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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 par pliage en U inverse

Reference number
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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.*

ISO 7539 consists of the following parts, under the general title *Corrosion of metals and alloys — Stress corrosion testing:*

— *Part 1: General guidance on testing procedures*

— *Part 2: Preparation and use of bent-beam specimens*

— *Part 3: Preparation and use of U-bend specimens*

— *Part 4: Method for the preparation and use of uniaxially loaded tension specimens*

— *Part 5: Preparation and use of C-ring specimens*

— *Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement*

— *Part 7: Method for slow strain rate testing*

— *Part 8: Preparation and use of specimens to evaluate weldments*

— *Part 9: Preparation and use of pre-cracked specimens for tests under rising load or rising displacement*

— *Part 10: Reverse U-bend test method*

— *Part 11: Guidelines for testing the resistance of metals and alloys to hydrogen embrittlement and hydrogen-assisted cracking*

Corrosion of metals and alloys — Stress corrosion testing —

Part 10:
Reverse U-bend method

WARNING — — This International Standard may involve hazardous materials, operations, and equipment. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1 Scope

This part of ISO 7539 covers 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 standard includes alloys.

2 Normative reference

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. Members of IEC and ISO maintain registers of currently valid International Standards.

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.

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 consists of exposing to the corroding medium a piece of metal of semicircular section bent back on itself (i.e. reversed bent) into a U-shape and held in a manner which 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 may influence the stress corrosion cracking tendency as compared to that of the material in the original condition.

The test is normally performed in the 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 rapid screening: if conventional U-bend or C-ring specimens are used for screening tests in high temperature solution as 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 may 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 may 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 plate, bar or other products formed into a semicircular shape along the axial direction. In this case, forming of the specimen should be followed by a heat treatment to relieve residual stresses before undertaking the reversed U-bending process.

5.2 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.

During bending, deformation of the tube half may be constrained by the forming jig to force it to maintain its semicircular cross-section or its sides may be allowed to deform freely in which case it may 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 named as “Half tube RUB specimen”, and the latter type specimen is named as “RUB specimen with a gauge section”, in this standard.

When testing RUB specimens with a gauge section (in which the stresses generated during reverse bending are lower because of reduced constraint), pre-straining can be used to achieve the desired stress level.

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

Final heat treatment shall be performed before bending (and pre-straining if this is adopted).

Either single-stage or two-stage stressing may be performed. In single-stage stressing the specimen is not allowed to spring back after bending before final stressing. In two-stage stressing the specimen is allowed to spring back after bending before final re-stressing.

When stressing specimens with a loading bolt after forming, care should be taken to ensure that the deflection is restored beyond that pertaining at the end of the forming operation. The final distance between the specimen legs at the loading bolt shall be at least 1 mm less than that at the end of the forming operation. The final separation of the legs should be the same for all specimens in a given series; overloading 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. In addition, the use of double nuts to reduce the likelihood of loosening of the bolts is recommended.

5.3 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 semicircular shape between inner and outer formers. 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.

Either single-stage or two-stage stressing may be performed. In single-stage stressing the specimen is not allowed to spring back after bending before final stressing. In two-stage stressing the specimen is allowed to spring back after bending before final re-stressing.

When stressing specimens with a loading bolt after forming, care shall be taken to ensure that the deflection is restored beyond that pertaining at the end of the forming operation. The final distance between the specimen legs at the loading bolt shall be at least 1 mm less than that at the end of the forming operation. The final separation of the legs should be the same for all specimens in a given series; overloading 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. In addition, the use of double nuts to reduce the likelihood of loosening of the bolts 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 effects, 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 prior to testing and should be handled with care thereafter.

Specimens shall be examined, after forming, for cracks that may 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.

Usually a series of specimens is tested for different exposure periods in order to chart the development of damage with time.

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. If required, a suitable cleaning method (ISO 8407) shall then be used to allow observation of possible cracks.

7 Post-exposure evaluation

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

Preliminary examination of specimens for evidence of cracks is generally by eye or by optical microscopy. In laboratory tests replicate specimens are frequently used to facilitate periodical examination and to determine the exposure time when cracks are first observed.

In order to make sure that a specimen does not contain any cracks, it is necessary to use scanning electron microscopy or high-magnification microscopy on metallographically prepared cross-sections. Dye penetrant inspection test may be useful for easy detect the small cracks.

Since some cracks may have origins other than stress corrosion cracking, it is necessary, if cracks are detected, to examine similarly stressed specimens that have not been exposed to the corroding environment for comparison.

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, 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) Tubing dimensions, specimen sizes and pre-straining, bending, and stressing procedures;

c) A full description of the test environment;

d) The inspection procedure, including type of microscope and magnification;

e) The times at which observations were made and when cracks became visible;

f) A description of the statistical methods used for the evaluation.

Annex A
(informative)

Preparation of non-pre-strained half tube RUB specimen

The half tube is forced to maintain its original semicircular cross-section (see Figure A.1).

Two-stage stressing (see Figure A.2):

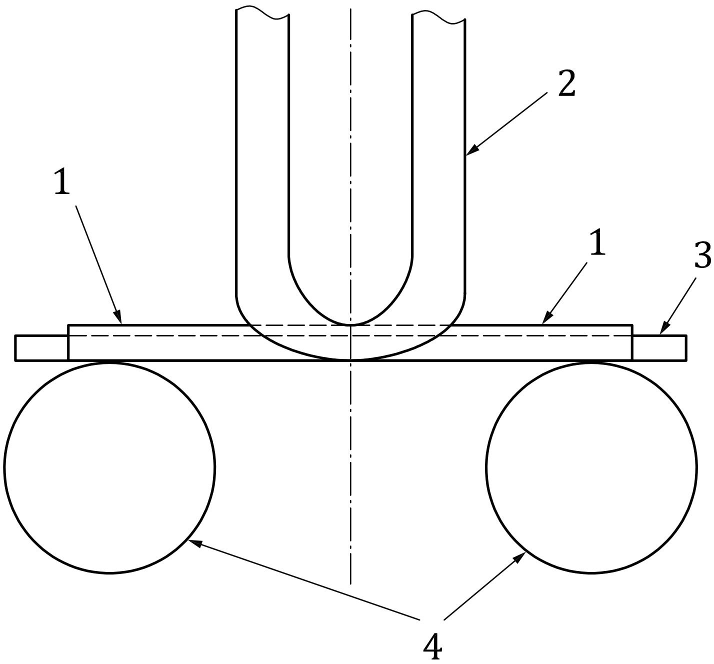
a) Cutting of a "half-tube" with two holes for the maintaining screw;

b) Cutting of a "half-rod" of carbon steel used to maintain the semicircular cross-section of the half tube during the bending operation.

c) Bending of the half tube to an angle of 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) Elimination of the carbon steel rod and use of a vice to bring the half tube legs to a parallel position;

e) Fastening of the legs with a screw provided with insulating washers made of oxidized Zircaloy.



Key

1 half tube

2 template

3 half rod

4 rolls

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

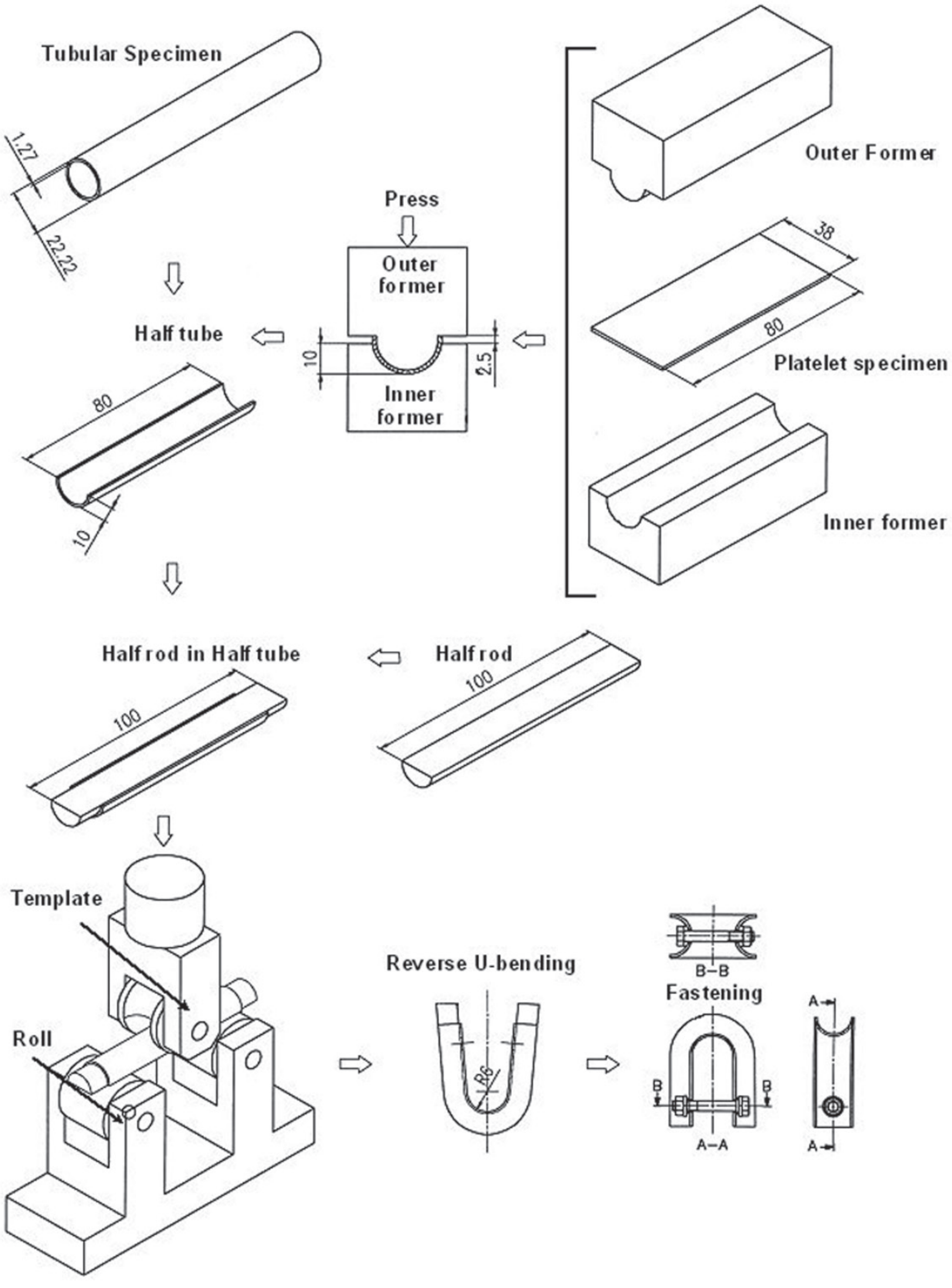


Figure A.2 — Preparation of a half tube RUB specimen from tubular and plate material (Unit: mm)

Annex B
(informative)

RUB specimens with a gauge section

B.1 Preparation of a RUB specimen with a gauge section:

a) Machining of a tensile type specimen with two holes for the maintaining screw (Figure B.1);

b) Optional: 0, 5, 10, 15, 20 or 25 percent pre-straining of the tensile type specimen with a tensile testing machine;

c) Bending of the pre-strained tensile specimen using the template and tensile testing machine (Figures B.2 and B.3);

d) Elimination of the carbon steel rod and use of a vice to bring the legs to parallel position;

e) Fastening of the legs: in doing so, galvanic coupling shall be avoided using either fasteners of the same alloy as the specimen or insulating the specimen from the fastener (Figures B.2 and B.3).

B.2 Features of pre-strained RUB specimens with a gauge section:

a) Scatter of residual stress at the top of RUB specimens with a gauge section is very small;

b) Scatter of cracking detection time in the stress corrosion cracking test by pre-strained RUB specimens with a gauge section is very small for not only tubing but also other products, as shown in Table B.1.

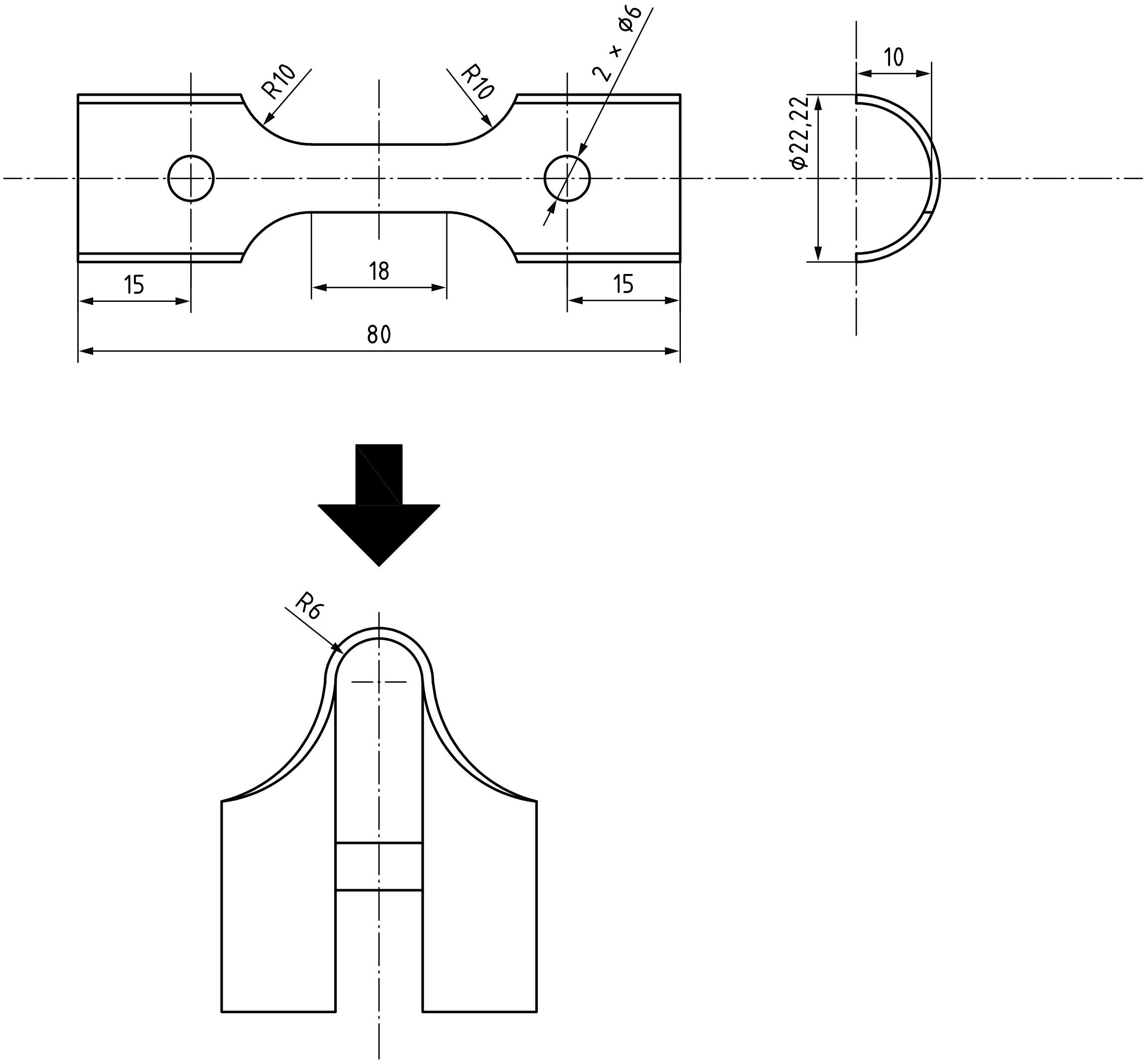
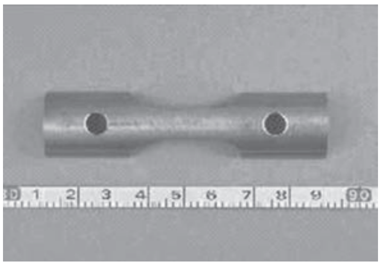
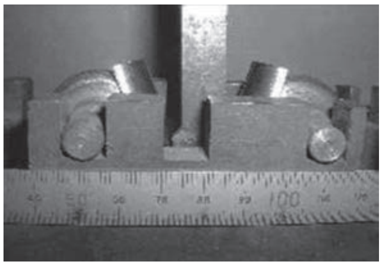


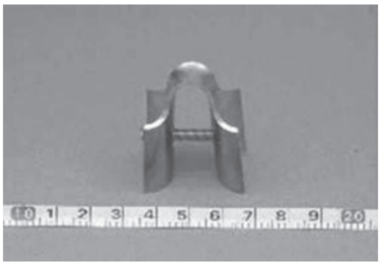
Figure B.1 — Pre-strained RUB specimen with a gauge section (Unit: mm)



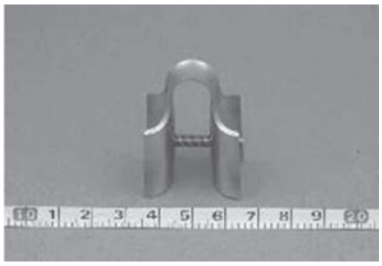
a) Tensile type specimen



b) Reverse U-bending



c) Non-pre-strained RUB specimen with a gauge section



d) Pre-strained RUB specimen with a gauge section

Figure B.2 — Preparation of pre-strained and non-pre-strained RUB specimen with a gauge section (Unit: mm)

Table B.1 — Stress corrosion cracking test results on RUB specimens with a gauge section

Material				SCC Test condition			Test results	
	C (%)	Heat treatment		Temp. (K)	Pre-straining (%)	Applied stress [a] (MPa)	Last inspection time before crack detection (h.)	Inspection time of crack detection (h.)
		Mill anneal	Thermal treatment					
Alloy 600 Tube 19 mm Outer-Diameter	0,027	1248K	-	633K	0	549	3568	4569
							3568	4569
							3568	4569
					5	598	832	1616
							832	1616
							832	1616
					10	774	500	832
							500	832
							500	832
					15	794	200	500
							300	832
							200	500
					20	823	100	300
							100	300
							100	300
		1193K	973K×15 h	633K	0	549	12300	-
							12300	-
							12300	-
					5	598	10700	-
							5581	6200
							10700	-
					10	774	2568	3068
							1085	2067
							3068	3568
					15	794	832	1616
							1616	2067
							500	1085
					20	823	500	832
							500	832
							500	832
Alloy 600 Plate 1,3mm t	0,026	1173K	-	633K	20	823	250	500
							250	500
							250	500

[a] Stress at the top of RUB specimens was measured by X-ray diffraction technique after fastening-

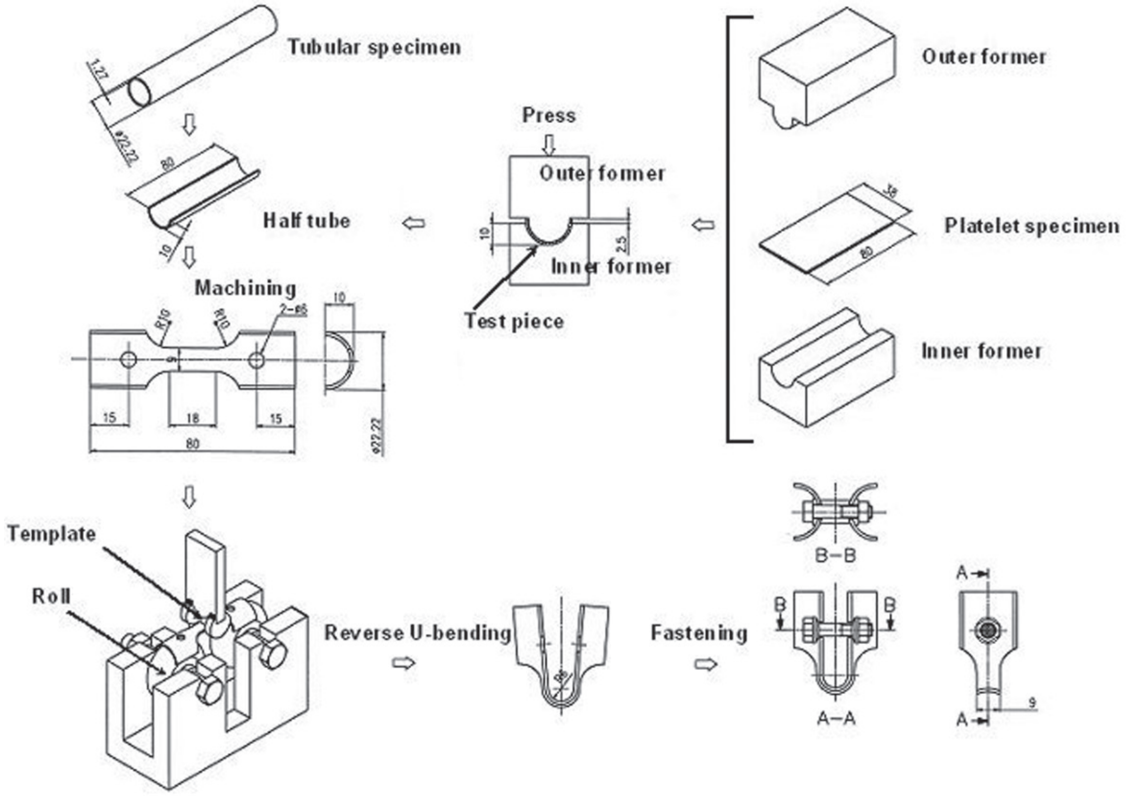


Figure B.3 — Preparation of RUB specimen with a gauge section from tubular and plate specimen (unit: mm)

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