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Corrosion of metals and alloys — Determination of bimetallic corrosion in atmospheric exposure corrosion tests

Corrosion des métaux et alliages — Détermination de la corrosion bimétallique par des essais d'exposition de corrosion atmosphérique

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Foreword

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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. www.iso.org/directives

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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 7441:1984), which has been technically revised.

Introduction

Bimetallic corrosion occurs when a metal in electrical contact with a more noble metal corrodes at a higher rate than it would in the same environment but without this contact.

Bimetallic corrosion in the atmosphere, in contrast to that in electrolytes, is characterized by a large potential drop between the anode and the cathode. Therefore, bimetallic corrosion is usually limited to a distance within about 0,5 cm from the point of contact[1].

The determination of bimetallic corrosion in atmospheric exposure tests can be made with several methods, each with its own advantages. Three standardized tests are compared and described in this International Standard:

— rectangular plates;

— washers;

— wire on bolt.

The standard starts with an overview and comparison of the three methods, with the purpose of aiding the selection of an appropriate test method. Test procedures for the rectangular plate and washer test are included in this standard since no independent standard describes these methods while those who wish to use the wire on bolt test need to consult ASTM G116 for a complete description of the method.

The standard describes how to derive the bimetallic effect, which is a relative measure of the bimetallic corrosion of a metal compared to the corrosion of the same metal but without the bimetallic effect. A high galvanic effect does not necessarily mean that the bimetallic corrosion rate is high. Therefore, valuable complementary information is the classification of the corrosivity of the test site according to ISO 9223[2].

Corrosion of metals and alloys — Determination of bimetallic corrosion in atmospheric exposure corrosion tests

1 Scope

This International Standard specifies and compares methods for the determination of bimetallic corrosion of metals and coated metals in atmospheric exposure corrosion tests.

NOTE In the text of this International Standard, the term "metal" is used for both metals and alloys, and the term "coated metal" for metals and alloys with metallic and non-metallic inorganic coatings.

The methods are intended for the determination of the amount and type of corrosion effect, arising in natural atmospheres, caused by contact with different metals.

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 1456, *Metallic and other inorganic coatings — Electrodeposited coatings of nickel, nickel plus chromium, copper plus nickel and of copper plus nickel plus chromium*

ISO 2081, *Metallic and other inorganic coatings — Electroplated coatings of zinc with supplementary treatments on iron or steel*

ISO 7599, *Anodizing of aluminium and its alloys — General specifications for anodic oxidation coatings on aluminium*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 8044, *Corrosion of metals and alloys — Basic terms and definitions*

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

ISO 8565, *Metals and alloys — Atmospheric corrosion testing — General requirements*

ISO 15510, *Stainless steels — Chemical composition*

ASTM G116, *Standard Practice for Conducting Wire-on-Bolt Test for Atmospheric Galvanic Corrosion*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and the following apply.

3.1
test specimens
specimens that are exposed for evaluation of bimetallic corrosion caused by contact with different materials

3.2
reference specimens
specimens prepared, exposed and evaluated in the same configuration and design as the test specimens but not subject to bimetallic corrosion, for example by being in contact with an inert non-conductive material or the same material, instead of the different material

3.3
standard specimens
specimens used to determine the corrosivity of the test environment in absence of bimetallic corrosion

3.4
control specimens
specimens prepared and evaluated in the same way as test specimens but, instead of being exposed in the test environment, stored under controlled conditions which prevent corrosion

4 Overview and comparison of methods

The determination of bimetallic corrosion in atmospheric exposure tests can be made with several methods. Three of these methods are compared and described in this International Standard:

— rectangular plates;

— washers;

— wire on bolt.

An overview and comparison of methods are shown in Table 1. Each configuration has its own advantages and the selection of method shall be based on the needs of the test programme. The main advantage with rectangular plate test is the possibility of evaluating the mechanical properties. The washer test is the only method where it is not necessary to know in advance which material is the anode. The short exposure time is the main advantage of the wire on bolt test.

Table 1 — Comparison of rectangular plates, washers and wire on bolt for conducting test assessing bimetallic corrosion in the atmosphere

Effect	Rectangular plates	Washers	Wire on bolt
Sensitivity (exposure time)	≥ 1 year	≥ 1 year	> 90 days[a]
Material limitation	None	None	Wire anode
Anode/cathode	Necessary to know in advance which material is the anode	Not necessary to know in advance which material is the anode	Necessary to know in advance which material is the anode
Evaluation method(s)	Mass loss Mechanical properties	Mass loss	Mass loss
Mechanical	Can be difficult to maintain electrical contact between panels throughout the exposure test.	Can be difficult to maintain electrical contact between panels throughout the exposure test.	Can be difficult to maintain enough wire tension without causing wire fracture
Crevice corrosion	Crevice corrosion can be a problem	Crevice corrosion can be a problem	Lower risk that crevice corrosion will be a problem

[a] A shorter duration of exposure is permissible under certain conditions, see Clause 6.

5 Preparation of specimens

5.1 Types of specimens

5.1.1 General

When determining the risk of bimetallic corrosion, depending on the particular test, the specimens will not only suffer from increased corrosion due to bimetallic effects. For example, in the wire on bolt test the wire tension may influence the outcome of the test depending on the particular application. Therefore, several types of specimens (test specimens, reference specimens, standard specimens and control specimens) as defined in Clause 3 are needed depending on the purpose of the test programme.

NOTE Comparison of effects of test and reference specimens gives the *relative* risk of bimetallic corrosion but reference specimens are generally not suitable for evaluation of the *absolute* corrosion attack when there is no risk of bimetallic corrosion due to the particular design of the specimens. For evaluation of the absolute attack standard specimens are more suitable. Flat or irregularly shaped specimens can be used, as described in ISO 8565, depending on the intended use of the tested material. For example, hanging wires can be used as standard specimens for the wire on bolt test but flat panels can also be used if they are easily obtained and more closely resembles the shape of the intended use.

Control specimens shall be used if evaluation of mechanical properties is part of the test programme.

Unless otherwise stated, the material, dimensions, direction of cutting, method of surface treatment and other parameters of anodic plates of test specimens, reference specimens and control specimens shall be the same.

5.1.2 Rectangular plates

The test specimens shall be as shown in Figure 1 or Figure 2.

NOTE 1 The configuration shown in Figure 1 cannot be used for evaluation based on mass loss. The configuration shown in Figure 2 cannot be used for evaluation based on mechanical properties.

Anodic plates shall have a thickness of 1 mm to 6 mm and their length shall be suitable for tensile testing in accordance with ISO 6892-1.

Cathodic plates shall have thickness of 1 mm to 6 mm. In the case of precious metals, cathodic plates can consist of a foil covering a plate of inert material, such as plastic material. In this case, the foil and inert material assembly shall have a thickness of 1 mm to 6 mm.

If it is not known which of the metals constituting the test specimen is nobler, each metal shall be tested in one complete set of specimens as the anode, and in the other, as the cathode.

The surfaces of specimens shall be free from visible defects, such as non-uniformity of rolling, scale, exfoliation, cracks, pores, blisters, scratches and dents. If there are no visual surface defects, as detected with the naked eye, specimens shall be tested with the surface in the condition as delivered or after treatment, as recommended for the articles concerned. If defects are removed by mechanical means, the surface roughness of specimens, including cut edges, shall at least be better than 2,5 µm, a surface roughness of 0,4 µm to 0,5 µm is recommended.

The surface conditions, including cut edges, of coated metallic plates shall be in accordance with ISO 1456, ISO 2081 or ISO 7599 or other appropriate international, national or regional standards depending on the specific coatings in question.

If a metal is tested in contact with a coated metal, damage to, or absence of, the coating is permissible only on the cut edges of anodic plates.

Washers and sleeves shall be used to insulate bolts from the metallic plates. The contact between two plates of metal shall be achieved by pressure. Ceramics or other insulating materials which are not susceptible to creep or degradations over extended periods of time are recommended as washer materials. Sleeves of polyethylene or polypropylene are recommended.

The bolts shall be tightened firmly until good electrical contact is achieved between the plates. Insufficient torque will cause too high a resistance between the washers, and too much torque will crack the bushing. The torque applied while tightening the bolts shall be the same for all specimens, a value of about (1,0 ± 0,1) N m^{-1} being typical. Otherwise, a good rule of thumb is to tighten until all components are in contact and then tighten an additional one quarter turn. After assembly, the electrical insulation (>10 kΩ) of the bolt from the washers and the electrical contact (<1 Ω) between the plates shall be verified with a resistance meter.

These electrical resistance checks should be repeated if assemblies are dry in connection with site visits. If the resistance increases or if there are other indications of relaxation, the bolts should be re-tightened without disturbing the assemblies. The reason for loss of contact could be that solid corrosion products accumulate between the washers pushing them apart. Another reason could be the relaxation of the non-metallic components caused by long term stress leading to creep.

Metallic bolts and washers shall be made of stainless steel of grade 1.4301/X5CrNi18-10/304 or higher chromium grades, see ISO 15510.

Specimens shall be examined for conformity to the requirements above by visual inspection and appropriate measurements.

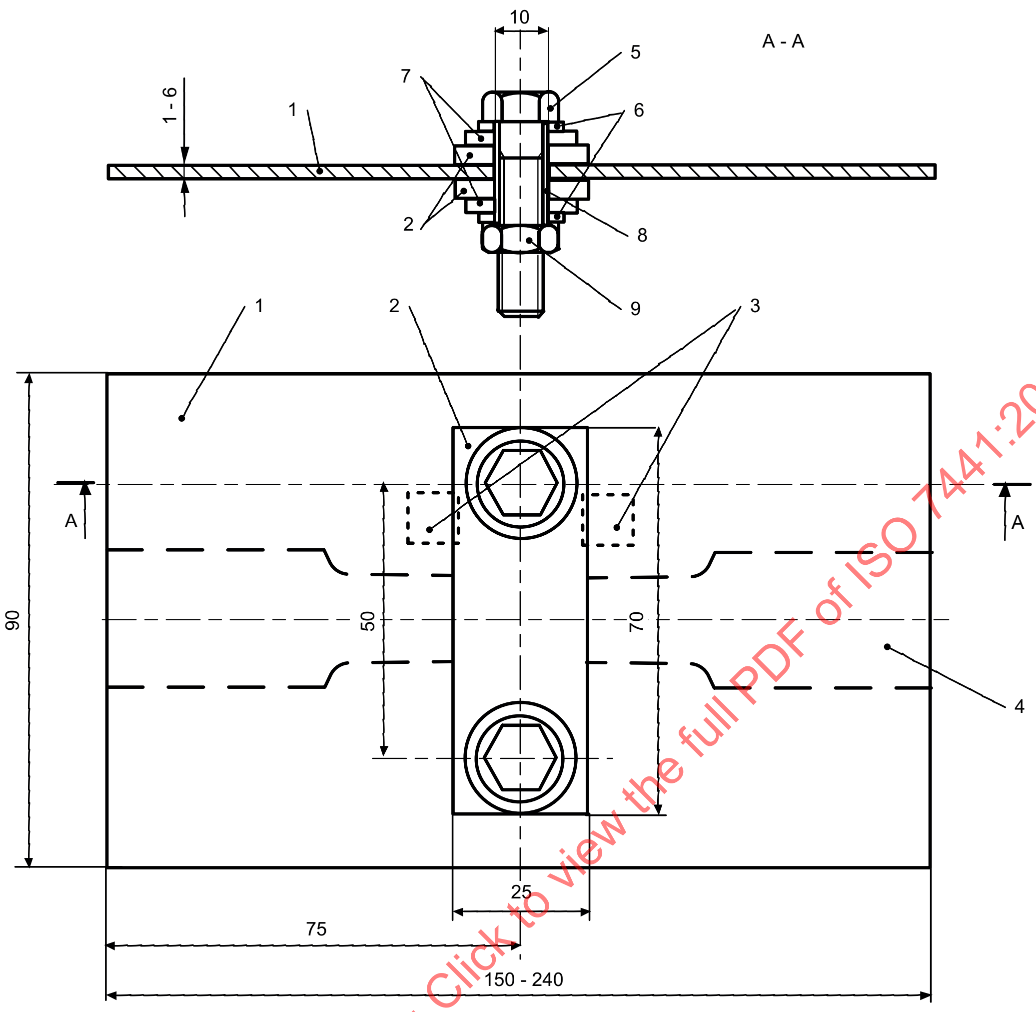
Immediately before testing, the surfaces of the specimens and other parts of the assemblies shall be degreased using organic solvents, for example ethanol, white spirit.

After degreasing, the specimens shall be handled only by the cut edges and when wearing cotton or rubber gloves.

After degreasing, test specimens and reference specimens, the corrosion behaviour of which is to be determined by mass loss, shall be kept in desiccators containing a desiccant (for example silica gel) for not less than 24 hours.

In preparing specimens a thin layer of an organic coating, glue, varnish or lacquer, such as cellulose acetate dissolved in acetone, is recommended to prevent crevice corrosion. This coating shall be applied to the degreased surface of the anodic plate in such a way as to seal completely the gap between the anode and cathode plates without projecting beyond the cathode plate. The dry coating thickness shall not exceed 10 µm. This coating shall not cover the area adjacent to bolt holes, in order to allow contact between the metallic plates when they are assembled.

Dimensions in millimetres

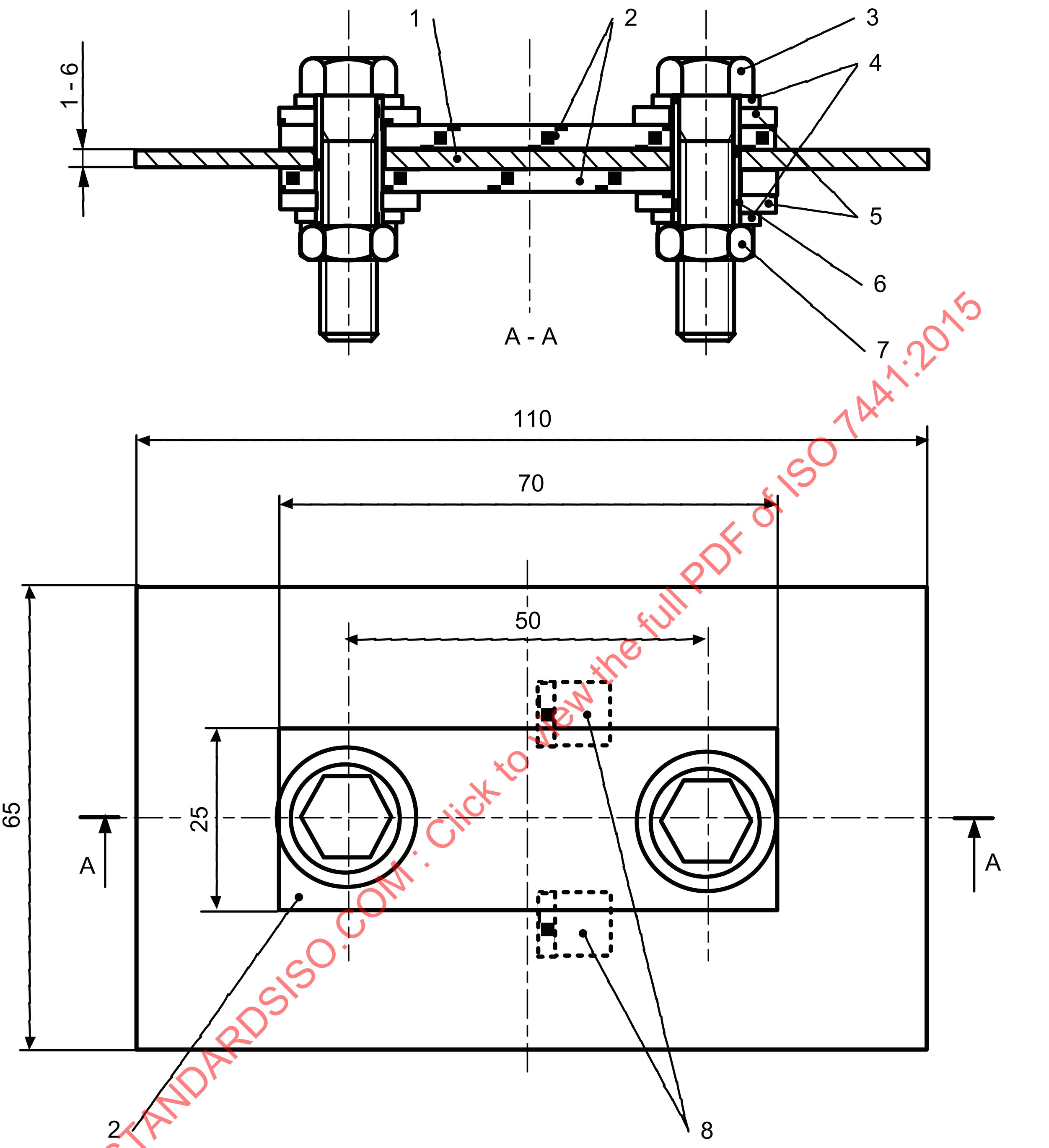


Key

1	anodic plate	6	washer, thickness 1 mm, diameter 16 mm
2	cathodic plate	7	insulating washer, thickness 1 mm to 3 mm, diameter 18 to 20 mm
3	microsections	8	insulating sleeve
4	tensile test specimen	9	nut
5	bolt 8 mm × 40 mm		

Figure 1 — Example of test specimen used for evaluations based on criteria other than mass loss

Dimensions in millimetres



Key

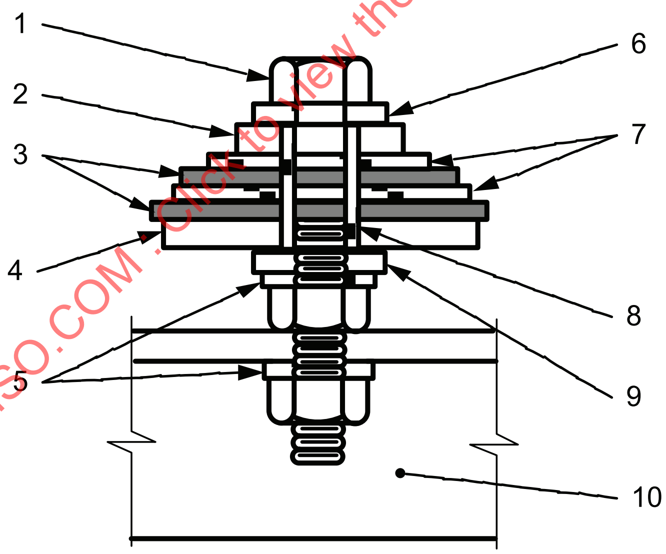
1 anodic plate
2 cathodic plate
3 bolt 8 mm × 40 mm
4 washer, thickness 1 mm, diameter 16 mm
5 insulating washer, thickness 1 to 3 mm, diameter 18 to 20 mm
6 insulating sleeve
7 nut
8 microsections

Figure 2 — Example of test specimen for evaluation based on criteria other than mechanical properties

The components specifications used to construct the specimen assemblies for this test is shown in Table 2 and Figure 3. Washer dimensions are critical to maintaining the 1:1 area ratio fixed by the geometry. Thickness shall be adjusted by surface grinding, if required.

Table 2 — Dimensions of components for the washer assembly

Component	Thickness/length mm	Inside diameter mm	Outside diameter mm	Designation
Bolt	40	—	—	M6S M5 × 40 A4
Washer	—	4,9	15,9	—
Polymer bushing	11,1	5,2	7,9	—
Polymer washer (small)	3,2	8,3	19,0	—
Metal A washers (small)	1,6	8,3	25,4	—
Metal B washers (small)	1,6	8,3	30,0	—
Metal A washers (large)	1,6	8,3	33,5	—
Metal B washers (large)	1,6	8,3	36,6	—
Polymer washer (large)	3,2	8,3	35,6	—
Washer	—	4,9	15,9	—
Lock washers	—	4,9	—	—
Nut	—	—	—	M6M M5 A4



Key

1 bolt
2 polymer washer
3 metal B washer
4 polymer washer
5 lock washer
6 washer
7 metal A washer
8 polymer bushing
9 washer
10 angle support

Figure 3 — Schematic completed washer assembly

The bolts, end washers, lock washers and nuts can be made of any material provided that the material will not degrade in the atmosphere for the duration of the exposure.

Washers shall not be made by punching directly to the final dimensions, as this introduces a deformed area near the edge. Washers can be made by first punching out discs a minimum of 3 mm diameter oversize and machining to final dimensions, then drilling holes in the disk centres.

The surfaces of specimens shall be free from visible defects, such as non-uniformity of rolling, scale, exfoliation, cracks, pores, blisters, scratches and dents. If there are no visual surface defects, as detected with the naked eye specimens shall be tested with the surface in the condition as delivered or after treatment, as recommended for the articles concerned. If defects are removed by mechanical means, the surface roughness of specimens, including cut edges, shall at least be better than 2,5 µm, a surface roughness of 0,4 µm to 0,5 µm is recommended.

Additional washers of the anode material shall be prepared to enable the construction of reference assemblies, where all four washers are made of the anode material and exposed under identical conditions to the test assemblies. The reference assemblies are used to assess non-galvanic effects.

All parts shall be thoroughly cleaned and degreased before assembly. After degreasing, the washers shall only be handled by the edges while wearing clean, cotton or rubber gloves.

If the relationship between the anode and the cathode of the materials is not known at the start of the test, the inner washers shall be weighed before assembly, otherwise, only the anode plate shall be weighed.

The bolts shall be tightened firmly until good electrical contact is achieved between plates. Insufficient torque will cause too high a resistance between the washers, and too much torque will crack the bushing. The torque applied while tightening the bolts shall be the same for all specimens, a value of about (1,0 ± 0,1) N m^{-1} being typical. Otherwise, a good rule of thumb is to tighten until all components are in contact and then tighten an additional one quarter turn. After assembly, the electrical insulation (>10 kΩ) of the bolt from the washers and the electrical contact (<1 Ω) between plates shall be verified with a resistance meter.

These electrical resistance checks should be repeated if assemblies are dry in connection with site visits. If the resistance increases or if there are other indications of relaxation, the bolts should be re-tightened without disturbing the assemblies.

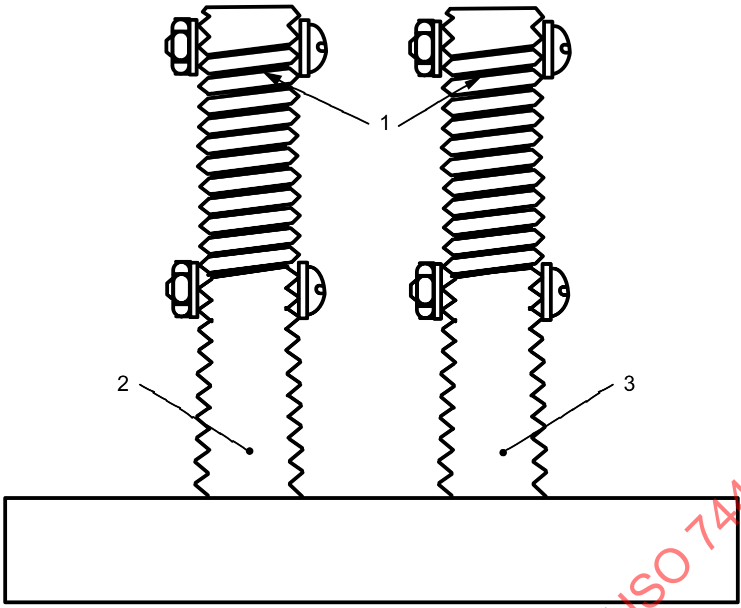
NOTE 2 The reason for loss of contact could be that solid corrosion products accumulate between the washers pushing them apart. Another reason could be the relaxation of the non-metallic components caused by long term stress leading to creep.

5.1.3 Wire on bolt

ASTM G116 shall be consulted for performing the wire on bolt test.

NOTE 1 The purpose of this subclause is to give enough information for making a decision if the wire on bolt test is appropriate for the test programme. If the wire on bolt method is selected, however, the text provided in this International Standard is not sufficient in all details.

The wire on bolt test consist of wrapping a wire of the anode material around the threads of a bolt or threaded rod of the cathode material, exposing the assembly to atmosphere, and determining mass loss of the anode wire after exposure. Reference specimens of the anode wire on a threaded, non-conductive, non-porous rod are used to separate general and crevice corrosion effects from bimetallic corrosion effects. A schematic view of the components used to construct the specimen assemblies for this test is shown in Figure 4.



Key

1 anode wires

2 plastic rod

3 cathode rod

Figure 4 — Schematic completed wire on bolt assemblies taken from ASTM G116 [reproduced with permission from the American Society for Testing and Materials (ASTM)]

The major disadvantage of this test is that the anode material shall be available in wire form and the cathodic material in the form of a threaded rod.

NOTE 2 The process used to make the wire and rod can affect their corrosion potential and the wire may not behave galvanically the same as the material of interest, for example fasteners in sheet roofing.

The length of the wire is typically 1 m and nominally with a diameter of 0,875 mm. The rods shall be M12, 100 mm long. Other dimensions can be used but reference specimens shall be of identical dimensions and prepared identically to the test specimens.

If the tension of the wire is critical it is necessary to use a special rig (see ASTM G116) in order to wrap the wire tightly around the rod to keep the tension constant while it is being wound.

5.2 Number and marking of specimens

For all three methods, the number of test specimens removed for analysis at one time shall not be less than three. Similarly, the number of reference specimens removed for analysis at one time shall not be less than three.

Specimens (plates, washers or wires subject to evaluation) shall not be marked directly, since there is no appropriate place to do so. However completed assemblies shall be marked by metal tags or other markings. The markings shall be legible and durable throughout the period of the test.

6 Exposure of specimens

Unless otherwise stated, procedures for exposures described in ISO 8565 shall be followed.

Test specimens and reference specimens shall be exposed in an identical way.

For the plate test, test and reference specimens shall be exposed at an angle of 45° from horizontal (30° are permissible) skyward-facing, or in other orientations required by the test programme. For the washer and wire on bolt tests, test and reference specimens shall be exposed horizontally on racks.

NOTE 1 This orientation minimizes the possibility of circumferential flow of water around the washers that could result in a greater accumulation of corrosion products at the lowest point of the assembly. This orientation also prevents drainage from the high point resulting in a non-uniform time of wetness around the circumference of the assembly.

For the plate test, the duration of the test shall not normally be less than two years. The recommended exposure period for the washer test is at least one year. For the wire on bolt specimens the recommended exposure period is at least 90 days. If technically justified, shorter durations of testing may be adopted.

NOTE 2 One such reason for the wire on bolt test is if the corrosion at the particular site is so high that the wire will not last for 90 days.

7 Evaluation of specimens

7.1 General

Test specimens and reference specimens shall be evaluated in an identical way.

The evaluation of bimetallic corrosion resistance shall be carried out with the mass loss method (7.2). For the plate test, other evaluations methods can in addition be used (7.3). Results shall be expressed according to 7.4.

7.2 Evaluation based on mass loss

Removal of corrosion products shall be done as described in ISO 8407. It is necessary to remove glue or varnish used to prevent crevice corrosion of specimens, before removal of corrosion products.

The mass loss is calculated as the difference between the initial mass before exposure and the final mass after exposure and after removal of corrosion products. The initial mass and the final mass shall be weighed by the same procedure. The balance shall have a precision better than the typical spread of mass loss of individual (triplicate) specimens: at least ± 0,0001 g.

For the wire on bolt test the mass loss is normalized to unit length of the wire (see ASTM G116) while for the plate and washer test the mass loss is normalized to unit area.

7.3 Other evaluation methods applicable for rectangular plates

7.3.1 Evaluation based on visual examination

The evaluation shall be carried out in the zone of bimetallic corrosion; i.e. the total area of the anodic plate, of width 10 mm, adjacent to the zone of direct contact with the cathodic plates.

Specimens chosen for inspection shall be examined visually in daylight or in artificial diffused light. Optical instruments can be used. The following changes in surface appearance shall be recorded for qualitative evaluations:

— tarnishing of the surface;

— the colour of corrosion products;

— the distribution of corrosion effect over the surface (uniform, non-uniform, local, etc.);

— the areas affected by corrosion (points, spots, etc.).

For quantitative evaluations, the amount of the corrosion effect per surface area, for example the number of pits, shall be determined after the removal of corrosion products according to ISO 8407. The amount of the corrosion effect shall be calculated using a grid, divided into squares of side 5 mm, placed on the anodic plates in the zone of bimetallic corrosion.

The corrosion depth in the zone of bimetallic corrosion shall be determined on each test specimen and reference specimen using profilometers, indicators, depth gauges or by metallographic examination of microsections. The number of microsections shall not be less than 2. Measurements shall be carried out after the removal of corrosion products. The mean of the maximums of the corrosion depths shall be determined from its five largest values.

The type of corrosion effect shall be determined by metallographic examination of microsections of anodic plates. Specific types of corrosion effects (intergranular, pitting, exfoliation, etc.) shall be recorded.

7.3.2 Evaluation based on mechanical properties

For evaluation of the increased risk of bimetallic corrosion based on mechanical properties, control specimens are needed in addition to reference specimens.

NOTE Bimetallic corrosion resistance can be evaluated from the change in mechanical properties by determining the ultimate tensile strength, yield strength or elongation of specimens.

The determination of mechanical properties is carried out on flat tensile specimens (see Figure 1) according to appropriate International Standards, for example ISO 6892-1.

7.4 Calculation of bimetallic effect

Results from the plate test, the washer test and the wire on bolt test shall be expressed in an identical way by calculating the bimetallic effect. The bimetallic effect is a relative measure of the bimetallic corrosion of a metal compared to the corrosion of the same metal but without the bimetallic effect. A high bimetallic effect does not necessarily mean that the bimetallic corrosion rate is high; it could also mean that the corrosion rate without the bimetallic effect is very low.

The bimetallic effect cannot be used in itself in a risk analysis but should be complemented with results from standard specimens. The expression of results as a relative number (bimetallic effect) allows for some flexibility in the exposure conditions and design of test specimens that would otherwise not be possible as long as reference specimens are prepared and exposed identically.

The test specimen value, as well as the reference specimen value, shall be calculated as the average value of individually determined values for three or more specimens.

The bimetallic effect can only be calculated if the relation between the test specimen value and the reference specimen value is as expected considering the initial assumption of anode and cathode materials. In the case of reversed results the result of the test shall not be reported but instead the test results of the reversed assembly.

The bimetallic effect (β) is a number between 0 and 1 but can also be reported as a percentage value. The calculation of β can only be made after two initial checks, representing the extreme cases of $\beta = 0$ and $\beta = 1$.

First, it shall be determined if the difference between the test specimen value and the reference specimen value is significant. The confidence level shall be selected based on the needs on the test programme and a common value is 95 %. The standard deviations used in the statistical test shall not necessarily be calculated only from the test/reference values of the specimens used in the test (at least three each) but all available information should be taken into account. If the difference is not significant, the bimetallic effect shall be reported as $\beta = 0$ or 0 %.

Second, if the difference between the test specimen value and the reference specimen value is significant, it shall be determined if the reference specimen value is significantly different from zero, using the same confidence level. If the reference specimen value is not significantly different from zero, the bimetallic effect shall be reported as $\beta = 1$ or 100 %. For evaluation based on mechanical properties it shall instead

