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Second edition
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# Corrosion of metals and alloys — Stress corrosion testing —

## Part 10: Reverse U-bend method

*Corrosion des métaux et alliages — Essais de corrosion sous contrainte —*

*Partie 10: Méthode d'essai par cintrage en U inversé*



Reference number
ISO 7539-10:2020(E)

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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 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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This document was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 262 *Metallic and other inorganic coatings, including for corrosion protection and corrosion testing of metals and alloys*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 7539-10:2013), which has been technically revised. The main changes compared with the previous edition are as follows:

— the specimen preparation, i.e. how RUB specimens are machined, bent and fastened, has been revised in Clause 5 and Annexes A and B;

— the experimental procedure of how specimens are tested in a multiple immersion test with different periods or in a serial immersion test has been revised in Clause 6;

— the post-exposure evaluation of how specimens are observed has been revised in Clause 7;

— information has been added for the test report in Clause 8;

— Figures A.1, A.2 and B.3 and Table B.1 have been revised;

— new Figures A.3 and B.4 have been added to illustrate the RUB specimen before and after fastening.

A list of all parts in the ISO 7539 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Corrosion of metals and alloys — Stress corrosion testing —

## Part 10: Reverse U-bend method

**WARNING — This document can involve hazardous materials, operations and equipment. It is the responsibility of the user of this document to consult and establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.**

## 1 Scope

This document specifies procedures for designing, preparing and using reversed U-bend (RUB) test specimens for investigating the susceptibility of the metal to stress corrosion cracking. The term "metal" as used in this document includes alloys.

## 2 Normative references



The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 7539-1, *Corrosion of metals and alloys — Stress corrosion testing — Part 1: General guidance on testing procedures*



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

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7539-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

## 4 Principle

The RUB test is a particularly severe test for assessing susceptibility to stress corrosion cracking. The test is intended primarily for application to metals with high corrosion resistance, such as Ni-based alloys, with the advantage, compared to methods such as the conventional U-bend test, of having significantly less stress relaxation. It is used primarily as a screening test for tubing, piping, plate, bar and other products including welded materials. It may also be used as an acceptance test for performance in service subject to agreement between the parties.

The principle of the test is to introduce very severe stresses in a high corrosion resistance metal, with minimum relaxation, in order to enhance the likelihood of inducing stress corrosion cracking.

The test involves exposing a piece of metal of a semi-circular section bent back on itself (i.e. reversed bent) into a U-shape to the corroding medium and holding it in a manner that ensures that there are initial tensile stresses in excess of the yield strength over a large proportion of the inner surface. The test is accelerated by the presence of complex bi-axial stresses that may or may not exist in service. In the act of forming specimens, varying amounts of cold work may be introduced, and this deformation can influence the stress corrosion cracking tendency as compared to that of the material in the original condition.

The test is normally performed in a laboratory by exposing the specimens to simulated service conditions.

A further objective of the test is to compare and evaluate the influence of different material parameters.

The principal advantages of the test are its simplicity and its ability to provide a rapid screening. If conventional U-bend or C-ring specimens are used for screening tests in a high temperature solution of 573 K or higher, marked stress relaxation occurs and a long testing time is needed for the evaluation. However, the stress relaxation in RUB specimens is smaller than that in conventional U-bend and C-ring specimens, due to the bi-axial stresses in RUB specimens. Therefore, screening tests can be done within a relatively short time through the use of RUB specimens.

A disadvantage is that the stress state is complicated and is difficult to quantify with accuracy. If an accurate stress state is desired, an alternative method should be used.

Wide variations in test results can be obtained for a given metal and environment even when testing nominally identical specimens and the replication of tests is frequently necessary.

If specimens are prepared from tubing of different dimensions or are subjected to different stressing procedures, test results can be even more variable.



# 5 Specimens

## 5.1 General



RUB specimens are prepared from pieces of production tubing, piping and other hollow cylindrical products cut into half longitudinally or from a plate, bar or other products formed into a semi-circular shape along the axial direction. The specimens should be cut by sawing or other such methods that do not affect the material properties. Then they should be shaped into their dimensions by machining. The side face of the specimens should be deburred and then finished by sequentially coarse-to-fine grinding using abrasive papers or cloths to a surface finish such as P600 (see ISO 3366 or ISO 21948) without increasing the temperature of the specimens.

Two-stage stressing consisting of bending and fastening with a loading bolt should be performed for RUB specimens. Elastic-stress relief should be avoided during fastening RUB specimens with a loading bolt.

## 5.2 Preparation of RUB specimens

### 5.2.1 Tubing and piping

A variety of tube dimensions and specimen sizes can be employed. The tube is cut to selected specimen lengths and then sectioned axially to produce specimens with a semi-circular section.

The tubing shall retain its original surface finish.

If heat treatment is added, final heat treatment shall be performed before the reverse U-bending process (and pre-straining, if this is adopted).

### 5.2.2 Other products

A variety of bar stock, plate and other forged or rolled material or welded material can be employed. These materials shall be machined into a plate after final heat treatment and pressed into a semi-circular shape between inner and outer formers. The surface of the specimens shall be finished by sequentially coarse-to-fine grinding using abrasive papers or cloths up to a surface finish such as P600 (see ISO 3366 or ISO 21948) without increasing the temperature of the specimens before the pressing process. Specimen preparation from a plate is shown in Annexes A and B.

When testing welds, consideration shall be given to the orientation of the weld relative to the longitudinal axis of the specimen and this shall be noted. Tests may be conducted on the weld metal itself or on sections containing the weld metal and heat-affected zone.

#### 5.2.3 Reverse U-bending process

During bending, deformation of the half tube may be constrained by the forming jig to force it to maintain its semi-circular cross-section or its sides may be allowed to deform freely, in which case it can tend to flatten at the apex. Both methods may be used. The latter procedure results in lower stresses but has the advantage of avoiding cracking at the edges. The former type specimen is called the “half tube RUB specimen”, and the latter type specimen is called the “RUB specimen with a gauge section”.

When testing RUB specimens with a gauge section, pre-straining can be used to achieve the desired stress level. The stresses generated in the RUB specimens with a gauge section during reverse U-bending are lower without pre-straining because of reduced constraint.

Examples of the preparation of non-pre-strained half tube RUB specimens are shown in Annex A.

Examples of the preparation of non-pre-strained and pre-strained RUB specimens with a gauge section are shown in Annex B.

The apex of the pressing template has a concave curve where the curvature is suited to the external diameter of the half tube, while the rolls have a convex curve where the curvature is suited to the internal diameter of the half tube.



Only RUB specimens that do not crack at the apex when bent should be adopted.



### 5.3 Fastening RUB specimens with a loading bolt

When fastening specimens with a loading bolt after a bending operation, care shall be taken to ensure that the deflection due to the fastening operation is restored beyond that reached at the end of the bending operation. RUB specimens should be stressed using a vice bench as the final stage of the bending operation before fastening the specimen to align its legs by attaching them with nuts and bolts. The final distance between the specimen’s legs at the loading bolt shall be approximately 1 mm less than the minimum distance during the bending operation. The final distance should be the same for all specimens in a given series. Loosening after loading should be avoided. To obtain consistency, a micrometer measuring device should be used.

The bolting material should have a similar or lower coefficient of thermal expansion to that of the specimen. Washers with a curved surface should be used to avoid non-uniform loading on the specimen during the screwing of the bolt. The washers help to keep the same contact point on the bolt-holes of a specimen. In addition, the use of double nuts to reduce the likelihood of loosening of the bolts is recommended.

Bolting material that avoids galvanic corrosion with RUB specimens and is resistant to corrosion in the environment should be selected. In a high-pH environment, the same material as RUB specimens can be adopted, but zirconia should not be adopted. In high-temperature water, the use of oxidized zircaloy washers for insulation is recommended.

## 6 Experimental procedure

If more than one metal is present in a system, electrical insulation of the specimen may be necessary to avoid galvanic corrosion, depending on the test environment. Where insulation is used, the insulating material shall not deform during the test. Ceramic insulating materials are suitable provided that they are compatible with the test conditions.

Specimens shall be degreased using a solvent such as acetone. Then they shall be rinsed with distilled water or ethanol and dried prior to testing. They should be handled with care thereafter.

Specimens shall be examined, after forming, for cracks that could have developed before exposure to the test environment. It may also be desirable to prepare additional specimens, which are stressed but not exposed to the test environment, for use as controls for later comparison.

Where it is necessary to mark the specimen for purposes of identification, the methods given in ISO 7539-1 should be followed.

As soon as possible after degreasing, stressing and inspection, the specimens should be put on test.

Multiple specimens shall be tested for one condition in order to chart damage development over time. Typically, two methods shall be applied. One is a multiple immersion test with different periods and the other is a serial immersion test.

In the multiple immersion test, multiple sets of specimens are tested for different exposure periods. Cracks are detected by inspection after the immersion test. It can be useful to test a sufficient number of identical specimens for statistical evaluation at each exposure time. On test completion, the specimens shall be rinsed with distilled water or ethanol and dried. Destructive inspection can be applied to detect cracks. If required, a suitable cleaning method in accordance with ISO 8407 shall then be used to allow observation of possible cracks.

In the serial immersion test, specimens are repeatedly observed by non-destructive inspection after lapses of certain times until a crack is detected in the test. Before the inspection, the specimens shall be rinsed with distilled water or ethanol and then dried. The test time for a specimen is defined as the accumulated period over which the specimen is tested in a test environment. It can be useful to test a sufficient number of identical specimens for statistical evaluation. The serial immersion test is a more effective evaluation of the inspection time for crack detection with limited specimens than the multiple immersion test.



Generally, it takes time for the corrosion potential of specimens to return back to their previous potential in an environment after restarting the immersion test because oxide film on the specimens is transformed in the atmosphere. This can result in a crack-initiation time different from the immersion test without intermediate inspections. When the time to return back to the previous potential is so short that it can be negligible compared with the immersion test time, the serial immersion test can be carried out without considering the effect of intermediate inspections. A thin solid oxide film formed on surface of high corrosion resistant alloys such as alloys 600 and 690 is hardly transformed in the atmosphere after taking out from the environment. Additionally, the corrosion potential returns back to the previous potential after several hours in the environment, e.g. a simulated primary water environment (PWR).

## 7 Post-exposure evaluation

Before specimens are examined, it is necessary to check that a failure or loosening of the loading bolt has not invalidated the test.

Preliminary examination of specimens for evidence of cracks is by predetermined, non-destructive observation methods such as a general visual inspection or a 10-to 40-fold magnification optical microscopy without loosening the loading bolt after rinsing the specimen with distilled water or ethanol and drying it.

If specimens are returned to the test environment in the serial immersion test, loosening of the loading bolt and destructive inspection should be avoided. The removal of corrosion products and the electric charging of the surface by electron microscopy change the conditions of corrosion phenomena.

High-magnification observation by scanning electron microscopy or optical microscopy on metallographically prepared cross-sections may be useful in checking to confirm that a specimen does not contain any cracks.

Any cracking observed, unless positively proved to have occurred for some reason other than stress corrosion cracking, should be considered as indicative of failure.

The test should be regarded as basically a "pass/fail" test and minor differences in behaviour, e.g. in time to first crack detection or in size of crack, should not be considered as significant.

Presentation of the results by means of statistical analysis methods such as Weibull statistics is recommended, i.e. plotting the cumulative number of failures as a function of time.

## 8 Test report

The test report shall include the following information:

a) a full description of the test material, including chemical composition, heat treatment and microstructural condition;

b) the International Standard used (including its year of publication);

c) tubing dimensions, specimen sizes and, if specimens were pre-strained, pre-strains;

d) a full description of the test environment;

e) the inspection procedure, including the type of microscope and magnification;

f) the time at which observations were made and when cracks became visible;

g) a description of the statistical methods used for the evaluation;

h) any deviations from the procedure;

i) any unusual features observed;

j) the starting and ending date of the test.

# Annex A
(informative)

# Preparation of non-pre-strained half tube RUB specimens

The half tube is forced to maintain its original semi-circular cross-section (See Figure A.1).

Two-stage stressing involves the following (see Figure A.2).

a) The cutting of a half tube with two holes for the maintaining screw.

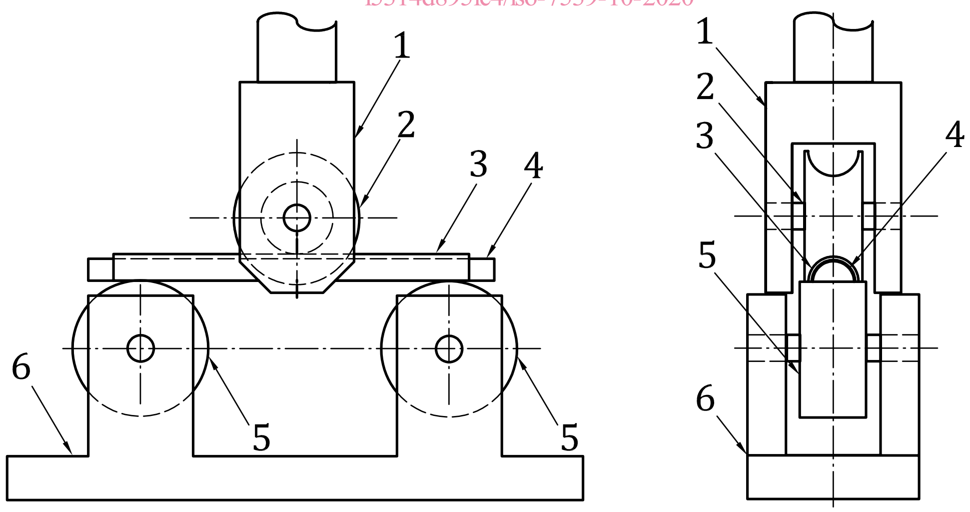
b) The cutting of a half rod of carbon steel or stainless steel used to maintain the semi-circular cross-section of the half tube during the bending operation.

c) The bending of the half tube to an angle of approximately 45° between its legs using a template and a tensile testing machine. A thin sheet of paper can be inserted between the half tube and the half rod to prevent the latter from polluting the half tube inner surface during the close friction generated by the bending operation.

d) The elimination of the half rod and the use of a vice to bring the half tube legs to a parallel position. RUB specimens should be stressed using a vice before fastening the specimen to align its legs by attaching them with nuts and bolts. The final distance, $L$, between the specimen's legs at the loading bolt shall be approximately 1 mm less than double the bend radius, $R_{RUB}$. The difference between twice $R_{RUB}$ and $L$ should not be more than 2 mm (see Figure A.3).

e) The legs are fastened with a screw and washers made of an appropriate material for avoiding galvanic corrosion with RUB specimens and for resisting corrosion in the environment. Zirconia is suitable for insulating washers in high-temperature water but is not used in high-pH environments.



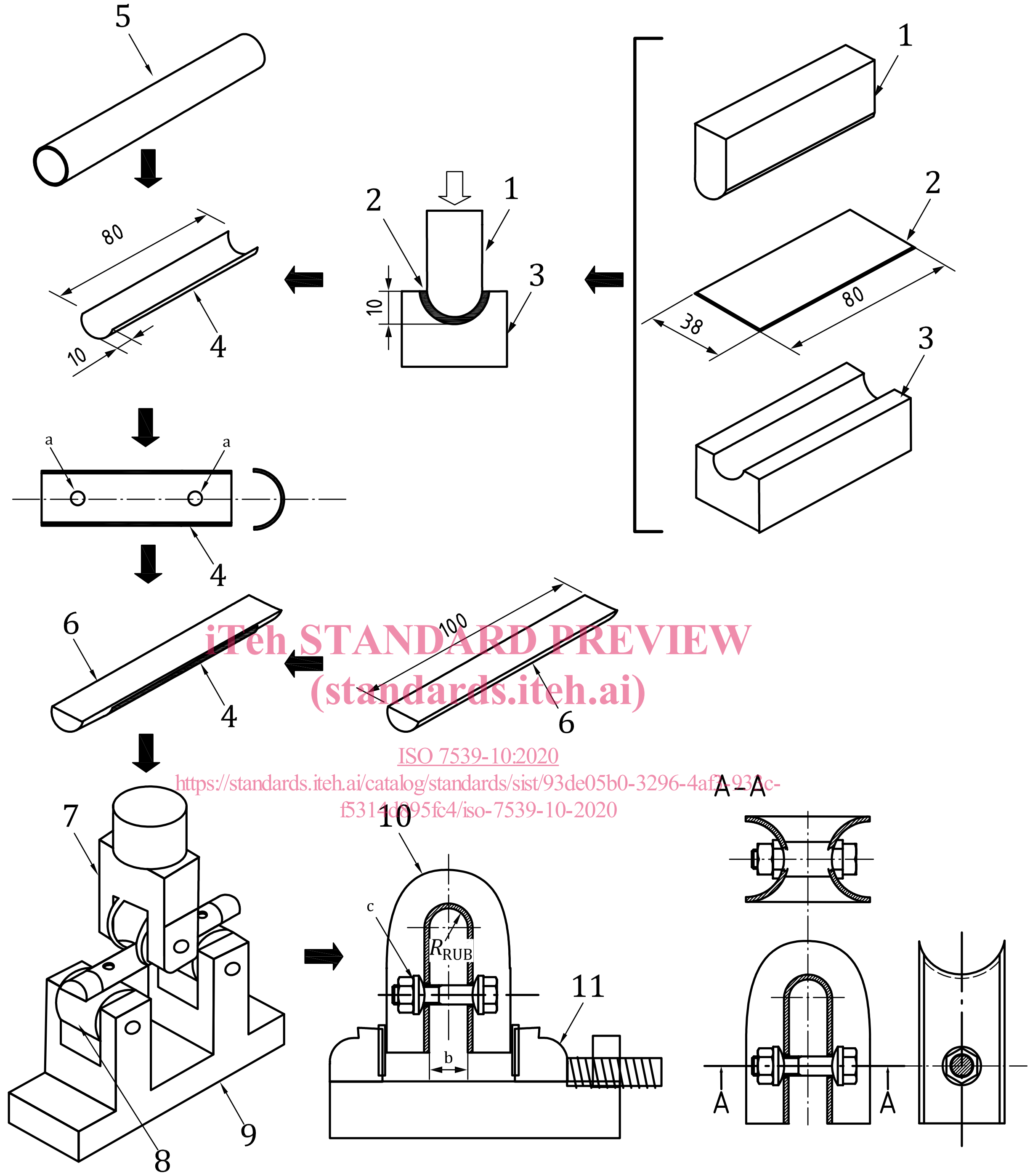



**Key**

1 template
2 outer former
3 half tube
4 half rod (support material)
5 rolls
6 body

**Figure A.1 — Schematic drawing of the bending apparatus for non-pre-strained half tube RUB specimen**

Dimensions in mm






**Key**

| | | | |
|---|---|---|---|
| 1 | outer former | 8 | roll |
| 2 | platelet material | 9 | body |
| 3 | inner former | 10 | RUB specimen |
| 4 | half tube | 11 | vice |
| 5 | tube material | a | Machining hole. |
| 6 | half rod (support material) | b | Bending parallel with both end of half tube. |
| 7 | template | c | Fastening after parallel. |

**Figure A.2 — Preparation of a non-pre-strained half tube RUB specimen from tubular and plate specimen**