
**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**

*Corrosion des métaux et alliages — Corrosion en atmosphère
artificielle — Essai de corrosion accélérée comprenant des
expositions sous conditions contrôlées à des cycles d'humidité et à des
vaporisations intermittentes de solution saline*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

The committee responsible for this document is ISO/TC 156, *Corrosion of metals and alloys*.

This second edition cancels and replaces the first edition (ISO 16701:2003), of which it constitutes a minor revision.

Introduction

Atmospheric corrosion of metallic materials, with or without corrosion protection, is influenced by many environmental factors, the importance of which might vary with the type of metallic material and with the type of environment. It is therefore not possible to design a laboratory corrosion test in such a way that the full complexity of real in-service conditions are taken into account. Acceleration (forced conditions) as such can also have a negative impact on the correlation to field performance. Nevertheless, tests with humidity cycling and only intermittent exposure to salt solution will generally provide a better correlation to field performance than tests using continuous salt spray.

This International Standard was developed in the automotive context, where the major contributor to corrosion is the use of winter time de-icing road salt in cool/cold temperate areas around the world, here as sodium chloride compounds acting in cyclic humidity conditions. The test procedure is moderately forced by humidity and salt and intended to be applicable for quality assurance of the metals and corrosion protections typically encountered in motor vehicles. The method can have relevance also in other areas of application, provided representing similar climatic conditions with an influence of sodium chloride compounds.

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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

1 Scope

This International Standard specifies the test method, the reagents, and the procedure to be used in an accelerated atmospheric corrosion test constituting a 6 h exposure to a slightly acidified solution of 1 % NaCl twice weekly, followed by a condition of controlled humidity cycling between 95 % RH and 50 % RH at a constant temperature of 35 °C.

This International Standard does not specify the dimensions of the tests specimens, the exposure period to be used for a particular product, or the interpretation of the results. Such details are provided in the appropriate product specifications.

The accelerated laboratory corrosion test applies to

- metals and their alloys,
- metallic coatings (anodic or cathodic),
- chemical conversion coatings, and
- organic coatings on metallic materials.

NOTE 1 If testing low-alloy stainless steels, especially austenitic grades, according to this International Standard, there is a risk of receiving exaggerated pitting, not representative for most service environments.

NOTE 2 This International Standard is not suitable for testing of wax and oil based rust protection agents, due to the constantly elevated temperature condition of the test.

2 Normative references

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

ISO 4628-1, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 1: General introduction and designation system*

ISO 4628-2, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 2: Assessment of degree of blistering*

ISO 4628-4, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 4: Assessment of degree of cracking*

ISO 4628-5, *Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 5: Assessment of degree of flaking*

ISO 8407, *Corrosion of metals and alloys — Removal of corrosion products from corrosion test specimens*

ISO 10289, *Methods for corrosion testing of metallic and other inorganic coatings on metallic substrates — Rating of test specimens and manufactured articles subjected to corrosion tests*

3 Reagent

A salt solution, prepared by dissolving a sufficient mass of sodium chloride in distilled or deionized water to a concentration of $10 \text{ g l}^{-1} \pm 1 \text{ g l}^{-1}$. The distilled or deionized water used shall have a conductivity not higher than 2 mS m^{-1} at $25 \text{ °C} \pm 2 \text{ °C}$.

The maximum permissible amounts of impurities in the sodium chloride are given in [Table 1](#).

Table 1 — Maximum permissible amounts of impurities in the sodium chloride as calculated for dry salt

Impurity	Maximum mass fraction of impurity %	Note
Copper (calculated for dry salt)	0,001	Determined by atomic absorption spectro-photometry or other method with similar accuracy
Nickel (calculated for dry salt)	0,001	
Sodium iodide	0,1	
Total	0,5	

Check the pH of the salt solution by using potentiometric measurement at $25 \text{ °C} \pm 2 \text{ °C}$. Finely adjust the pH of the salt solution to a value of $4,2 \pm 0,1$ by standard addition of a diluted sulphuric acid solution (e.g. 1 ml of $0,05 \text{ mol/L H}_2\text{SO}_4$ is added to 1 l of salt solution).

4 Apparatus

4.1 Climate chamber

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 $\pm 4 \%$ in the range from 50% to 95% at 35 °C , which corresponds to a temperature accuracy requirement of $\pm 0,8 \text{ °C}$ at that temperature. For the mean value in relative humidity during a period of constant climatic conditions 7 h to 8 h an accuracy of $\pm 2 \%$ shall apply, corresponding to temperature accuracy requirement of in this case $\pm 0,4 \text{ °C}$.

To meet the temperature and humidity accuracy requirements, the climate chamber should be equipped with means for efficient circulation of air to provide for small temperature and humidity variations in the chamber. Sufficient insulation of the chamber walls and lids are required in order to avoid excessive condensation on these surfaces.

The climate chamber shall also be designed so that the relative humidity can be changed linearly with respect to time from 95% to 50% within 2 h and back from 50% to 95% also within 2 h. [Figure B.1](#) shows a suitable design of climate chamber.

The humidity and temperature levels of the climate chamber during a test cycle shall be continuously monitored or regularly checked so that it can be confirmed that the relative humidity versus time for a complete test cycle is within the specified ranges at 95% RH and 50% RH. For measurement of the relative humidity use a hygrometer designed for measurements at high humidity levels, e.g. a high-quality combined temperature and capacitance humidity sensor or a gold mirror dewpoint meter. For measurement of temperature preferably use Pt 100 sensors.

4.2 Spraying device

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 $15 \text{ mm h}^{-1} \pm 5 \text{ mm h}^{-1}$.

If a graduated glass cylinder with a collecting area of 80 cm^2 is used to check whether this flow rate is within the specified range, the collection rate of salt solution shall be $120 \text{ ml h}^{-1} \pm 40 \text{ ml h}^{-1}$.

The device for salt spraying is preferably made of a number of nozzles mounted in series on a rail or tube. A spray pattern in the form of a fan, partly overlapping, is then obtained. The spraying device shall be made of, or lined with, materials resistant to corrosion by the salt solution and which do not influence the corrosivity of the sprayed salt solution. The use of molybdenum-alloyed stainless steel or plastic is recommended. [Figure B.2](#) shows a suitable design of spraying device.

Salt solution that has already been sprayed shall not be re-used.

4.3 System for forced drying

The climate chamber shall be equipped with a system for forced airflow 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.

Forced drying is preferably arranged by supercooling and reheating an internal circulating flow. Alternatively, drying can be arranged by letting a forced flow of pre-heated ambient air ventilate the chamber. For a climate chamber of the volume 1 m^3 to 2 m^3 an airflow rate of 50 ls^{-1} to 100 ls^{-1} is recommended. The forced airflow shall not be pre-heated to such temperature levels that the maximum chamber temperature of $35 \text{ }^\circ\text{C}$ is exceeded.

NOTE Pre-heating of the forced airflow to a temperature of $40 \text{ }^\circ\text{C}$ has been found suitable from practical experience.

5 Test objects

5.1 The number and type of test objects, their shape and their dimensions shall be selected according to the specification for the material or product being tested. When not specified accordingly, these details shall be mutually agreed between the interested parties.

5.2 For each series of test objects, data records shall be kept and include the following information.

- a) Specification of material to be tested, e.g. for surface-treated materials: type of base material, its pretreatment, type of coating, method of application, and dry film thickness.
- b) If the test specimen is subjected to intentional damage in the coating, the shape and the location of the damage should be described, as well as how the damage was achieved. The orientation of the damage during testing should also be specified.

If the test objects are cut from a larger coated article, cutting shall be carried out in such a way that the coating is not damaged in the area adjacent to the cut. Unless otherwise specified, the cut edges shall be adequately protected by coating them with a suitable material, stable under the conditions of the test, such as paint, wax or adhesive tape.

- c) Information on cleaning procedure to be used prior to testing.
- d) Information on reference material or materials with which the test specimen is to be compared.
- e) How the test object is to be examined and which properties are to be assessed, see [Clause 7](#).

6 Procedure

6.1 Arrangement of the test objects

The test objects shall be placed in the chamber on stands with their test surface facing upwards. The angle at which the surface of the test specimens is exposed in the chamber is important. For flat test objects the angle at which the test surface is inclined shall preferably be $20^\circ \pm 5^\circ$ to the vertical. In the case of irregular surfaces, e.g. entire components, this angle shall be adhered to as closely as possible.

The stands with the test objects shall be placed on the same level of the climate chamber. The stands shall be made of inert non-metallic material, such as glass, plastic or suitably coated wood. If it is necessary to suspend the test object, the material used shall on no account be metallic but shall be synthetic fibre, cotton thread, or other inert insulating material.

6.2 Exposure conditions of test cycle

6.2.1 Execute an exposure test in the climate chamber according to the following scheme of 12 h cycles. In the 1st cycle, the 8th cycle, the 15th cycle, and subsequently every seventh cycle, a cycle A with salt spraying as specified in 6.2.3 is used. In the other cycles, a cycle B as specified in 6.2.2 is used.

NOTE From a practical point of view, it is sometimes preferable to perform the salt spraying on the first day of the working week and the last day of the working week. If the test is started on the first day of the working week, accordingly, use cycle A in the 1st cycle, 9th cycle, 15th cycle, 21st cycle, 29th cycle, etc. In the other cycles, cycle B is used.

6.2.2 Cycle B is composed of the following steps, see also [Figure 1](#):

- 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.

6.2.3 Cycle A consists of the following steps, see also [Figure 2](#):

- Step 5 Spraying of the test objects inside the climate chamber at 35 °C with salt solution 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 % to 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.

- Step 7 Drying of the test objects, see [4.3](#), at a set (target) relative humidity of 50 % and at a temperature of 35 °C over a period of 4 h. The specified humidity level should be reached within 2 h, leaving the test objects and chamber interior without visible wetness.
- 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.

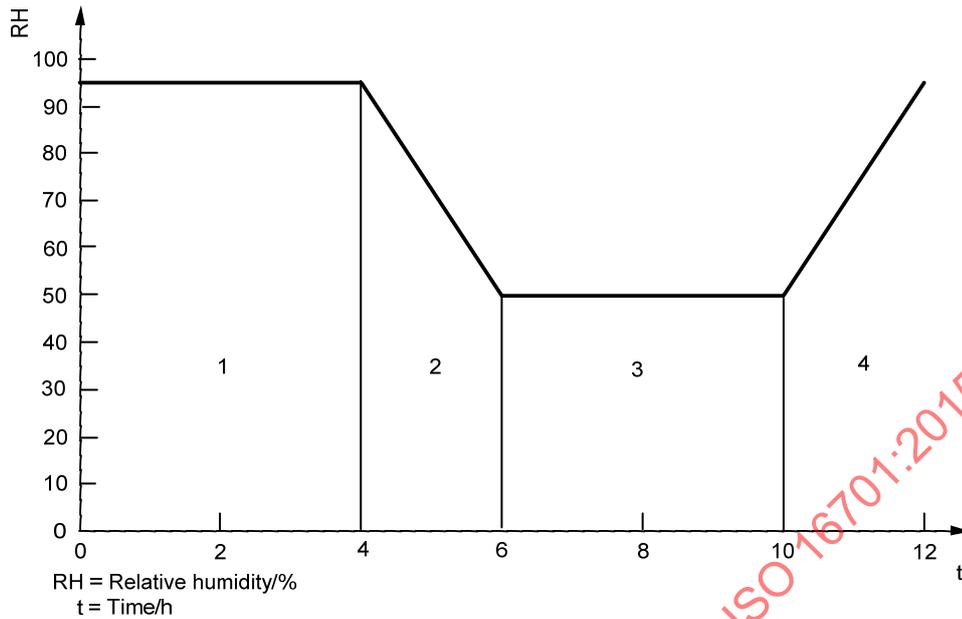


Figure 1 — Cycle B without spraying composed of the following sequence of steps: 1,2,3,4

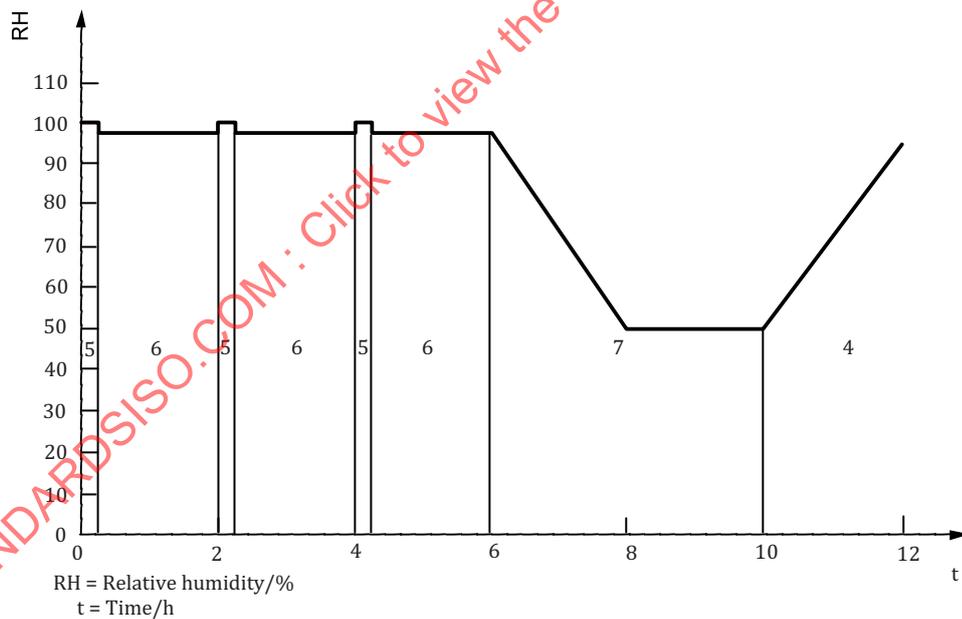


Figure 2 — Cycle A with spraying composed of the following sequence of steps: 5,6,5,6,5,6,7,4

NOTE 1 A simpler but less favourable alternative to spraying the test objects with salt solution inside the climate chamber is the use of manual alternate immersion of the test objects in salt solution outside the chamber. In this case, it is recommended to replace cycle A with cycle C composed of the following steps:

— Step 5 a) Remove the test objects from the climate chamber and immerse them for 15 min in the specified salt solution at a temperature of 35 °C. After emersion, manually spray the test objects with salt solution to restore droplets on the surface.

— Step 6 a) After manual over-spraying, let excessive fluid run off then return the test objects to the test chamber at 35 °C with the relative humidity set point at 95 % to 99 % for 1 h 45 min.

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

From a practical point of view, it is further recommended that the manual immersion be performed on Mondays and Fridays so that cycle C with salt exposure is used: in the 1st cycle, 9th cycle, 15th cycle, 21st cycle, 29th cycle, etc. (the test is started on a Monday). In the other cycles, cycle B is used.

Specimens of different metals should not be immersed in the same salt solution, in order to avoid contamination of dissolved ions of other metals (forming cathodes when reduced).

6.2.4 To check the reproducibility of test results, it is necessary to verify the corrosivity of the test at regular intervals.

NOTE A suitable method for evaluation of the corrosivity using reference specimens is described in [Annex C](#).

6.3 Duration of test

The period of test shall be as designated by the specification covering the material or product being tested. When not specified, the period shall be agreed by the interested parties.

NOTE Recommended periods of exposure for assessment of the corrosion resistance of different kinds of materials are given in [Annex A](#).

6.4 Treatment of test objects after test

At the end of the test period, remove the test objects from the chamber and allow them to dry for 0,5 h to 1 h before rinsing, in order to reduce the risk of removing corrosion products. Before they are examined, carefully remove the residues of spray solution from their surfaces.

NOTE This can be accomplished by dipping the test specimens gently in clean running water at a temperature not exceeding 40 °C and then drying it immediately in a stream of air at a pressure not exceeding 200 kPa at a distance of approximately 300 mm.

7 Evaluation of results

Many different criteria for the evaluation of the test results can be applied to meet particular requirements, for example, the following:

- a) appearance after the test;
- b) appearance after removing superficial corrosion products;
- c) number and distribution of corrosion defects, i.e. pits, cracks, blisters, etc.; these can be assessed by methods described in ISO 10289, ISO 4628-1, ISO 4628-2, ISO 4628-4, and ISO 4628-5;
- d) the time elapsing before the appearance of the first signs of corrosion;
- e) change in mass and evaluation of metallic mass loss in accordance with ISO 8407;
- f) alteration revealed by micrographic examination;
- g) change in mechanical properties.

NOTE It is good engineering practice to define the appropriate criteria in the specification for a coating or a product to be tested.

8 Test report

The test report shall include following information:

- a) reference to this International Standard, i.e. ISO 16701;
- b) description of the test equipment;
- c) the type, designation, dimensions and shape of the test object (material or product) and nature, and area of the surface tested;
- d) supplementary data in accordance with [5.2](#), such as preparation of the test object, including any cleaning treatment applied before testing and any protection given to edges;
- e) the angle at which the tested surfaces were inclined during test;
- f) the number of cycles or the duration of the test;
- g) the frequency and intervals of inspection during testing;
- h) the corrosivity of the test;
- i) any deviations from the prescribed testing method;
- j) test results after final evaluation of test objects, such as mass and thickness losses for uncoated specimens and blister width and peeling width for coated specimens, in accordance with [Clause 7](#).

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Annex A (informative)

Recommended periods of testing

In general, a 6-week test should be sufficient to rank any bare metal (alloy) or a metal protected by a thin conversion coating or a metallic, inorganic or organic coating. A 12-week test is recommended for the ranking of high quality coating systems.

[Table A.1](#) illustrates how the recommended periods of testing according to this International Standard relate to two different kinds of field exposure test conditions in the case of cold rolled carbon steel and pure zinc (99,9 % mass fraction).

If the more simple alternative to salt exposure as described in NOTE 1 in [6.2.3](#) is used, the corrosivity of the test, or in other words, the metal thickness loss of cold rolled carbon steel and pure zinc after different periods of test is different from that given in [Table A.1](#). Recommended periods of testing should in this case be based on what metal thickness losses are obtained for the reference specimens after different periods of testing.

Table A.1 — Comparison of metal losses due to corrosion in different tests

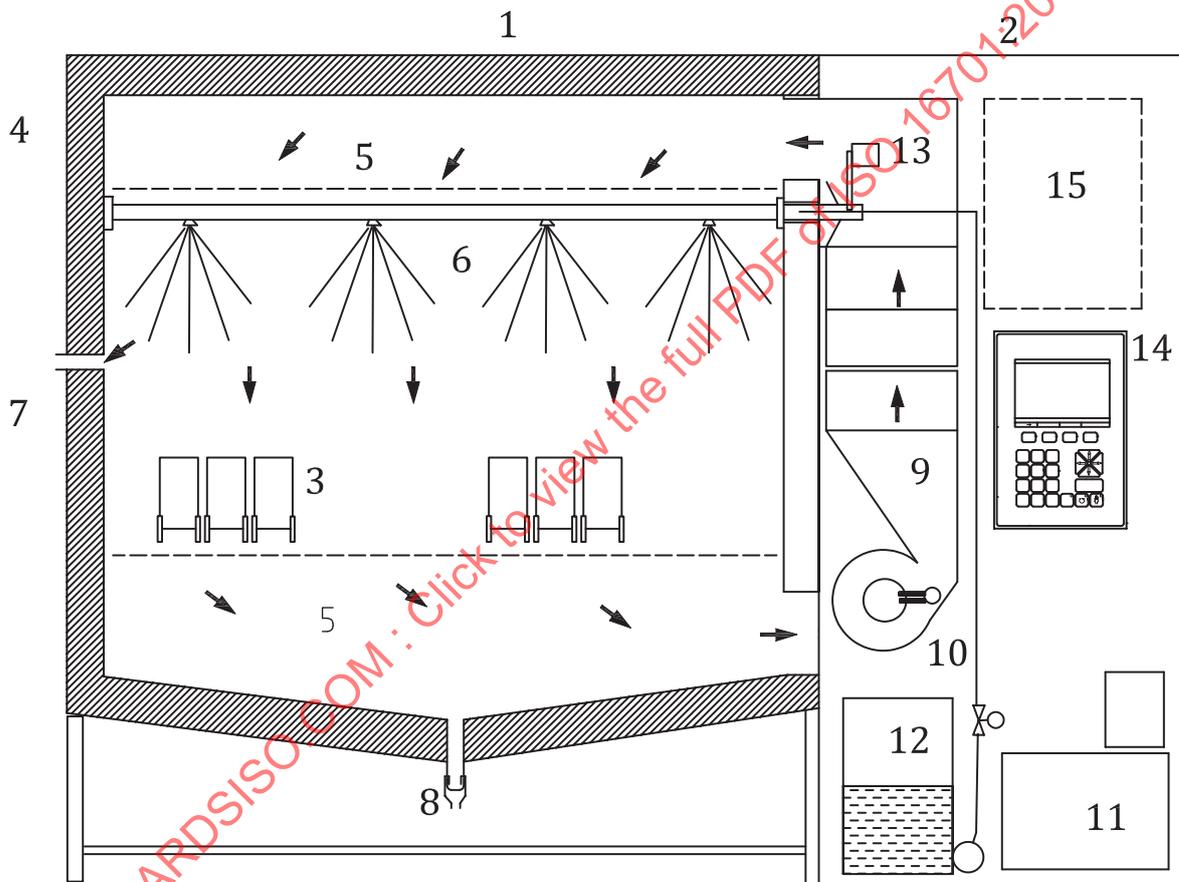
Material tested	Metal losses in thickness obtained after test μm		
	In accordance with this International Standard	In on-vehicle test after 2 y, vertical exposure, Gothenburg ^[5]	According to corrosivity class C5 in ISO 9223:2012, first year data
Cold rolled carbon steel	115 to 130 (4 weeks of exposure)	80 to 150	80 to 200
	180 to 220 (6 weeks of exposure)		
	315 to 385 (12 weeks of exposure)		
Pure zinc	5 to 7 (4 weeks of exposure)	5 to 8	4,2 to 8,4
	7 to 10 (6 weeks of exposure)		
	15 to 20 (12 weeks of exposure)		

Annex B (informative)

Suitable design of test apparatus with spraying device

B.1 Climate chamber

See [Figure B.1](#).



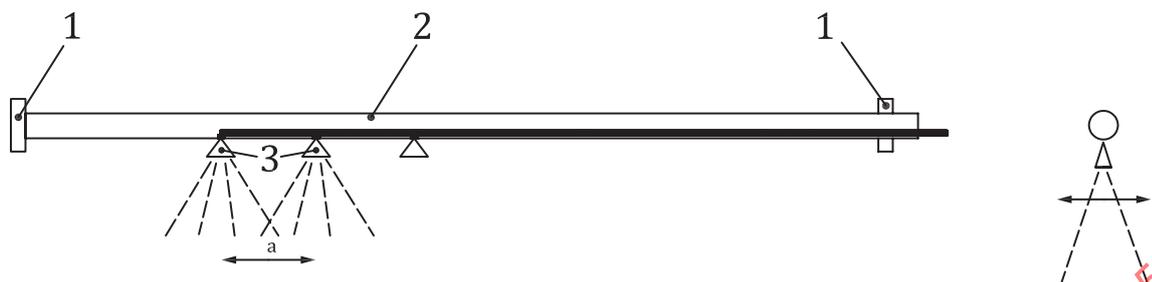
Key

- | | | | |
|---|---|----|--|
| 1 | test chamber | 9 | climatization unit (cooling/heating/humidification) |
| 2 | machinery unit | 10 | wet and dry Pt 100 sensors |
| 3 | test object area | 11 | cooling machine |
| 4 | well-insulated walls/lid | 12 | vessel with spray solution + pressurizing pump |
| 5 | air distribution grid plane | 13 | motor and link arms for swaying motion of precipitation rail |
| 6 | swaying rail with precipitation nozzles | 14 | control unit |
| 7 | air purge outlet | 15 | electronics and regulatory devices |
| 8 | precipitate sewer | | |

Figure B.1 — Climate chamber

B.2 Spray-rack design

See [Figure B.2](#).



Key

- 1 bearing
- 2 tube/member
- 3 nozzles
- a 0,5 m to 0,6 m.

Figure B.2 — Spray-rack design

Principle: Swaying tube or member supporting overlapping flat-spray nozzles.

Recommended nozzle type: Spraying Systems UniJet 800050VP. C/C mounting of nozzles on supporting tube 0,5 m to 0,6 m (approximately 1 m above test objects).

Swaying mode implemented by having supporting tube in bearings (free rotation, one side penetrating chamber wall) and rotating device with link-arms on outside of chamber wall.

Precipitation: $15 \text{ mm h}^{-1} \pm 5 \text{ mm h}^{-1}$ throughout the whole rectangular test area (2 m^3 , 4 nozzles in array).