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Corrosion of metals and alloys — Stress corrosion testing —

Part 5:
Preparation and use of C-ring specimens

Corrosion des métaux et alliages — Essais de corrosion sous contrainte —
Partie 5: Préparation et utilisation des éprouvettes en forme d'anneau en C

Reference number
ISO 7539-5 : 1989 (E)

Foreword

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

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 7539-5 was prepared by Technical Committee 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: 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*
- *Part 7: Slow strain rate testing*
- *Part 8: Preparation and use of welded specimens*

Annex A forms an integral part of this part of ISO 7539.

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Introduction

This part of ISO 7539 is one of a series giving procedures for designing, preparing and using various forms of test specimen to carry out tests to establish a metals resistance to stress corrosion.

Each of the standards in the series needs to be read in association with ISO 7539-1. This helps in the choice of an appropriate test procedure to suit particular circumstances as well as giving guidance towards assessing the significance of the results of the tests.

Corrosion of metals and alloys — Stress corrosion testing —

Part 5: Preparation and use of C-ring specimens

1 Scope

1.1 This part of ISO 7539 covers procedures for designing, preparing, stressing, exposing and inspecting C-ring test specimens for investigating the susceptibility of a metal to stress corrosion. Analysis of the state and distribution of stress in the C-ring is presented.

The term "metal" as used in this part of ISO 7539 includes alloys.

1.2 The C-ring is a versatile, economical specimen for determining the susceptibility to stress corrosion cracking of all types of metals in a wide variety of product forms including parts joined by welding. It is particularly suitable for tests of tube, rod and plate (see figure 1). Notched specimens may also be used (see 5.3.8).

1.3 C-ring specimens may be stressed to predetermined levels, using simple equipment for application of either constant load or constant strain.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 7539. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 7539 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7539-1 : 1987, *Corrosion of metals and alloys — Stress corrosion testing — Part 1: General guidance on testing procedures.*

ISO 7539-6 : 1989, *Corrosion of metals and alloys — Stress corrosion testing — Part 6: Preparation and use of pre-cracked specimens.*

3 Definitions

For the purposes of this part of ISO 7539, the definitions given in ISO 7539-1 are applicable.

4 Principle

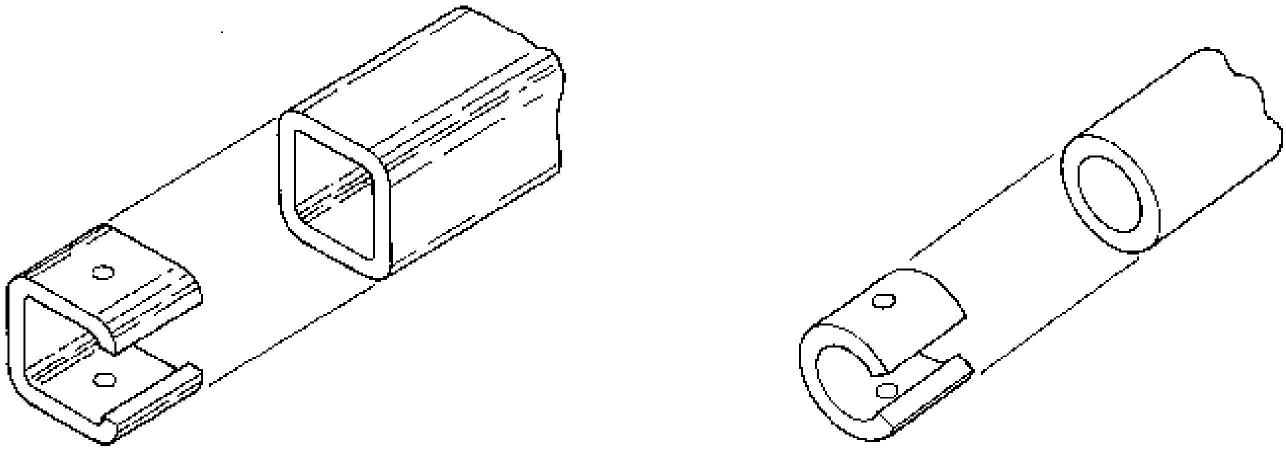
4.1 The test consists of subjecting a specimen to constant load or to constant strain with a view to determining stress corrosion susceptibility by reference to one or more of the parameters enumerated in clause 7.

4.2 Corrosive environments may cause a deterioration of the properties of stressed materials beyond those observed with the same combination of environment and material when the latter is not subjected to stress. This enhanced deterioration may be expressed in a number of different ways for the purpose of assessing stress corrosion susceptibility.

4.3 The commonest form of deterioration due to stress corrosion involves the initiation and growth of cracks, one or more of which may eventually lead to total failure of a specimen if the test is conducted for an appropriate time.

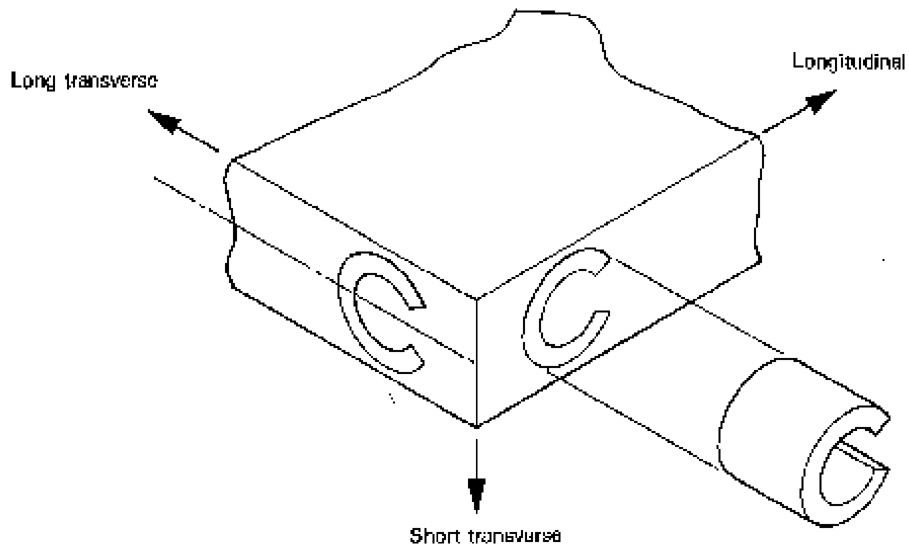
4.4 Wide variations in test results may be obtained for a given metal and environment even when testing nominally identical specimens and the replication of tests is frequently necessary. If specimens are prepared to different sizes or orientations or are subjected to different stressing procedures, test results may be even more variable.

4.5 The time required for cracks to appear after exposure of stressed specimens to the test environment or the threshold stress below which cracks do not appear can be used as a measure of the stress corrosion resistance of the material in the test environment at the stress level employed.



Tube

Rod and bar



Plate

Figure 1 — Sampling procedure for testing various products

5 Specimens

5.1 Specimen design

5.1.1 The size of C-rings may be varied over a wide range, but C-rings with an outside diameter less than 15 mm are not recommended because of increased difficulties in machining and decreased precision in stressing. The dimensions of the ring can affect the stress state, and these considerations are discussed in 5.2. Figure 2 is a drawing showing typical dimensions for the manufacture of a C-ring.

5.1.2 In testing thick sections that have a directional grain structure, it is essential that the C-ring should be orientated in the section so that the direction of the principal stress is normal to the plane of minimum resistance to stress corrosion cracking. If the ring is not so orientated it will tend to crack off-centre at a location where the stress is unknown and lower than the calculated stress (see 5.3.3). Appropriate instructions should therefore be given to workshop personnel. C-ring specimens may be used as notched or fatigue pre-cracked specimens, the stress states of which are considered in 5.3.8 for notched specimens and in ISO 7539-6 for pre-cracked specimens.

5.2 Stress considerations

5.2.1 The stress of principal interest in the C-ring specimen is the circumferential stress. This is not uniform: there is a gradient through the thickness, varying from a maximum in tension on one surface to a maximum in compression on the opposite surface. The stress varies also around the circumference of the C-ring from zero at each bolt hole to a maximum at the centre of the arc opposite the stressing bolt. The stress calculated according to annex A is present only along a line across the ring at the middle of the arc. Thus, if the stress is determined by measuring the strain on the tension surface of the C-ring, the strain gauge should be positioned at the middle of the arc in order to indicate the maximum strain. The stress varies across the width of the ring to an extent which depends on the width-to-thickness and diameter-to-thickness ratios. In general, if loaded as shown in figure 3a) and b), the tensile stress on the outer surface is greater at the edges than at the centre, while if loaded as shown in figure 3c), the tensile stress on the inner surface is less at the edges than at the centre.

5.2.2 Another characteristic of the stress system in the C-rings is the presence of biaxial stresses; that is, transverse as well as circumferential stresses are developed. The transverse axial stress varies from a maximum at the mid-width to zero at the edges, and has the same sign as the circumferential stress. In general, the transverse stress decreases with decreasing width-to-thickness and increasing diameter-to-thickness ratios.

5.2.3 In the case of the notched C-ring a triaxial stress state is present adjacent to the root of the notch. In addition, the circumferential stress at the root of the notch will be greater than the nominal stress and generally may be expected to be in the plastic range.

5.2.4 When C-rings are machined from products that contain appreciable residual stress or are subjected to heat treatment involving quenching after being machined, internal stresses may be present. These may introduce errors in the calculated stress.

It is necessary to measure the tubing diameter before and after the axial cut is made and to use these measurements to calculate the residual stresses in the tube.

5.2.5 The possibility of relaxation during the exposure period should be considered, especially when specimens are exposed at elevated temperatures. Relaxation can be estimated if creep data are available for both the ring and the stressing bolt.

NOTE — If the ring and bolt have different coefficients of thermal expansion, the applied stress may be significantly changed when testing at elevated temperatures. Also, if plastic insulators are used to

Dimensions in millimetres

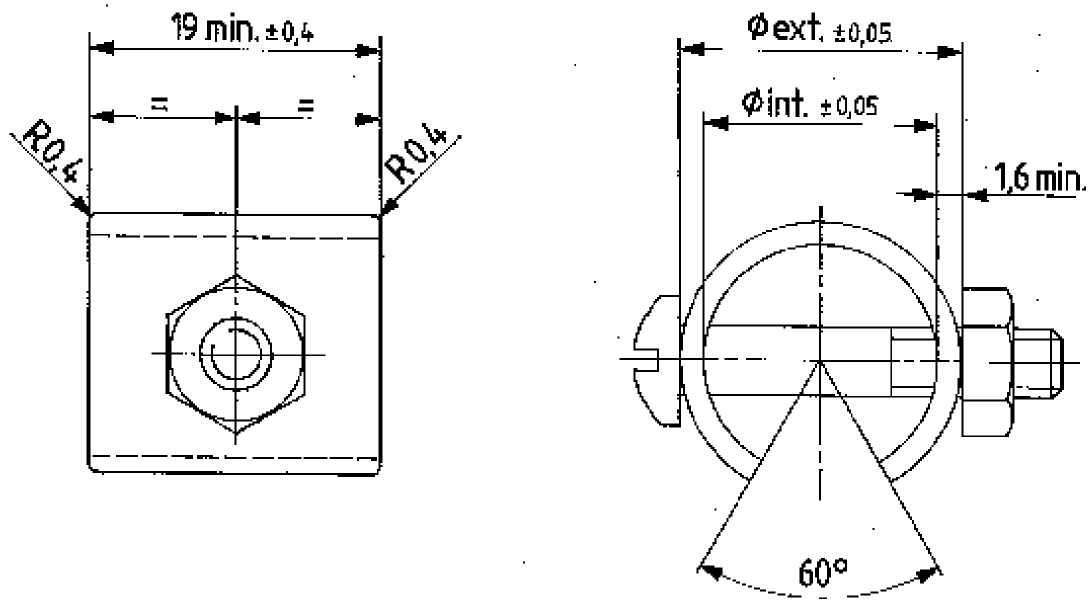


Figure 2 — Example of C-ring specimen

avoid galvanic corrosion, the possibility of stress relaxation should be anticipated.

5.3 Stressing methods

5.3.1 C-ring specimens are usually loaded under constant displacement conditions with tensile stress produced on the exterior of the ring by tightening a bolt centred on the diameter of the ring [see figure 3a)].

5.3.2 C-rings can alternatively be stressed in the reverse direction by spreading the ring and creating a tensile stress on the inside surface as in figure 3c) or, preferably, by the use of a wedge opening technique to displace the arms of the C-rings as in figure 4. In the latter case the necessary displacement is provided by inserting an accurately machined wedge of the same material as the C-ring, so avoiding galvanic effects. A suitable jig for inserting the wedge is shown in figure 4.

5.3.3 The C-ring test can be modified for approximately constant load conditions by the use of a suitably calibrated spring placed on the loading bolt [see figure 3b)].

5.3.4 The most accurate stressing procedure is to attach circumferential and transverse electrical strain gauges to the surface stressed in tension and to tighten the bolt until the strain measurements indicate the desired circumferential stress.

The circumferential σ_c and transverse σ_t stresses are calculated as follows provided that they are within the elastic range:

$$\sigma_c = \frac{E}{1 - \mu^2} (\varepsilon_c + \mu \varepsilon_t)$$

$$\sigma_t = \frac{E}{1 - \mu^2} (\varepsilon_t + \mu \varepsilon_c)$$

where

E is the modulus of elasticity, in newtons per square metre;

μ is Poisson's ratio;

ε_c is the circumferential strain;

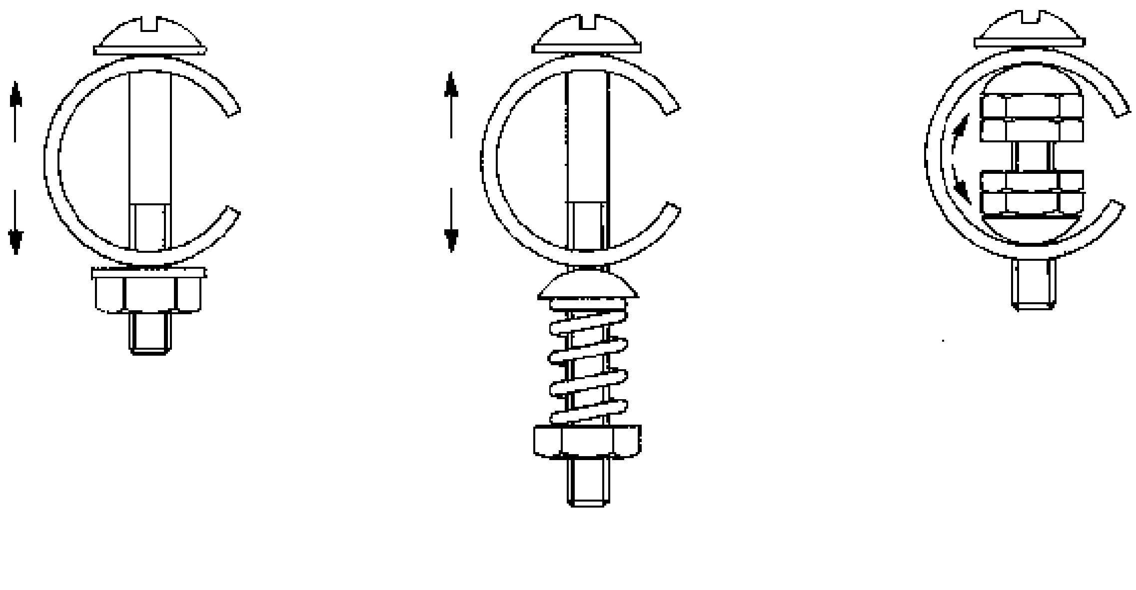
ε_t is the transverse strain.

When using electrical strain gauges on thin walled C-rings, a correction should be allowed for the displacement of the gauge from the surface of the ring. All traces of the gauge and adhesive must be removed from the C-ring before it is exposed.

Calculation of stresses above the limit of elasticity may be carried out on the basis of an electric-plastic analysis.

5.3.5 When several rings of the same alloy and dimensions are to be loaded, it is convenient to determine a calibration curve of circumferential stress versus ring deflection to avoid the inconvenience of strain-gauging each ring.

5.3.6 The amount of compression required on the C-ring to produce elastic straining only, and the degree of elastic strain can be predicted theoretically. Therefore, C-rings may be stressed by calculating the deflection required to develop a desired elastic stress by using the individual ring dimensions in a modified curved beam formula as shown in annex A. Experience shows good agreement between the stresses calculated in this way and those measured by fixing strain gauges to specimens.



a) Constant strain b) Constant load c) Constant strain

Figure 3 — Methods of stressing C-rings

5.3.7 Alternatively the stress strain distribution throughout the specimen, for various applied displacements of the C-ring, may be calculated using the finite element method of stress analysis. Such analyses should be done using well established finite element programmes and by personnel fully conversant with the finite element technique. The method would normally be used for specimens with more complex geometries or loading configurations for which simple theoretical analysis is not applicable.

5.3.8 For notched specimens (see 5.2.3) a nominal stress is assumed using the ring outside diameter measured at the root of the notch. The maximum stress at the notch is then calculated from the product of the nominal stress and the stress concentration factor K_T for the specific notch.

5.4 Machining and surface preparation

5.4.1 A high quality machined surface is the most desirable for corrosion test purposes unless it is desired to test the as-manufactured surface of a tube or bar. When rings are machined from solid stock, precautions should be taken to avoid practices that overheat, plastically deform, or develop residual stress in the metal surface. Machining should be done in stages so that the final cut leaves the principal surface with a clean finish of 1 µm rms or better.

Lapping, mechanical polishing, and similar operations that produce flow of the metal should be avoided.

5.4.2 The surface of the specimen should be degreased before exposure. Chemical or electrochemical treatments may be used to remove oxide films or thin layers of surface metal which have become distorted during machining. If chemical or electrochemical treatments are employed, care must be taken to ensure that the conditions used do not result in selective phase attack on the metal or leave a deposit of undesirable residues on the surface. Treatments that generate hydrogen on the specimen surface must not be used for materials that are susceptible to hydrogen-induced damage.

5.4.3 The surface preparation should be completed before the C-ring is stressed except for a possible final degreasing of the stressed area.

5.4.4 Every precaution should be taken to avoid finger-printing or any rough handling which could mar the finish of the surface after its final preparation.

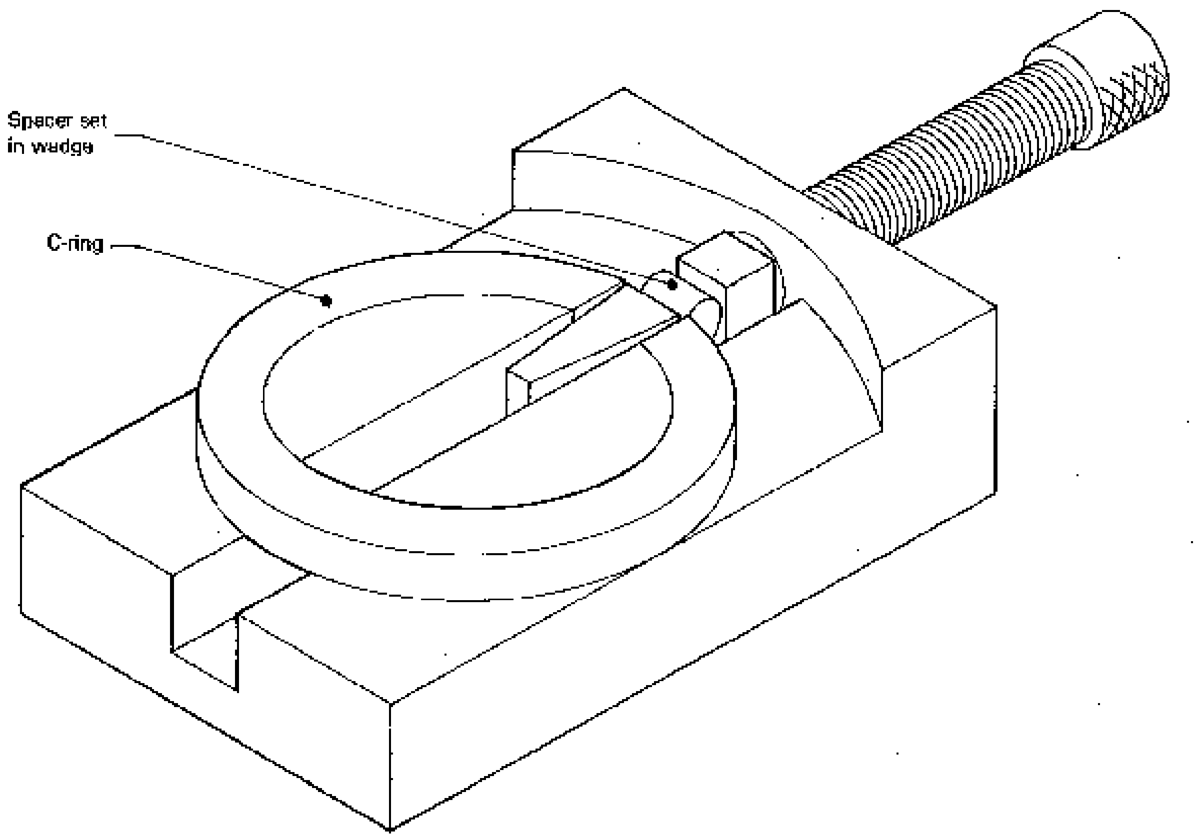


Figure 4 — Suitable jig for the placement of a wedge opening insert

5.5 Specimen identification

5.5.1 Specimen numbers may be scribed on one of the ends adjacent to the cut away segment of the C-ring. No markings of any kind should be made on the critically stressed arc between the bolt holes. Non-metallic tapes may be attached to the stressing bolt by means of a second nut.

5.5.2 Numbers for wedge-opening loaded specimens may be scribed on the outer surface of the C-ring adjacent to the wedge insert.

6 Procedure

6.1 The C-ring, because of its small size and the simple methods of stressing, can be exposed to almost any kind of corrosive environment. The specimens should be supported so that nothing except the corrosive medium contacts the critically stressed area.

6.2 Care should be exercised to avoid galvanic effects between the C-ring, the stressing bolt, nuts or wedge insert and the exposure racks. Protection can be provided by insulating bushing as shown in figure 5a) and b) or by coatings as shown in figure 5c). It is also essential to prevent crevice corrosion that could develop corrosion products between the ring and its stressing assembly and thus alter the stress in the C-ring; coating as shown in figure 5c) is suitable for this purpose. The coatings or insulators selected should not contaminate the corrosive environment nor be deteriorated by it.

6.3 Specimens should be exposed to the test environment immediately after being stressed or should be stored, in such a way as to avoid contamination or deterioration, until they can be exposed.

7 Assessment of results

7.1 The time required for cracks to appear after exposure of stressed specimens to the test environment or the threshold stress below which cracks do not appear can be used as a measure of stress corrosion resistance of the material in the test environment at the stress level employed.

7.2 Cracking is usually obvious in highly stressed C-rings of alloys that are susceptible to stress corrosion cracking.

7.3 Cracking may be much less obvious in C-rings exposed to lower stress, or in more resistant alloys, especially if corrosion products obscure the cracks.

7.4 If a C-ring does not fracture, some arbitrary criterion of failure must be adopted, based on a recognizable degree of cracking.

It is common practice to inspect for cracks with the naked eye or at a low magnification.

7.5 If there are indications noted that cannot be established definitely as a crack by this examination, the investigator should either

a) note the time and date of this first suspicion of cracking and continue the exposure of the specimen, watching for further growth to confirm the first indication as the failure time;

or

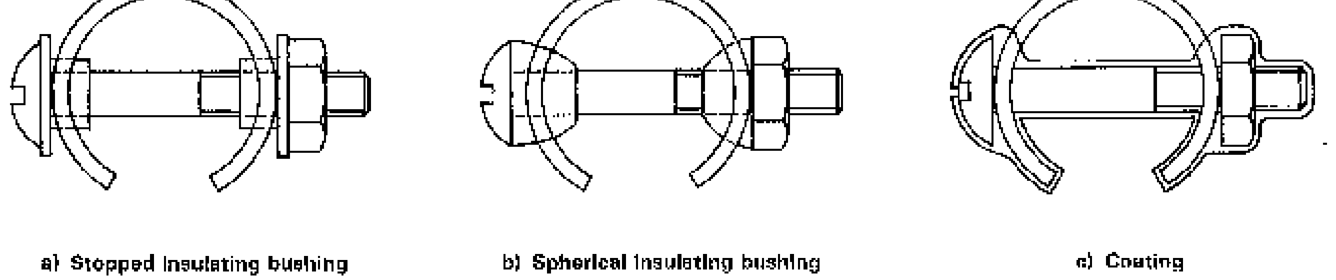
b) discontinue exposure of the specimen and perform a metallographic examination of a cross-section taken through the suspected crack to establish whether there is cracking.

7.6 Metallographic examination of fractured or cracked C-rings can also be helpful in determining whether failure was caused by stress corrosion cracking or by some other form of corrosion.

8 Test report

8.1 In addition to reporting the number of specimens failed and the time to failure of each specimen, particulars should be reported concerning the following:

a) the method of stressing;



a) Stopped insulating bushing   b) Spherical insulating bushing   c) Coating

Figure 5 — Protection against crevice corrosion and galvanic effects

b) the magnitude of the applied stress;

c) the orientation of the specimen;

d) the dimensions and surface preparation;

e) the test environment;

f) the duration of the test;

g) the criterion of failure.

8.2 Complete information should also be reported about the metal being tested, including the following :

a) alloy designation or specification number;

b) the composition of the material under test;

c) the fabrication history;

d) the heat treatment;

e) the mechanical properties.

Annex A
(normative)

Formula for calculating stressing of C-ring specimens

The final diameter D_f required to give the desired stress can be calculated using the following equations:

$$D_f = D \pm \Delta D$$

and

$$\Delta D = \sigma \pi d^2 / 4EtZ$$

where

D is the outside diameter, in millimetres, of the C-ring before stressing;

D_f is the outside diameter of stressed C-ring, in millimetres, measured at right angles to a centre line passing through the point of maximum stress;

σ is the desired stress, in meganewtons per square metre, within the limit of proportionality;

ΔD is the change of D, in millimetres, giving the desired stress;

d is the mean diameter $(D - t)$, in millimetres;

t is the wall thickness, in millimetres;

E is the modulus of elasticity, in meganewtons per square metre;

Z is a correction factor for curved beams (see figure A.1).

Tables such as table A.1 can be developed to avoid repetitive calculations for investigations involving many tests of a given size of C-ring.

The main source of error in this procedure is in the measurement of the C-ring dimensions. If in a typical example of a C-ring of 19 mm outside diameter and 1,50 mm wall thickness the measurements are made to the nearest 0,03 mm, the random error in the calculated value should not exceed 3 %; and the error would be less for longer and thicker rings. An error of 0,03 mm in measuring to the outside diameter before and after stress, however, will have a variable effect upon the stress actually developed, depending upon the magnitudes of the desired stress and outside diameter of the rings. For the size of rings mentioned the percentage error in applying ΔD would be $\pm$ 3 % for σ = 350 MN/m^2 ranging to $\pm$ 30 % for σ = 35 MN/m^2.

Table A.1 — Deflection ΔD for a C-ring of nominal 19 mm outside diameter and 1,50 mm wall thickness of alloy with a modulus of elasticity of 100 000 MN/m² for stressing to 500 MN/m²

Dimensions in millimetres

Wall thickness	Outside diameter								
	18,88	18,91	18,94	18,97	19,00	19,03	19,06	19,09	19,12
1,41	0,899	0,902	0,905	0,907	0,910	0,913	0,916	0,919	0,922
1,42	0,892	0,894	0,897	0,900	0,903	0,906	0,910	0,912	0,915
1,43	0,885	0,887	0,890	0,893	0,896	0,899	0,902	0,905	0,908
1,44	0,878	0,881	0,884	0,887	0,890	0,892	0,895	0,898	0,901
1,45	0,871	0,874	0,877	0,880	0,883	0,886	0,889	0,892	0,895
1,46	0,865	0,868	0,871	0,874	0,876	0,879	0,882	0,885	0,888
1,47	0,858	0,861	0,864	0,867	0,870	0,873	0,876	0,878	0,881
1,48	0,851	0,854	0,857	0,860	0,863	0,866	0,869	0,871	0,874
1,49	0,845	0,848	0,851	0,853	0,856	0,859	0,862	0,865	0,867
1,50	0,839	0,842	0,844	0,847	0,850	0,853	0,856	0,859	0,861
1,51	0,833	0,835	0,838	0,841	0,844	0,847	0,849	0,852	0,854
1,52	0,827	0,829	0,832	0,835	0,838	0,841	0,843	0,845	0,848
1,53	0,821	0,823	0,826	0,829	0,832	0,835	0,837	0,839	0,842
1,54	0,815	0,817	0,820	0,823	0,825	0,829	0,831	0,833	0,836
1,55	0,808	0,811	0,814	0,817	0,820	0,823	0,825	0,827	0,830
1,56	0,802	0,805	0,808	0,811	0,814	0,817	0,819	0,821	0,824
1,57	0,797	0,800	0,802	0,805	0,808	0,811	0,813	0,815	0,818
1,58	0,791	0,794	0,797	0,799	0,802	0,805	0,807	0,810	0,813
1,59	0,786	0,788	0,791	0,793	0,796	0,799	0,802	0,804	0,807
1,60	0,780	0,783	0,785	0,788	0,791	0,793	0,796	0,799	0,801

NOTES

1 To obtain the deflection required to develop the intended stress, σ, in a particular C-ring, locate the number corresponding to the outside diameter and wall thickness for that particular C-ring and multiply by $\sigma/500$.

2 For alloys with a different modulus of elasticity E, another table could be calculated, or the value of ΔD found in the table could be divided by $E \times 10^{-5}$.

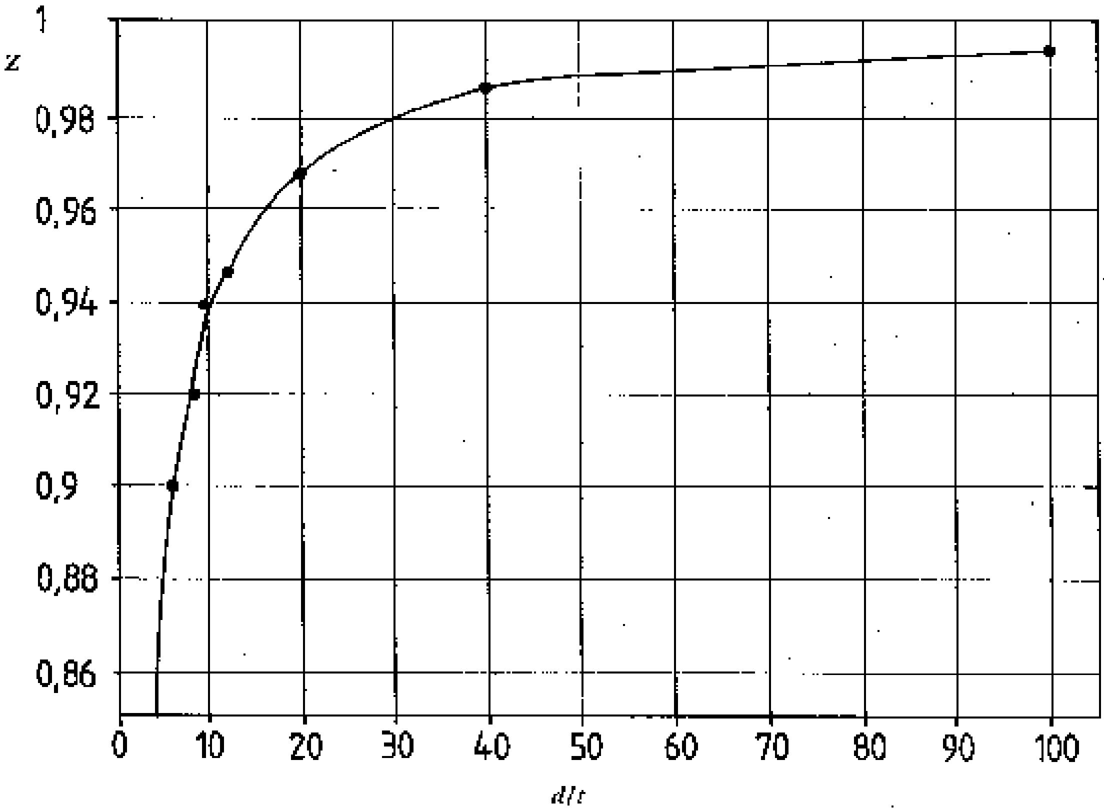


Figure A.1 — Correction factor for curved beams

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Descriptors: metals, alloys, tests, corrosion tests, stress corrosion tests, test specimens.

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