm 0.005) \cdot 10^{-6}$</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$(0.02 \pm 0.005) \cdot 10^{-6}$</td>
</tr>
<tr>
<td>D</td>
<td>$(0.5 \pm 0.1) \cdot 10^{-6}$</td>
<td>$(0.10 \pm 0.02) \cdot 10^{-6}$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>E</td>
<td>$(0.20 \pm 0.05) \cdot 10^{-6}$</td>
<td>-</td>
<td>$(0.5 \pm 0.1) \cdot 10^{-6}$</td>
<td>-</td>
</tr>
<tr>
<td>F</td>
<td>$(0.5 \pm 0.1) \cdot 10^{-6}$</td>
<td>$(0.10 \pm 0.02) \cdot 10^{-6}$</td>
<td>$(0.02 \pm 0.005) \cdot 10^{-6}$</td>
<td>-</td>
</tr>
</tbody>
</table>
Table A.2.2 Test options for temperature and relative humidity

<table>
<thead>
<tr>
<th>Test options</th>
<th>Temperature (°C)</th>
<th>Relative humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>II</td>
<td>40</td>
<td>80</td>
</tr>
</tbody>
</table>

A.2.3 Corrosivity of tests

Data on corrosivity can not be presently be found in the standard.

A.2.4 Requirement on test equipment

1) The apparatus shall enable the use, singly or in mixtures, of polluting gas(es) such as SO₂, H₂S, Cl₂ and NO₂ up to at least the concentration required, for each gas, by the test method.

2) The inner chamber and gas flow system shall consist of inert materials, e.g. PTFE (polytetrafluoro-ethylene) or glass, to avoid or minimise adsorption of hostile gases on surfaces other than of that of the test panels.

3) The chamber shall have a volume not less than 0.1 m³, and designed to avoid condensation at any point, and to allow easy and thorough cleaning of inner walls and fittings. The test chamber shall not be exposed to direct sunlight and the level of illumination (due to daylight or to incandescent or fluorescent lamps) measured inside the test chamber at any point on the exposed surface shall not exceed 300 lx.

4) The airflow and hostile gas injection system shall be designed to ensure uniform test conditions in the inner chamber or working space of cabinet. This flow rate shall be sufficient to ensure at least three exchanges per hour of the atmosphere in the test chamber. The air used may be taken from pressurised cylinders or delivered by a dry pump after filtration and purification by activated charcoal or molecular sieve (size 5a) and a particulate filter. The test atmosphere extracted from the chamber shall be collected in such a manner as to conform with legal safety standards.

5) Uniformity of temperature in the working space shall be better than ± 1 °C and uniformity of relative humidity better than ± 3 %.

6) The tolerance of the damp airflow shall be within ± 1 °C of the specified temperature and the tolerance on relative humidity ± 3%. The damp airflow shall be free of water droplets or aerosols. The gas(es) shall be free of contaminants that may also influence the corrosion process.

7) The temperature, relative humidity, and concentration of sulphur dioxide and nitrogen dioxide in the airflow at the outlet of working space shall be monitored so that they reflect the true test conditions for the test objects.

A.2.5 Bibliography

[1] Shigeru Suga, Results from corrosion tests in artificial atmospheres at very low concentration of polluting gases and proposal for amendment to ISO 10062 (to be published in The Journal of the Surface Finishing Society of Japan, 2004)
A.3  ISO ISO 11130, Corrosion of metals and alloys –Alternate immersion test in salt solution

A.3.1 Recommended fields of applications

The alternative immersion test, with or without applied mechanical stress, is particularly suitable for use as a quality control test during the manufacture of metals including aluminium alloys and ferrous materials, and for assessment purposes during alloy development.

Depending upon the chemical composition of the test solution, the test may be used to simulate the corrosive effects of marine splash zones, deicing fluids, acid salt environments, etc.

The alternate immersion test applies to metals and their alloys, certain metallic coatings (anodic and cathodic with respect to the substrate), certain conversion coatings, certain anodic oxide coatings, and organic coatings on metals.

A.3.2 Test conditions

The test consists of immersion of a test specimen (stressed, see ISO 7539-1, or unstressed) in a salt solution followed by withdrawal and a period of drying.

The immersion/drying cycle is repeated at a given frequency for a given period. The extent of attack is then evaluated. For many materials, this provides a more severe corrosion test than simple continuous immersion.

The test solutions that are specified in the standard are given in Table A.3.1

<table>
<thead>
<tr>
<th>Test solution</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral salt solution</td>
<td>Sodium chloride (NaCl): 3.5 g/litre</td>
</tr>
<tr>
<td>Deicing salt solution</td>
<td>Sodium sulphate (Na₂SO₄): 0.500 g/litre</td>
</tr>
<tr>
<td></td>
<td>Sodium sulphite (Na₂SO₃): 0.250 g/litre</td>
</tr>
<tr>
<td></td>
<td>Sodium thiosulphate (Na₂S₂O₃): 0.100 g/litre</td>
</tr>
<tr>
<td></td>
<td>Sodium chloride (NaCl): 52.5 g/litre</td>
</tr>
<tr>
<td></td>
<td>Calcium chloride dihydrate (CaCl₂. 2H₂O): 52.5 g/litre</td>
</tr>
<tr>
<td>Acidic salt solution</td>
<td>Sodium chloride (NaCl): 50 g/litre</td>
</tr>
<tr>
<td></td>
<td>pH = 3.5</td>
</tr>
<tr>
<td>Ocean water</td>
<td>see ISO 11130 for specification</td>
</tr>
</tbody>
</table>

Generally, the test conditions are prescribed in the agreed specifications. If this is not the case, the exposures should involve 10 minutes immersion followed by withdrawal and 50 minutes drying. The cycle should be repeated continuously throughout the duration of the test unless prior failure occurs. Test duration in the range 20 - 90 days is usually adequate for aluminium alloys and ferrous metals. The solution temperature should be 25°C ± 2°C unless otherwise specified.

For drying a mild circulation of air is recommended with the air temperature at 27°C and the relative humidity at 45%.

A.3.3 Corrosivity of tests

Data on corrosivity of tests can not be found in the standard.
A.3.4 Requirement on test equipment

1) The apparatus shall include a suitable system designed for the automatic, continuous performance of complete cycles of alternate immersion and withdrawal of the test specimens. This system should provide uninterrupted operation throughout the duration of the test. Each test specimen should be connected to the system by suitable insulating material. The apparatus shall also include one or more glass or plastic containers for the reagent. In the immersed position, only one kind of metal, alloy or coating should be immersed in each container.

2) Materials of construction that come into contact with the test solution shall be such that they are not affected by the corrosive to the extent that they can cause contamination of the solution and change its corrosivity.

3) Test specimen holders should be designed to insulate electrically the test specimens from each other and from any other bare metal. The shape and form of test specimen supports and holders should be such that they avoid, as much as possible, any interference of free contact of the test specimen with the salt solution and that they do not obstruct air flow over the test specimen thereby retarding the drying rate. They should also be such that they do not retain a pool of solution in contact with the test specimen after withdrawal from the solution and that drainage from one test specimen does not directly contact any other test specimen.

4) The system for air circulation should be designed so that moderate and uniform drying conditions are achieved meaning that drying by forced air blasts on the test specimens is not recommended and stagnant air conditions should be avoided.
A.4 ISO 11474, Corrosion of metals and alloys – Corrosion tests in artificial atmosphere – Accelerated outdoor test by intermittent spraying of a salt solution (Scab test)

The accelerated outdoor exposure test of ISO 11474 involves intermittent spraying of a salt solution to simulate and enhance the environmental stress prevailing at marine test sites. It is based on the so-called VOLVO SCAB method, which has long been used by the automotive industry.

A.4.1 Recommended fields of applications

The method is mainly intended for comparative testing and one or more reference materials are therefore always necessary. The results obtained do not permit any more far-reaching conclusions on the corrosion resistance of the tested metal in all environments where it may be used. The method described can nevertheless give valuable information on the relative performance of materials in service.

The accelerated outdoor corrosion test applies to organic coatings on metals, metallic coatings (anodic and cathodic), chemical conversion coatings, and metals and their alloys. The method is especially suitable for comparative testing in the optimisation of surface treatment systems.

A.4.2 Test conditions

In this method, the corrosion process during outdoor exposure is accelerated by intermittently spraying a solution of sodium chloride (mass fraction 3 %) twice a week, 3-4 days apart, onto the test surface. The test duration is normally six months.

A.4.3 Corrosivity of tests

Since the test result depends on the location of the exposure site and on the exposure conditions, it is necessary to characterize the corrosivity of the atmosphere at the exposure site. This can be accomplished by the direct measurement of the corrosion rate of standard test specimens or by measuring atmospheric data.

A.4.4 Requirement on test equipment

A.4.4.1 Spray bottle

The spraying device for the salt solution may simply be a bottle, capable of producing a finely distributed mist.

A.4.4.2 Exposure frames

Exposure frames for holding the test specimens in an appropriate position shall be designed in accordance with the requirements of ISO 8565. They shall normally hold the test specimens at an angle of 45° to the horizontal plane and face the equator. The frames shall be located so that the test specimens are neither protected nor shaded by nearby objects.

The frames shall be positioned so that the reverse sides of the test specimens are freely exposed to air and so that no water runs off from one test specimen to another. During exposure, the test specimens shall not be in direct contact with metallic parts and, if possible, not in contact with wood or other porous materials. If the test specimens are set in tracks, suitable drainage holes shall be made to prevent water collection.

The frames shall be positioned so that all test specimens are at least 0,75 m above ground level.

A.4.5 Recommended procedures for product qualification

The test is mainly suitable for comparative testing. Its use for qualification of rust protective coating systems is limited due to the fact that the quantitative results of the test vary very much with the climatic outdoor conditions during testing. Tests, for example that are started in Sweden in the autumn and finished in the springtime, are generally two to three times more aggressive than tests performed during the summer season due to longer periods of wetting during the winter season compared to the summer season.
A.5 ISO 14993, Corrosion of metals and alloys – Accelerated testing involving cyclic exposure to salt mist, "dry" and "wet" conditions

This test method involves cyclic exposure of test specimens to a mist of salt solution, to drying conditions, and to periods of high humidity. Its particular advantage over the neutral salt spray test (NSS) lies in its better ability to reproduce the corrosion that occurs in outdoor salt-contaminated environments.

A.5.1 Recommended fields of applications

The method is recommended for comparative testing and the results obtained do not permit far-reaching conclusions on the corrosion resistance of the tested metallic material under the whole range of environmental conditions within which it may be used. Nevertheless, the method provides valuable information on the relative performance of materials exposed to salt-contaminated environments similar to those employed in the test.

The test applies to: metals and their alloys, metallic coatings (anodic and cathodic), conversion coatings, anodic oxide coatings, and organic coatings on metallic materials.

A.5.2 Test conditions

The test conditions are summarized in Table A.5.1.

<table>
<thead>
<tr>
<th></th>
<th>Test Conditions</th>
</tr>
</thead>
</table>
| **1** | Salt mist conditions | Temperature = 35 °C  
|       |                   | Salt solution = 50 g NaCl / litre |
| **2** | "Dry" conditions  (The air is purged during dry conditions) | Temperature = 60 °C  
|       |                   | Relative humidity < 30 %RH |
| **3** | "Wet" conditions  (Condensation on the test specimens shall not occur during wet conditions) | Temperature = 50 °C  
|       |                   | Relative Humidity > 95 %RH |
| **4** | Period and content of a single exposure cycle | Total period 8 hours, as follows:  
|       |                   | Salt mist spray 2 hours  
|       |                   | "Dry" conditions 4 hours  
|       |                   | "Wet" conditions 2 hours  
|       |                   | (These times include the time for reaching the specified temperature for each condition) |
| **5** | Time to reach the specified condition (i.e. period taken for temperature and humidity to reach the specified values once the test condition has begun) | Mist to "Dry" < 30 minutes  
|       |                   | "Dry" to "Wet" < 15 minutes  
|       |                   | "Wet" to Mist < 30 minutes  
|       |                   | (Mist conditions are attained almost instantaneously once this condition begins) |
| **6** | Angle at which test specimens are supported | 20° to the vertical |

A.5.3 Corrosivity of tests

In terms of mass loss of carbon steel and zinc after testing, the corrosivity of the different salt spray tests may be expressed as shown in Table A.5.2.
Table A.5.2 Corrosivity of the test in terms of mass losses for standard specimens

<table>
<thead>
<tr>
<th>Test duration (h)</th>
<th>Mass loss of the steel reference specimens (g/m²)</th>
<th>Mass loss of the zinc reference specimens (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>200 ± 40</td>
<td>40 ± 10</td>
</tr>
</tbody>
</table>

A.5.4 Requirement on test equipment

1) All components in contact with the spray or the test solution shall be made of, or lined with, materials which are resistant to corrosion by the test solution and which do not influence the corrosivity of the sprayed test solution.

2) The exposure cabinet shall have a capacity of not less than 0.4 m³. The upper parts of the cabinet shall be designed so that drops of sprayed solution formed on its surface do not fall on the specimens being tested.

3) The compressed air supplied to the atomizers shall be passed through a filter to remove all traces of oil or solid matter and shall be at an overpressure of 70 kPa to 170 kPa.

4) In order to prevent evaporation of water from the sprayed droplets, the air shall be humidified before entering the atomizer, by passage through a saturation tower containing hot water at a temperature several degrees Celsius higher than that of the cabinet. The level of water must be maintained automatically to ensure adequate humidification.

5) The atomizers shall be made of inert material, for example glass or plastics materials.

6) The level of the salt solution in the supply tank shall be maintained automatically to ensure constant spray delivery throughout the test.

7) At least two suitable collecting devices shall be available, consisting of clean funnels with a collecting area of approximately 80 cm² made of glass or other chemically inert material.

8) A heating device and fan shall supply dried air of the specified humidity during "dry" periods.

9) The system by which air is exhausted from the spray cabinet shall not be influenced by the back pressure of the atmosphere when the air is released at a point outside the building.

A.5.5 Bibliography


A.6  ISO 16151, Corrosion of metals and alloys – Accelerated cyclic tests with exposure to acidified salt spray, 'dry' and 'wet' conditions

This standard specifies two test methods A and B, which involve cyclic exposure of test specimens to a mist of acidified salt solution, to drying conditions, and to periods of high humidity.

A.6.1  Recommended fields of applications

The particular advantages of the two tests over the neutral salt spray test (NSS) as specified in ISO 9227 lie in their better ability to reproduce the corrosion that occurs in outdoor salt-acid rain environments. They are also useful for evaluating cosmetic corrosion.

Method A applies to metals and their alloys, metallic coatings (cathodic), anodic oxide coatings, and organic coatings on metallic materials. Method B applies to steel coated with anodic coatings, steel coated with anodic coatings covered with conversion coatings.

The methods are mainly intended for comparative testing and the results obtained do not permit far-reaching conclusions on the corrosion resistance of the tested metallic material under the whole range of environmental conditions in which they may be used. Nevertheless, the methods provide valuable information on the relative performance of materials exposed to salt-acid rain environments similar to those employed in the test.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Method A</th>
<th>Method B</th>
</tr>
</thead>
</table>
| 1 Acidified salt mist conditions | Temperature = 35 °C  
Salt solution: 50 g NaCl/litre  
$\text{pH} = 3.5$ | Temperature = 35 °C  
Ocean salt solution: 6 g /litre  
$\text{pH} = 2.5$ |
| 2 "Dry" conditions | Temperature = 60 °C  
Relative humidity < 30 %RH | Temperature = 60 °C  
Relative humidity < 30 %RH |
| 3 "Wet" conditions | Temperature = 50 °C  
Relative Humidity > 95 %RH | Temperature = 40 °C  
Relative Humidity = 85 %RH |
| 4 Period and content of a single exposure cycle | Total period 8 hours:  
Acidified salt mist: 2 h  
"Dry" conditions:  4 h  
"Wet" conditions: 2 h  
(These times include the time for reaching the specified temperature for each condition) | Total period 8 hours:  
Acidified salt mist: 1 h  
"Dry" conditions:  4 h  
"Wet" conditions: 3 h  
(These times include the time for reaching the specified temperature for each condition) |
| 5 Time to reach the specified condition (i.e. period taken for temperature and humidity to reach the specified values once the test condition has begun) | Mist to "Dry":  < 30 min  
"Dry" to "Wet": < 15 min  
"Wet" to Mist: < 30 min  
(Mist conditions shall be attained almost instantaneously once this condition begins) | "Mist" to "Dry" < 30 min  
"Dry" to "Wet" < 15 min  
"Wet" to "Mist" < 30 min  
(Mist conditions shall be attained almost instantaneously once this condition begins) |
| 6 Angle at which test specimens are supported | 20 °to the vertical | 20° to the vertical |
A.6.2 Test conditions

The test conditions are summarized in Table A.6.1.

A.6.3 Corrosivity of tests

In terms of mass loss of carbon steel and zinc after testing, the corrosivity of the different salt spray tests may be expressed as shown in Table A.6.2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Test duration (h)</th>
<th>Mass loss of the steel reference specimens (g/m²)</th>
<th>Mass loss of the zinc reference specimens (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>48</td>
<td>110 ± 35</td>
<td>32 ± 9</td>
</tr>
<tr>
<td>B</td>
<td>96</td>
<td>180 ± 54</td>
<td>9 ± 5</td>
</tr>
</tbody>
</table>

A.6.4 Requirement on test equipment

1) All components in contact with the spray or the test solution shall be made of, or lined with, materials which are resistant to corrosion by the test solution and which do not influence the corrosivity of the sprayed test solution.

2) The exposure cabinet shall have a capacity of not less than 0.4 m³. The upper parts of the cabinet shall be designed so that drops of sprayed solution formed on its surface do not fall on the specimens being tested.

3) The compressed air supplied to the atomizers shall be passed through a filter to remove all traces of oil or solid matter and shall be at an overpressure of 70 kPa to 170 kPa.

4) In order to prevent evaporation of water from the sprayed droplets, the air shall be humidified before entering the atomizer, by passage through a saturation tower containing hot water at a temperature several degrees Celsius higher than that of the cabinet. The level of water must be maintained automatically to ensure adequate humidification.

5) The atomizers shall be made of inert material, for example glass or plastics materials.

6) The level of the salt solution in the supply tank shall be maintained automatically to ensure constant spray delivery throughout the test.

7) At least two suitable collecting devices shall be available, consisting of clean funnels with a collecting area of approximately 80 cm² made of glass or other chemically inert material.

8) A heating device and fan shall supply dried air of the specified humidity during "dry" periods.

9) The system by which air is exhausted from the spray cabinet shall not be influenced by the back pressure of the atmosphere when the air is released at a point outside the building.

A.6.5 Bibliography


A.7 ISO 16701, Corrosion of metals and alloys – Corrosion in artificial atmosphere – Accelerated corrosion test involving exposure under controlled conditions of humidity cycling and intermittent spraying of a salt solution

This cyclic corrosion test includes two phases. One wet phase, during which the test object is repeatedly subjected first to a spray of aqueous salt-containing solution then to a wet stand-by period during which residual wetness remains on the test object. A second phase of controlled cyclic humidity conditions, where the test object is subjected to an environment which alternates between high humidity and comparative dryness.

A.7.1 Recommended fields of applications

The accelerated laboratory corrosion test applies to metals and their alloys, metallic coatings (anodic and cathodic), chemical conversion coatings, and organic coatings on metals. The method is especially suitable for comparative testing in the optimization of surface treatment systems.

The test method has been developed for simulation of corrosion on open surfaces (cosmetic corrosion) and consequently the dry periods are relatively short. As the drying up time in crevices is usually much longer, prolonged drying periods are needed to simulate corrosion phenomena in specimens with crevices in a realistic way. The method is thus preferably recommended for evaluation of corrosion and corrosion protection on open surfaces.

A.7.2 Test conditions

The following scheme of 12 h cycles is adopted. In the 1st cycle, the 8th cycle, the 15th cycle, and subsequently every seventh cycle, a cycle A with salt spraying is used. In the other cycles, a cycle B involving humidity changes between a low and a high value, is used.

Cycle B is composed of the following steps:

Step 1) Exposure at 35 °C and 95 % RH for 4 h.

Step 2) Exposure at 35 °C to a linear reduction of relative humidity with time from 95 % RH to 50 % RH over a total period of 2 h.

Step 3) Exposure at 35 °C and at 50 % RH for 4 h.

Step 4) Exposure at 35 °C to a linear increase of relative humidity with time from 50 % RH to 95 % RH over a total period of 2 h.

Cycle A consists of the following steps:

Step 5) Spraying of the test objects inside the climate chamber at 35 °C with a sodium chloride solution (concentration 10 g/litre and pH = 4.2) at a linear downward flow rate of 15 mm h⁻¹ for 15 min.

Step 6) Exposure at 35 °C for 1 h 45 min with the relative humidity set point at 95 % - 99 % RH in such a way that the test objects remain wet.

Steps 5 and 6 are then repeated in sequence two more times to give a total period of wetness of 6 h.

A.7.3 Corrosivity of tests

In terms of mass loss of carbon steel and zinc after testing, the corrosivity of the different salt spray tests may be expressed as shown in Table A.7.1.
Table A.7.1 Corrosivity of test with respect to carbon steel and zinc corrosion

<table>
<thead>
<tr>
<th>Material tested</th>
<th>Metal losses in thickness obtained after test (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold rolled carbon steel</td>
<td>115 -130 (4 weeks of exposure)</td>
</tr>
<tr>
<td></td>
<td>180 - 220 (6 weeks of exposure)</td>
</tr>
<tr>
<td></td>
<td>315 - 385 (12 weeks of exposure)</td>
</tr>
<tr>
<td>Pure zinc</td>
<td>5 - 7 (4 weeks of exposure)</td>
</tr>
<tr>
<td></td>
<td>7 - 10 (6 weeks of exposure)</td>
</tr>
<tr>
<td></td>
<td>15 - 20 (12 weeks of exposure)</td>
</tr>
</tbody>
</table>

A.7.4 Requirement on test equipment

1) The climate chamber shall be designed so that the following test conditions can be obtained, controlled and monitored during the test.

An instantaneous maximum deviation from set relative humidity value of ± 4 % in the range from 50 % to 95 % at 35 °C, which corresponds to a temperature accuracy requirement of ± 0,8 °C at that temperature. For the mean value in relative humidity during a period of constant climate conditions 7 h - 8 h an accuracy of ± 2 % shall apply, corresponding to temperature accuracy requirement of in this case ± 0,4 °C.

The climate chamber shall also be designed so that the relative humidity may be changed linearly with respect to time from 95 % to 50 % within 2 h and back from 50 % to 95 % also within 2 h. In Figure X a suitable design of climate chamber is shown.

2) The spraying device for salt solution installed in the climate chamber shall be capable of producing a finely distributed uniform vertical downward flow of mist or small droplets falling on the test objects at a linear flow rate of 15 mm h⁻¹ ± 5 mm h⁻¹.

3) The climate chamber shall be equipped with a system for forced air flow drying, as after spraying/wet stand-by all test objects should be dried from excessive macro wetness and climate control shall be made possible to regain within a reasonable time. For a climate chamber of the volume 1 m³ - 2 m³ an air flow rate of 50 Litre/ s to 100 Litre/s is recommended.

A.7.6 Recommended procedures for product qualification

A.7.6.1 Surface treated exterior automotive parts

In general a six-week test should be sufficient to rank any bare metal (alloy) or a metal protected with a thin conversion coating or a metallic, inorganic or organic coating. A twelve-week test is recommended for the ranking of high quality coating systems.

A.7.7 Bibliography


A.8  ISO 21207, Corrosion tests in artificial atmospheres – Accelerated corrosion tests involving alternate exposure to corrosion promoting gases, neutral salt spray and drying

The standard describes two cyclic corrosion test methods involving a short period of neutral salt spray testing, followed by drying and a longer time period of exposure to an air flow containing corrosion promoting gaseous pollutants and high humidity.

A.8.1 Recommended fields of applications

The two test methods defined are intended for use in assessing the corrosion resistance of products with metals in environments where there is a significant influence of chloride ions, mainly as sodium chloride from a marine source or by winter road de-icing salt, and of corrosion promoting gases from industrial or traffic air pollution.

The methods are especially suitable for assessing the corrosion resistance of sensitive products with metals, e.g. electronic components, used in traffic and industrial environments.

A.8.2 Test conditions

The accelerated corrosion test methods described in this standard, methods A and B, are designed to simulate and enhance the environmental influence of exposure to an outdoor climate where salt-contaminated conditions and corrosion promoting gases from an industrial or a traffic environment occur which may promote corrosion. Test method A simulates a moderately aggressive traffic environment while test method B simulates a more severe industrial or traffic environment.

Test method A involves exposure of the test objects to the following test cycle:

a) neutral salt spray testing (ISO 9227) for 2 h in a mist of a salt solution containing a mass fraction of 5 % of sodium chloride at 35 °C, followed by drying for 22 h in a standard laboratory climate, and

b) exposure for 120 h in a test atmosphere containing a mixture of corrosion promoting gases, volume fraction of NO₂ equal to $1.5 \times 10^{-6}$ and of SO₂ equal to $0.5 \times 10^{-6}$, at a relative humidity of 95 % and at a temperature of 25 °C, followed by drying for 24 h in a standard laboratory climate.

Test method B involves exposure of the test object to the following test cycle:

a) neutral salt spray testing (ISO 9227) for 2 h in a mist of a sodium chloride salt solution of a mass fraction of 5 % at 35 °C, followed by drying for 22 h in a standard laboratory climate,

b) exposure for 48 h in a test atmosphere containing a mixture of corrosion promoting gases, volume fraction of NO₂ equal to $10^{-6}$ and of SO₂ equal to $5 \times 10^{-6}$, at a relative humidity of 95% and at a temperature of 25 °C,

c) neutral salt spray testing (ISO 9227) for 2 h in a mist of a sodium chloride salt solution of a mass fraction of 5 % at 35 °C, followed by drying for 22 h in standard laboratory climate, and

d) exposure for 72 h in a test atmosphere containing a mixture of corrosion promoting gases, volume fraction of NO₂ equal to $10^{-6}$ and of SO₂ equal to $5 \times 10^{-6}$, at a relative humidity of 95% and at a temperature of 25 °C.

A.8.3 Corrosivity of tests

For measurement of the corrosivity of the tests according to this standard, four reference panels of metallic copper shall be used as specified for Cu- DHP in ISO 1337 (minimum 99.85 % mass fraction of Cu). The reference specimens should have a dimension of 50 mm x 50 mm x 1 mm. The mass of a reference panel shall be within the following intervals:
Table A.8.1 Corrosivity with respect to copper corrosion of the two test methods

<table>
<thead>
<tr>
<th>Test method</th>
<th>Test duration</th>
<th>Mass loss of reference panel of copper (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2 weeks</td>
<td>7,5 ± 0,6</td>
</tr>
<tr>
<td></td>
<td>4 weeks</td>
<td>14,5 ± 1,5</td>
</tr>
<tr>
<td></td>
<td>6 weeks</td>
<td>20,0 ± 4,0</td>
</tr>
<tr>
<td>B</td>
<td>1 week</td>
<td>10,0 ± 1,0</td>
</tr>
<tr>
<td></td>
<td>2 weeks</td>
<td>25,0 ± 2,5</td>
</tr>
<tr>
<td></td>
<td>3 weeks</td>
<td>40,0 ± 4,0</td>
</tr>
<tr>
<td></td>
<td>5 weeks</td>
<td>70,0 ± 7,0</td>
</tr>
</tbody>
</table>

A.8.4 Requirement on test equipment

A.8.4.1 Exposure of test objects to mixtures of NO₂ and SO₂ at a relative humidity of 95 % and a temperature of 25 °C

The climatic cabinet with inner chamber and gas flow system shall comply with the requirements of ISO 10062.

The equipment used for testing shall be constructed so that:

1) The inner chamber and gas flow system consist of inert materials, e.g. PTFE (polytetrafluoroethylene) or glass, to avoid or minimise adsorption of hostile gases on surfaces other than of that of the test panels.

2) The airflow and hostile gas injection system are designed to ensure uniform test conditions in the inner chamber or working space of cabinet.

3) Uniformity of temperature in the working space shall be better than ± 1 °C and uniformity of relative humidity better than ± 3 %. In terms of corrosivity, expressed as the corrosion rate of copper metal, the uniformity shall be not less than 5 %.

4) The tolerance of the damp air flow shall be within ± 1 °C of the specified temperature and the tolerance on relative humidity ± 3 %. The linear flow rate of air shall be in the range of 0,5 mm/s to 5 mm/s. The damp airflow shall be free of water droplets or aerosols.

5) For exposure of test panels in the working space, specimens holder shall be used so that the test panels do not shield one another or disturb the uniformity of airflow across the chamber.

6) The temperature, relative humidity, and concentration of sulphur dioxide and nitrogen dioxide in the airflow at the outlet of working space shall be monitored so that they reflect the true test conditions for the test objects.

A.8.4.2 Salt spray testing according to ISO 9227

The apparatus and reagents to be used shall comply with the requirements of ISO 9227.
A.8.4.3  Drying in standard laboratory climate

For the test a room with an appropriate system for control of its temperature at 23 °C ± 2 °C and its relative air humidity at 50 % ± 5 % shall be used.

A.8.5  Recommended procedures for product qualification

Table A.8.2 shows recommended periods of test duration for simulating the corrosive load after certain years of exposure in a moderately aggressive traffic environment (Test method A) and in a more severe traffic environment or industrial environment with salt contamination (Test method B).

The recommended periods of test duration for test method A originate from a field study on copper corrosion in engine compartments of motor vehicles. The motor vehicles were used in road environments where de-icing salts contribute significantly to the atmospheric corrosivity, see references [1-3] in clause 3.9.7. The recommended periods of test duration for test method B are based on results from atmospheric corrosion tests of copper at 39 different industrial sites in Europe and North America.

If the atmospheric corrosivity of the test under service conditions is measured and expressed in terms of the corrosion rate of a metal other than copper the relation between years in specified environment and corresponding test duration may be somewhat different from what is shown in Table A.8.2. In Table A.8.3 corresponding metal mass loss of other metals than copper in test A and test B is shown.

<table>
<thead>
<tr>
<th>Test method</th>
<th>Type of environment</th>
<th>Years in specified environment</th>
<th>Assumed metal mass loss of copper defining corrosivity of specified environment (g/m²)</th>
<th>Corresponding test duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Moderately aggressive traffic (salt contaminated)</td>
<td>4 - 8</td>
<td>14,5</td>
<td>4 weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 - 14</td>
<td>20</td>
<td>6 weeks</td>
</tr>
<tr>
<td>B</td>
<td>Industrial (salt contaminated)</td>
<td>2 - 3</td>
<td>10</td>
<td>1 week</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 - 13</td>
<td>25</td>
<td>2 weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 - 25</td>
<td>40</td>
<td>3 weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 - 50</td>
<td>70</td>
<td>5 weeks</td>
</tr>
</tbody>
</table>

Table A.8.3  Corresponding metal mass loss of other metals than copper in test methods A and B

<table>
<thead>
<tr>
<th>Test method</th>
<th>Test duration</th>
<th>Metal mass loss of copper (g/m²)</th>
<th>Metal mass loss of zinc (g/m²)</th>
<th>Metal mass loss of aluminium (g/m²)</th>
<th>Metal mass loss of carbon steel (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4 weeks</td>
<td>14,5</td>
<td>40</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>3 weeks</td>
<td>40</td>
<td>90</td>
<td>7-10</td>
<td>580</td>
</tr>
</tbody>
</table>

Assuming 14 years of exposure, the data for test method B in Table A.8.3 can be used to estimate the corrosivity category for the service environment assumed for method B in Table A.8.2 with respect to all the different metals in Table A.8.3. From the average corrosion rates given for those metals in ISO 9224, corrosion rates for copper, zinc and carbon steel can be estimated that all fall within the lowest one third of the interval between corrosivity category 3 and corrosivity category 4. In case of aluminium the corrosivity category amounts to around 4.
A.8.6 Bibliography


Annex B

Initial risk analysis of potential failure modes for products or functional units

B.1 Principle

Initial risk analysis is an important step in the planning of a product qualification testing scheme. It entails collecting information on performance and durability of the product or functional unit of the product and its materials. This knowledge base is analysed with respect to the intended application to identify critical functional properties, environmental conditions and associated risks for failure. If it is not possible at this stage to conclude whether the product or functional unit of the product should be qualified or disqualified, qualification testing is performed.

From a practical point of view, but also from an economic viewpoint, an assessment of durability or service life by way of testing has to be limited in its scope and focused on the most critical failure and damage modes.

NOTE 1 If it is not possible to make a reasonable judgement on qualification because reliable tests can not be found, in-service tests should be started. For products with new materials the general recommendation is to start long-term in-service exposure testing on samples of the material as soon as possible in the development process. In-service testing may require a long time, but the result of it constitutes the definite answer to whether the previous prediction of expected service life was reasonable.

NOTE 2 For functional units, which require high service reliability with respect to functional performance the statistical variation in service life may be very important. In such cases reliability testing, including the testing of large number of test objects is recommended.

B.2 Functional and service life requirements on product and functional units

Identify as the first step in the analysis the most important functional attributes of the product or functional unit to be qualified by taking into consideration general end-user or specific product requirements related to functional capability or performance. Formulate in terms of those functional properties thereafter performance requirements for the product or functional unit to be qualified. Defining performance requirement shall be accompanied by an assessment of the economic effects of a functional failure. Based on this, a service life requirement shall be defined or a reliability level that must be maintained for a given number of years be set.

NOTE 3 It may be important to understand the consequences of different failures to define general requirements for performance as failure is defined to occur below that performance level at which satisfactory functioning can not be guaranteed. Thus, if the performance requirements are not fulfilled, the particular product or functional unit are regarded as having failed.

NOTE 4 Performance requirements can be formulated on the basis of optical properties, mechanical strength, aesthetic values or other criteria related to the performance of the product or functional unit and its materials. For failure modes characterised by a gradual deterioration in performance, the consequences of failure may not be very significant shortly after the service life requirement is no longer met. For catastrophic types of failure modes, however, the intended functional capability of the functional unit or some part of it may be completely lost.

B.3 Potential failure modes and associated material degradation mechanisms

After failures have been defined in terms of the minimum performance levels set, potential failure and damage modes and important degradation processes associated with those shall be identified.

NOTE 5 In general, there exist many kinds of failure modes for a particular functional unit and the different damage mechanisms, which may lead to the same kind of failure, may sometimes be quite numerous.

Fault tree analysis is a tool, which provides a structure relating failure to various damage modes and underlying chemical or physical changes.
For the purpose of product qualification by testing, select also suitable degradation indicators for the different potential failure modes so that failure and the degradation process causing this failure may be assessed properly.

B.4 Critical factors of environmental stress and degradation factors

Assess critical factors of environmental stress or degradation factors associated with the potential failure modes, damage modes and critical degradation processes previously identified. Assess also their expected severity under in-service conditions. Specify thereafter the in-service severity the product or functional unit must resist during its expected service life.

NOTE 6 For the purpose of product qualification, in-service severity representing a worst case may be selected. Alternatively, in-service severity based on the most representative case of in-service environment may be used for product qualification.

NOTE 7 For specifying environmental stress severity with respect to atmospheric corrosivity the classification system described in ISO 9223-ISO 9226 is recommended. Alternatively, the classification system in ISA S71.04 may be used. For assessing atmospheric corrosivity by measurements, the exposure of metal coupons and determination of the rate of corrosion of those, as is described in ISO 9226, is the preferred method.

NOTE 8 In the initial risk analysis, the most important issue is to identify in a qualitative way the most critical in-service conditions and environmental stress factors which may contribute to material degradation and cause failure to occur. It is first at the qualification testing stage specification of the in-service severity has to be made in strictly quantitative terms.

B.5 Risk analysis

Estimate from the information gathered in the analysis described in clauses B2-B4, the risk for failure or unsatisfactory functional performance associated with each of the potential failure and damage modes identified. The estimated risk shall be the point of departure to judge whether a particular failure or damage mode needs to be further evaluated or not. It should also be used as starting point when identifying what kind of testing is needed for qualification of the product or functional unit considered.

NOTE 9 The risk or risk number associated with each potential failure/damage mode identified can be estimated by use of the methodology of FMEA (Failure Modes and Effect Analysis) and FMECA (Failure Modes Effects and Critically Analysis, see e.g references [4,5] in Annex C.

NOTE 10 Literature research should be performed prior to risk assessment to gather relevant data on durability and service life data on similar functional units and materials in the same kind of application as the present. For the same reason durability and service life data on the specific functional unit and materials in other applications and in-service environments as the present should also be gathered.
Annex C

Bibliography

[1] NT elec 025 - Electrical equipment: Combined damp heat, Steady state, Cold water spraying test


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