

# International Standard 7441

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

*Corrosion des métaux et alliages — Détermination de la corrosion bimétallique par des essais de corrosion en milieu extérieure*

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 7441 was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

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

## 1 Scope and field of application

This International Standard specifies methods for the determination of bimetallic corrosion of metals and alloys, and metals and alloys with metallic and non-metallic non-organic coatings, in outdoor 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 non-organic 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 (coated metals), and for the evaluation of the effectiveness of bimetallic corrosion protection treatments.

## 2 References

ISO 1456, *Metallic coatings — Electroplated coatings of nickel plus chromium.*

ISO 2081, *Metallic coatings — Electroplated coatings of zinc on iron or steel.*<sup>1)</sup>

ISO 2082, *Metallic coatings — Electroplated coatings of cadmium on iron or steel.*<sup>2)</sup>

ISO 4540, *Metallic coatings — Coatings cathodic to the substrate — Rating of electroplated test specimens subjected to corrosion tests.*

ISO 4542, *Metallic and other non-organic coatings — General rules for stationary outdoor exposure corrosion tests.*

ISO 6892, *Metallic materials — Tensile testing.*

## 3 General principles

**3.1** The test consists of simultaneous exposure of test specimens and reference specimens at atmospheric field stations and subsequent comparative evaluation of their corrosion resistance.

The test specimens are assemblies in which one plate of metal (coated metal) may act as the anode and two plates of a different metal (coated metal) as the cathode, thereby producing an electrochemical cell in the presence of an electrolyte. (See figures 1 and 2.)

Reference specimens are anodic plates exposed with the test specimens.

Control specimens are anodic plates which are kept under conditions which prevent corrosion during the test period.

The amount and type of corrosion effect is evaluated on the basis of:

- changes in surface appearance;
- depth and area of corrosion effect;
- changes in mechanical properties;
- loss in mass;
- other characteristics resulting from bimetallic corrosion.

The effectiveness of corrosion protection treatments may be evaluated by applying coatings to the anodic or cathodic plates or to the test specimen assembly, with the exception that electrodeposited coatings shall not be applied to the test specimen assembly.

Coated specimens should be tested simultaneously with specimens without protective coatings.

**3.2** The test conditions (macroclimatic region, type of atmosphere and conditions for the location and exposure of specimens at the atmospheric field stations) should be chosen according to the expected conditions of service of articles, joints and parts in which the contacted metals (coated metals) will be used.

**3.3** Atmospheric field stations should be suitably equipped and the equipment should comply with the requirements of relevant International Standards. (See, for example, ISO 4542.)

1) At present at the stage of draft. (Revision of ISO 2081-1973.)

2) At present at the stage of draft. (Revision of ISO 2082-1973.)

## 4 Specimens

**4.1** The test specimens shall be as shown in figure 1 or figure 2.

Anodic plates may be up to 6 mm thick and their length should be suitable for torsion testing in accordance with ISO 6892.

Cathodic plates shall have a thickness of 1 to 6 mm. In the case of precious metals, cathodic plates may comprise a foil covering a plate of inert material, such as a plastic material; the contact between two plates of metal should be achieved by pressure. The thickness should not be less than 1 mm.

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

The presence of gaps and crevices between anodic and cathodic plates should be minimized and such clearances should not exceed 0,02 mm. When assembling the test specimens, the maximum value of the torque applied while tightening the bolts should be more than 5,0 N·m.

**4.2** The surfaces of specimens shall be free from visible defects, such as non-uniformity of rolling, scale, exfoliation, cracks, pores, blisters, scratches, dents.

If there are no surface defects, specimens shall be tested with the surface in the condition as delivered or after treatment, as recommended for the material (articles) concerned.

If defects are removed by mechanical means, the surface roughness ( $R_a$ ) of test specimens, reference specimens and control specimens, including cut edges, shall be within the range 0,75 to 2,5  $\mu\text{m}$ .

**4.3** The surface finish (including cut edges) of metallic plates (coated metals) shall be in accordance with appropriate International Standards, for example ISO 1456, ISO 2081, ISO 2082.

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.

**4.4** The evaluation of bimetallic corrosion resistance according to all criteria except loss in mass shall be carried out using specimens as shown in figure 1.

The evaluation of bimetallic corrosion resistance according to all criteria except changes in mechanical properties shall be carried out using specimens as shown in figure 2.

**4.5** 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.

**4.6** Specimens shall be identified by marking. Such marking shall include the characteristics and agreed designation of the tested anodic and cathodic metal (coated metal), in accordance with an inventory of specimens (see annex A) and serial numbers assigned to the metallic plates. The marking may be made with a stamp or using indelible paint or by drilling notches on the face of each metallic plate of the specimen.

The designation of a metal (coated metal) shall be marked in the top left hand corner and the serial number in the top right-hand corner of anodic and cathodic plates.

Areas bearing markings made by mechanical means shall be protected by water-resistant varnishes. The markings should be legible and durable throughout the period of test.

**4.7** Washers and sleeves shall be used to insulate bolts from the metallic plates and to avoid pressing metallic plates together during the period of test. 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.

Metallic bolts and washers shall be made of 18-8 or higher chromium grades of stainless steel.

**4.8** The number of test specimens, reference specimens and control specimens removed for inspection at any one time shall be not less than three.

If mechanical tests are not required by the test programme, the number of control specimens may be decreased to three per lot.

## 5 Preparation of specimens for test

**5.1** Test specimens, reference specimens and control specimens shall be examined for conformity to the requirements of clause 4 by visual examination and appropriate measurements.

**5.2** Immediately before testing, the surfaces of specimens 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.

**5.3** After degreasing, test specimens and reference specimens, the corrosion behaviour of which is to be evaluated by loss in mass, shall be kept in desiccators containing a desiccant (for example silica gel) for not less than 24 h. They shall then be weighed to the nearest 0,000 1 g.

**5.4** Control specimens shall be stored throughout the test period under conditions which prevent corrosion, for example in desiccators or in polyethylene bags containing a desiccant (silica gel) at a relative humidity of less than 50 %.

Control specimens made from metals susceptible to natural ageing should be stored only for evaluation of changes in mechanical properties.

**5.5** 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 should 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 should not exceed 10  $\mu\text{m}$ . This coating should not cover the area adjacent to bolt holes, in order to allow contact between the metallic plates when they are assembled.

Transition resistance between cathodic and anodic plates should be kept constant throughout the period of test.

## 6 Procedure

**6.1** Test specimens and reference specimens shall be exposed to the outdoor atmosphere either in shutter sheds or under cover. They shall be exposed at an angle of 45°, but angles of 30° and 90° are also permissible. The marked faces shall be uppermost, facing south in the northern hemisphere and north in the southern hemisphere. The long axis of the cathodic plates of the test specimens shall be perpendicular to the base of the rack.

Reference specimens shall be exposed in the same way as the anodic plates of the test specimens.

**6.2** Test specimens and reference specimens shall be fastened to frames, racks, etc., by means of appropriate isolators, for example made of porcelain.

The bolts used to clamp the test specimens may also be used to fasten the specimens to the rack.

**6.3** The duration of testing shall not normally be less than two years. If technically justified, shorter durations of testing may be adopted. During testing, test specimens shall be removed for inspection on no fewer than three occasions.

The periodicity of removal and inspection of specimens shall be determined by the test programme.

**6.4** Specimens which have been removed shall be examined, disassembled and treated to remove corrosion products. The evaluation of test results shall be carried out in accordance with the chosen criteria.

## 7 Evaluation of test results

### 7.1 General

The evaluation of bimetallic corrosion resistance shall be carried out according to one or more of the chosen criteria, by examination of the metal (coated metal) of the anodic plate of

the test specimen in the zone of bimetallic corrosion. The zone of bimetallic corrosion is the total area of the anodic plate, of width 10 mm, adjacent to the zone of the direct contact with the cathodic plates.

Evaluations of bimetallic corrosion resistance by change in surface appearance and by the amount and type of corrosion effect shall be carried out separately for the marked (face) and unmarked (reverse) sides of the specimens.

The result of the test shall be taken as the average value of the corrosion increase index (indices) determined for three or more specimens.

### 7.2 Evaluation based on change in surface appearance

**7.2.1** Specimens chosen for inspection, either during or on completion of the test, shall be examined visually in daylight or in artificial diffused light. Optical instruments may be used if this is specified in the test programme.

**7.2.2** 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.).

**7.2.3** For quantitative evaluations of the corroded area in the zone of bimetallic corrosion or in the case of pitting, the amount of corrosion effect per unit surface area shall be determined after the removal of corrosion products.

The amount of 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 number of local corrosion centres or the corroded surface area of reference specimens shall be determined over the same surface area and at the same locations as for the test specimens.

**7.2.4** Bimetallic corrosion resistance is determined by the corrosion increase index, that is, the ratio of the amount of corrosion effect per unit surface area in the zone of bimetallic corrosion of the test specimens to the amount of corrosion effect on the reference specimens, or the ratio of the corroded surface area in the zone of bimetallic corrosion to the corroded surface area of the reference specimen. The test results shall be recorded on a form as shown in annex B.

### 7.3 Evaluation by measuring the depth of corrosion effect

**7.3.1** 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.

**7.3.2** Measurements shall be carried out after the removal of corrosion products.

**7.3.3** The mean of the maximums of the corrosion depth shall be determined from its five largest values.

**7.3.4** Bimetallic corrosion resistance is determined by the corrosion increase index, that is, the ratio of the mean of the maximums of the corrosion depth in the zone of bimetallic corrosion on the anodic plate of the test specimen to the mean of the maximums of the corrosion depth on the reference specimens.

The test results shall be recorded on a form as shown in annex C.

#### 7.4 Evaluation based on the type of corrosion effect

The type of corrosion effect shall be determined by metallographic examination of microsections of anodic plates of the test specimens and of reference specimens.

Specific types of corrosion effects (intergranular, pitting, exfoliation, etc.) shall be recorded; substrate, filiform and other types of corrosion effects shall be recorded for coated specimens. The type of corrosion effect shall be recorded on the form as shown in annex C.

#### 7.5 Evaluation based on change in mechanical properties

**7.5.1** Bimetallic corrosion resistance may be evaluated from the change in mechanical properties by determining the ultimate tensile strength, yield strength and elongation of test specimens, reference specimens and control specimens.

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

**7.5.3** The relative change in ultimate tensile strength of a test specimen, expressed as a percentage, is given by the formula

$$\frac{R_{m,c} - R_{m,t}}{R_{m,c}} \times 100$$

where

$R_{m,c}$  is the ultimate tensile strength, in megapascals, of a control specimen;

$R_{m,t}$  is the ultimate tensile strength, in megapascals, of the anodic plate of the test specimen.

**7.5.4** The relative change in ultimate tensile strength of a reference specimen, expressed as a percentage, is given by the formula

$$\frac{R_{m,c} - R_{m,r}}{R_{m,c}} \times 100$$

where

$R_{m,c}$  is the ultimate tensile strength, in megapascals, of a control specimen;

$R_{m,r}$  is the ultimate tensile strength, in megapascals, of the reference specimen.

NOTE — Changes in yield strength ( $R_p$ ) and elongation (A) are calculated similarly.

**7.5.5** Bimetallic corrosion resistance is determined by the corrosion increase index, that is, the difference between the relative changes in mechanical properties of test specimens and reference specimens. The test results shall be recorded on a form as shown in annex D.

#### 7.6 Evaluation based on loss in mass

**7.6.1** For evaluations based on loss in mass, the test specimens and reference specimens shall be examined, and dust, dirt and corrosion products shall be removed.

Anodic plates with evidence of corrosion effect under the cathodic plates extending for a distance of more than 3 mm from the contact edge shall not be examined.

It is necessary to remove glue or varnish used to prevent crevice corrosion of specimens, before removal of corrosion products.

**7.6.2** After removal of the corrosion products, the metallic plates (coated metals) shall be washed, dried, degreased, scored for 24 h in a desiccator, and then weighed.

**7.6.3** The rate of corrosion of test specimens, expressed in grams per square metre per year, is given by the formula

$$\frac{\Delta m_1}{(S_1 - 2S_2) \times t}$$

where

$\Delta m_1$  is the loss in mass, in grams, of the anodic plate of the test specimen;

$S_1$  is the total surface area, in square metres, of the anodic plate;

$S_2$  is the surface area, in square metres, masked by the cathodic plate on one side only;

$t$  is the test duration, in years.

**7.6.4** The rate of corrosion of reference specimens, expressed in grams per square metre per year, is given by the formula

$$\frac{\Delta m_2}{S_3 \times t}$$

where

$\Delta m_2$  is the loss in mass, in grams, of the reference specimen;

$S_2$  is the total surface area, in square metres, of the reference specimen;

$t$  is the test duration, in years.

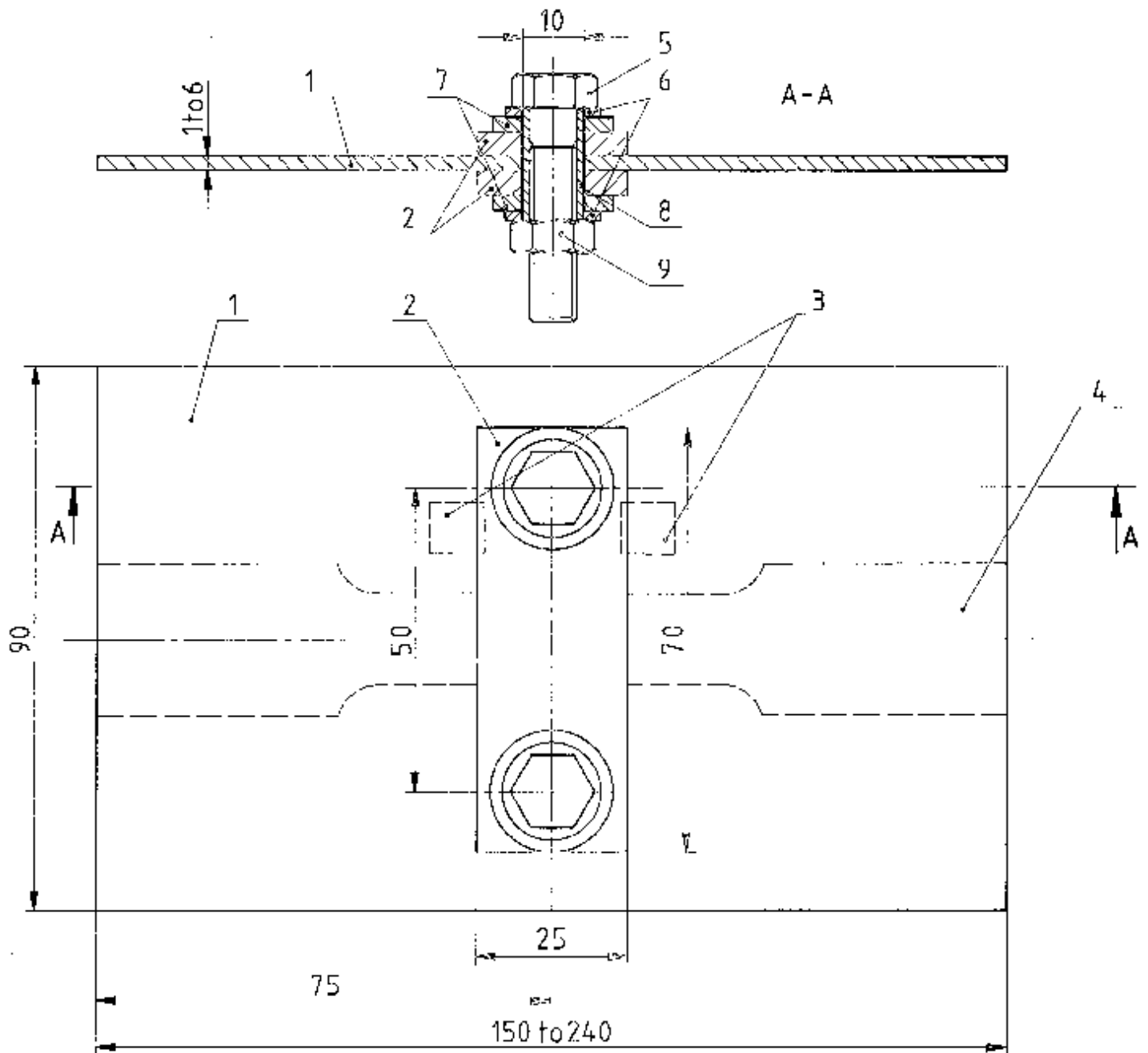
**7.5.5** Bimetallic corrosion resistance is determined by the corrosion increase index, that is, the difference between the rate of corrosion of the test specimens and that of the reference specimens.

The test results shall be recorded on a form as shown in annex E.

## 8 Test report

The test report shall include the following information:

- a) the purpose of the test;
- b) the designation and description of the metals (coated metals) tested [chemical composition, method of treatment (thermal, chemical and mechanical), type of coating, thickness] (see annex A);
- c) the number of specimens;
- d) the identification of the atmospheric field station, its location, and characteristics of the atmosphere;
- e) the method of fastening specimens during the test;
- f) the duration of the test and the periodicity of removal of specimens;
- g) the test results with the test criteria, including both descriptive and numerical data, presented in accordance with annexes B, C, D and E, and, if possible, with photographs of the specimens;
- h) any other data required to fulfil the purpose of the test.

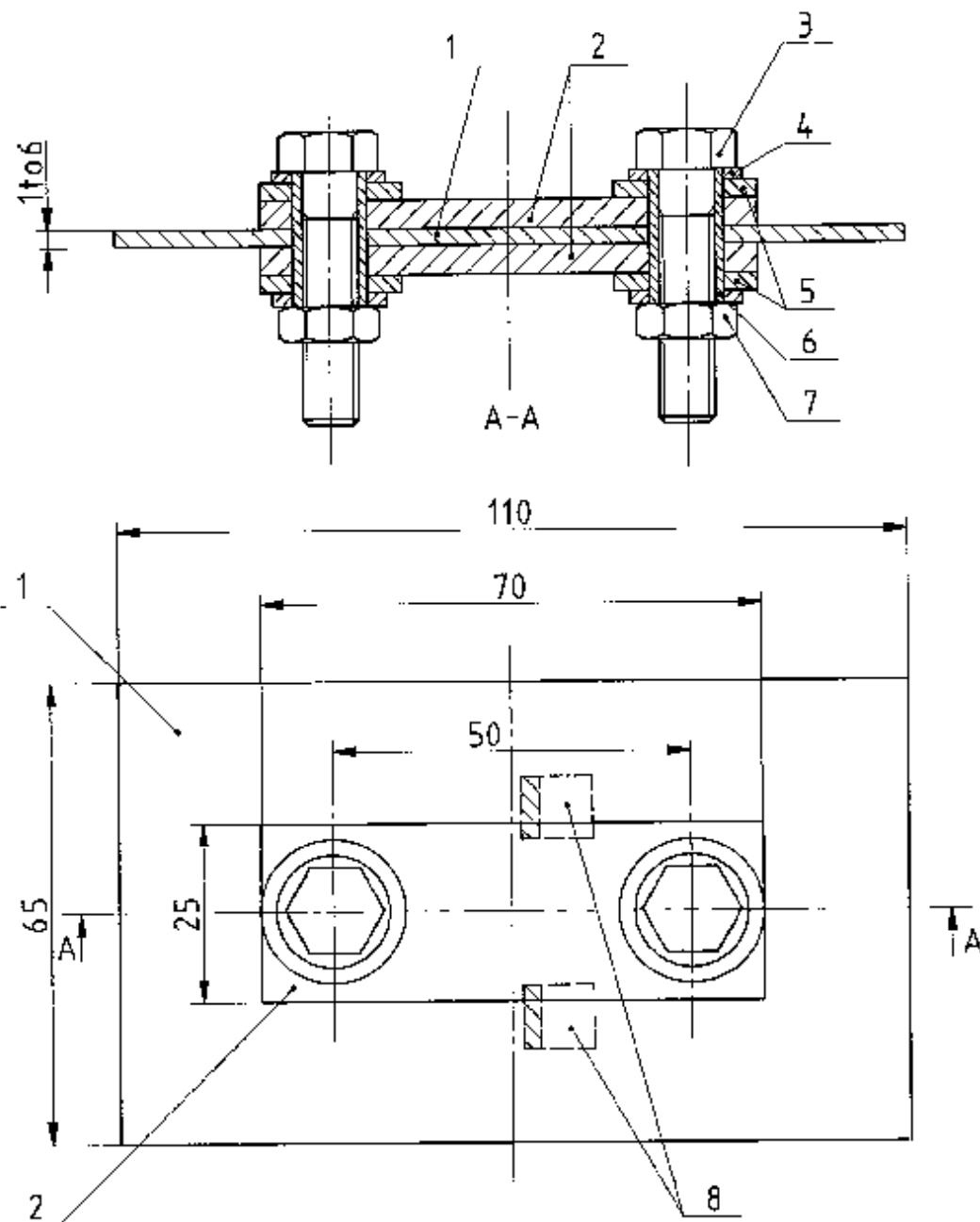


- |                         |                                                                |
|-------------------------|----------------------------------------------------------------|
| 1 Anodic plate          | 6 Washer, thickness 1 mm, diameter 16 mm                       |
| 2 Cathodic plate        | 7 Insulating washer, thickness 1 to 3 mm, diameter 18 to 20 mm |
| 3 Microsections         | 8 Insulating sleeve                                            |
| 4 Tensile test specimen | 9 Nut                                                          |
| 5 Bolt 8 mm x 40 mm     |                                                                |

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



Dimensions in millimetres



- 1 Anodic plate
- 2 Cathodic plate
- 3 Bolt 8 mm  $\times$  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 evaluations based on criteria other than change in mechanical properties

## Annex A

## Inventory of specimens

Designation of metallic plates	Anodic	
	Cathodic	
Serial number of metallic plates	Anodic	
	Cathodic	
	Control	
	Reference specimen	
Characteristics of metallic plates (type of metal, thermal treatment)	Anodic	
	Cathodic	
Dimension of metallic plates, mm	Anodic	
	Cathodic	
Surface condition	Anodic	
	Cathodic	
Type of coating, thickness, mm	Anodic	
	Cathodic	
Type of specimen coating in assembly		
Test site		
Date of start of test and angle of exposure of specimen		
Date of removal		

## Annex B

Form for recording test results for evaluations  
based on change in surface appearance

Date of examination	
Marking on anodic plate	
Indices of appearance of anodic plates	Tarnishing
	Colour and other characteristics of corrosion products
	Distribution of corrosion effect (uniform, non-uniform, continuous, local)
	Maximum size of corrosion effect, mm
	Amount of corrosion effect per square centimetre, $n_1$
	Corroded area in the zone of bimetallic corrosion, $S_1$ , %
Marking on reference specimens	
Indices of appearance of reference specimens	Tarnishing
	Colour and other characteristics of corrosion products
	Distribution of corrosion effect (uniform, non uniform, continuous, local)
	Maximum size of corrosion effect, mm
	Amount of corrosion effect per square centimetre, $n_2$
	Corroded area, $S_2$ , %
Corrosion increase index	Ratio of amount of corrosion effects, $n_1/n_2$
	Ratio of corroded areas, $S_1/S_2$

## Annex C

Form for recording test results for  
evaluations based on the depth of corrosion effect

Marking	Anodic plate of test specimen		
	Reference specimen		
Corrosion depth	Face	In the zone of bimetallic corrosion	Mean value of five deepest, $h_{f,1}$ , mm
		On reference specimen	Mean value of five deepest, $h_{f,2}$ , mm
		Corrosion increase index	$h_{f,1}/h_{f,2}$
	Reverse	In the zone of bimetallic corrosion	Mean value of five deepest, $h_{r,1}$ , mm
		On reference specimen	Mean value of five deepest, $h_{r,2}$ , mm
		Corrosion increase index	$h_{r,1}/h_{r,2}$
Type of corrosion	In the zone of bimetallic corrosion On reference specimen		

## Annex D

Form for recording test results for evaluations  
based on changes in mechanical properties

<b>Marking</b>	Control specimen _____	
	Anodic plate of test specimen _____	
	Reference specimen _____	
<b>Mechanical properties of control specimens</b>	$R_{m,c}$ MPa	_____
	$R_{p,0,2}$ MPa	_____
	$A_{0r}$ %	_____
<b>Mechanical properties of anodic plates of test specimens</b>	$R_{m,t}$ MPa	_____
	$R_{p,t,0,2}$ MPa	_____
	$A_{1t}$ %	_____
<b>Mechanical properties of reference specimens</b>	$R_{m,r}$ MPa	_____
	$R_{p,r,0,2}$ MPa	_____
	$A_{1r}$ %	_____
<b>Relative change of mechanical properties of anodic plates of test specimens</b>	$K_{R_{m,t}}$ %	_____
	$K_{R_{p,t}}$ %	_____
	$K_{A_{1t}}$ %	_____
<b>Relative change of mechanical properties of reference specimens</b>	$K'_{R_{m,r}}$ %	_____
	$K'_{R_{p,r}}$ %	_____
	$K'_{A_{1r}}$ %	_____
<b>Corrosion increase index in the zone of bimetallic corrosion</b>	$K_{R_{m,t}} - K'_{R_{m,r}}$	_____
	$K_{R_{p,t}} - K'_{R_{p,r}}$	_____
	$K_{A_{1t}} - K'_{A_{1r}}$	_____

## Annex E

Form for recording test results  
for evaluations based on loss in mass

Marking	Anodic plate of test specimen
	Reference specimen
Test duration, years	
Surface area of anodic plate, $S_1$ , m <sup>2</sup>	
Surface area covered by cathodic plate (one side), $S_2$ , m <sup>2</sup>	
Surface area of reference specimen, $S_3$ , m <sup>2</sup>	
Mass of anodic plate, g	Before testing
	After testing
	Loss in mass, $\Delta m_1$
Mass of reference specimen, g	Before testing
	After testing
	Loss in mass, $\Delta m_2$
Rate of corrosion of anodic plate, $K_1$ , g/(m <sup>2</sup> ·year)	
Rate of corrosion of reference specimen, $K_2$ , g/(m <sup>2</sup> ·year)	
Corrosion increase index in the zone of bimetallic corrosion, $K_1/K_2$	