BRITISH STANDARD

BS EN ISO
11782-1:2008

Corrosion of metals and alloys — Corrosion fatigue testing —

Part 1: Cycles to failure testing

ICS 77.060

British Standards

National foreword

This British Standard is the UK implementation of EN ISO 11782-1:2008. It is identical with ISO 11782-1:1998. It supersedes BS ISO 11782-1:1998 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ISE/NFE/8, Corrosion of metals and alloys.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English Version

Corrosion of metals and alloys - Corrosion fatigue testing - Part 1: Cycles to failure testing (ISO 11782-1:1998)

Corrosion des métaux et alliages - Essais de fatigue-corrosion - Partie 1: Essais cycliques à la rupture (ISO 11782-1:1998)

Korrosion von Metallen und Legierungen - Prüfung der Schwingungskorrosion - Teil 1: Prüfung unter Anwendung von Bruch-Schwingspielen (ISO 11782-1:1998)

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Foreword

The text of ISO 11782-1:1998 has been prepared by Technical Committee ISO/TC 156 “Corrosion of metals and alloys” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 11782-1:2008 by Technical Committee CEN/TC 262 “Metallic and other inorganic coatings” the secretariat of which is held by BSI.

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Endorsement notice

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Contents

Descriptors: Metal products, metals, alloys, corrosion, corrosion tests, fatigue tests, cyclic tests, breaking.

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Introduction

The study of cycles to failure testing uses plain or notched specimens to provide data on the intrinsic corrosion fatigue crack like behaviour of a metal or alloy and can be used to develop criteria for engineering design to prevent fatigue failures.

The study of cycles to failure can be applied to a wide variety of product forms including plate, rod, wire, sheet and tubes as well as to parts joined by welding.

The results of corrosion fatigue testing are suitable for direct application only when the service conditions exactly parallel the test conditions especially with regard to material, environmental and stressing considerations. The combination of material/load/environmental may not be directly comparable to the application. For these cases engineering judgement must be applied.

1 Scope

1.1 This International Standard provides guidance and instruction on corrosion fatigue testing of metals and alloys in aqueous or gaseous environments and is concerned with cycles to failure testing. Crack propagation testing is considered in ISO 11782-2.

1.2 Corrosive or otherwise chemically active environments can promote the initiation of fatigue cracks in metals and alloys and increase the rate of fatigue crack propagation. Corrosion fatigue processes are not limited to specific metal/environment systems and reliable estimates of fatigue life for all combinations of loading and environment cannot be made without data from laboratory tests.

1.3 This International Standard is not intended for application to corrosion fatigue testing of components or parts; nevertheless many of the general principles will apply.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this part of ISO 11782. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this part of ISO 11782 are encouraged to investigate the possibility of applying the most recent edition of the standard 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.*

3 Definitions

For the purposes of this part of ISO 11782, the following definitions apply.

3.1

corrosion fatigue

process involving conjoint corrosion and alternating straining of the metal, often leading to cracking

NOTE Corrosion fatigue may occur when a metal is subjected to cyclic straining in a corrosive environment.

3.2

stress amplitude, S_a, in fatigue loading

one half of the range of a cycle (also known as the alternating stress):

$$S_a = \frac{S_{max} - S_{min}}{2}$$

3.3

mean stress, S_m, in fatigue loading

algebraic average of the maximum and minimum stresses in constant amplitude loading or of individual cycles in spectrum loading:

$$S_m = \frac{S_{max} + S_{min}}{2}$$

3.4

maximum stress, S_{max}, in fatigue loading

that stress having the highest algebraic value:

$$S_{max} = S_m + S_a$$

3.5

minimum stress, S_{min}, in fatigue loading

that stress having the lowest algebraic value:

$$S_{min} = S_m - S_a$$

3.6

stress ratio, R, in fatigue loading

algebraic ratio of the minimum and maximum stress of a cycle:

$$R = \frac{S_{min}}{S_{max}}$$

NOTE The stress ratio, R, is equal to the load ratio P_{min}/P_{max}, where P_{min} and P_{max} are the minimum and maximum loads in the cycle, respectively.

3.7

***S-N* diagram**

plot of stress against the number of cycles to failure

the stress can be the maximum stress, S_{max}, minimum stress, S_{min}, stress range, ΔS or S_r, or alternating stress, S_a. The diagram indicates the S-N relationship for a specified value of S_m, R and a specified probability of survival. For N, a log scale is almost always used. For S, a linear scale or a log scale is used

3.8
fatigue notch factor, K_f

ratio of the fatigue strength of a specimen with no stress concentrator to that of a specimen with a stress concentrator for the same percent survival at N cycles for the same loading and environmental conditions

NOTE In specifying K_f, it is necessary to specify the geometry and the values of stress amplitude, mean stress and N for which it is computed.

3.9
stress concentration factor, K_t

ratio of the greatest stress in the region of a notch or other stress concentrator as determined by the theory of elasticity to the corresponding nominal stress

K_t becomes invalid when the stress at the notch root exceeds the yield strength

3.10
cycle (in fatigue)

smallest segment of the load- or stress-time function which is repeated periodically. The terms fatigue cycle, load cycle and stress cycle are also commonly used

3.11
waveform

shape of the peak-to-peak variation of load as a function of time

3.12
cyclic frequency, f

number of cycles per unit time, usually expressed in terms of cycles per second (Hz)

3.13
fatigue strength at N load cycles, S_N

value of stress for failure at exactly N load cycles as determined from an S-N diagram. The value of S_N thus determined is subject to the same conditions as those that apply to the S-N diagram

NOTE 1 The value of S_N is also known as the median fatigue strength for N cycles.

NOTE 2 In a corrosive environment the fatigue strength is likely to be reduced compared with that in air.

3.14
fatigue strength limit, S_f

limiting value of the median fatigue strength as the fatigue life, N, becomes very large. Most materials and environments preclude the attainment of well defined fatigue limits

4 Test

4.1 Principle

In the presence of an aggressive environment the fatigue strength of a metal or alloy is reduced to an extent which depends on the nature of the environment and the test conditions. For example, the well-defined fatigue strength limit observed for steels in air may no longer be evident as illustrated in Figure 1. Interpretation of results is then based on the assumption of an acceptable life of the component.

The test involves subjecting a series of specimens to the number of stress cycles required for a fatigue crack to initiate and grow large enough to cause failure during exposure to a corrosive or otherwise chemically active environment at progressively smaller alternating stresses in order to define either the fatigue strength at N cycles, S_N, from an S-N diagram or the fatigue strength limit as the fatigue life becomes very large.

The test is used to determine the effect of environment, material, geometry, surface condition, stress, etc, on the corrosion fatigue resistance of metals or alloys subjected to applied stress for relatively large numbers of cycles. The test may also be used as a guide to the selection of materials for service under conditions of repeated applied stress under known environmental conditions.

4.2 Specimens

4.2.1 *General*

The design and type of specimen used depends on the fatigue testing machine used, the objective of the fatigue study and the form of the material from which the specimen is to be made. Fatigue test specimens are designed according to the mode of loading which can include axial stressing, plane bending, rotating beam, alternate torsion or combined stress.

Specimens may have circular, square, rectangular, annular or, in special cases, other cross-sections.

The gripped ends may be of any shape to suit the holders of the test machine. Problems may arise unless the gripped portion of the specimen is isolated from the corrosive test environment.

The test section of the specimen shall be reduced in cross-section to prevent failure in the grip ends and should be of such a size as to use the middle to upper ranges of the load rating of the fatigue machine to optimize the sensitivity and response of the system.

The transition from the gauge section to the gripped ends of the specimen shall be designed to minimize any stress concentration. It is recommended that the radius of the blending fillet shall be at least eight times the specimen test section diameter or width. The cross-sectional area of the gripped ends shall, where possible, be at least four times that of the test section area.

The test section length shall be greater than three times the test section diameter or width.

For tests run in compression, the length of the test section shall be less than four times the test section diameter or width in order to minimize buckling.

For the purposes of calculating the load to be applied to obtain the required stress, the dimensions from which the area is calculated shall be measured to within 0,02 mm.

Specimens shall be identified by an indelible marking method, such as stamping, on surface areas, preferably on the plain ends, without having an influence on the test results.

Specimens shall be stored after appropriate cleaning under desiccated conditions prior to testing in order to avoid corrosion which may influence the test results.

4.2.2 *Cylindrical specimens*

Two types of specimens with circular cross-section are frequently used for corrosion fatigue tests:

a) specimens with tangentially blending fillets between the test section and the grip ends (see Figure 2); these are suitable where axial loading is employed;

b) specimens with a continuous radius between the grip ends with the minimum diameter at the centre (see Figure 3); these are suitable for rotating bend tests.

A minimum cross-section diameter of 5 mm is preferred.

4.2.3 *Flat sheet or plate specimens*

Flat specimens for fatigue tests are reduced in width in the test section and may have thickness reductions.

If the specimen thickness is less than 2,5 mm, and the tests are performed in compression, provisions for lateral support should be made to prevent buckling without affecting the applied load by more than 5 %.

The most commonly used types include:

a) specimens with tangentially blending fillets between the test section and the grip ends (see Figure 4);

b) specimens with a continuous radius between the grip ends (see Figure 5).

4.2.4 *Notched specimens*

The effect of machined notches on corrosion fatigue strength can be determined by comparing the *S-N* curves of notched and unnotched specimens.

The data for notched specimens are usually plotted in terms of nominal stress based on the net cross-section of the specimen.

The effectiveness of the notch in decreasing the fatigue limit is expressed by the fatigue notch factor, K_f (the ratio of the fatigue limit of unnotched specimens to the fatigue limit of notched specimens).

The notch sensitivity of a material in fatigue is expressed by the notch sensitivity factor, q;

$$q = \frac{K_f - 1}{K_t - 1}$$

where

K_t is the stress concentration factor;

$q = 0$ for a material that experiences no reduction in fatigue limit due to a notch;

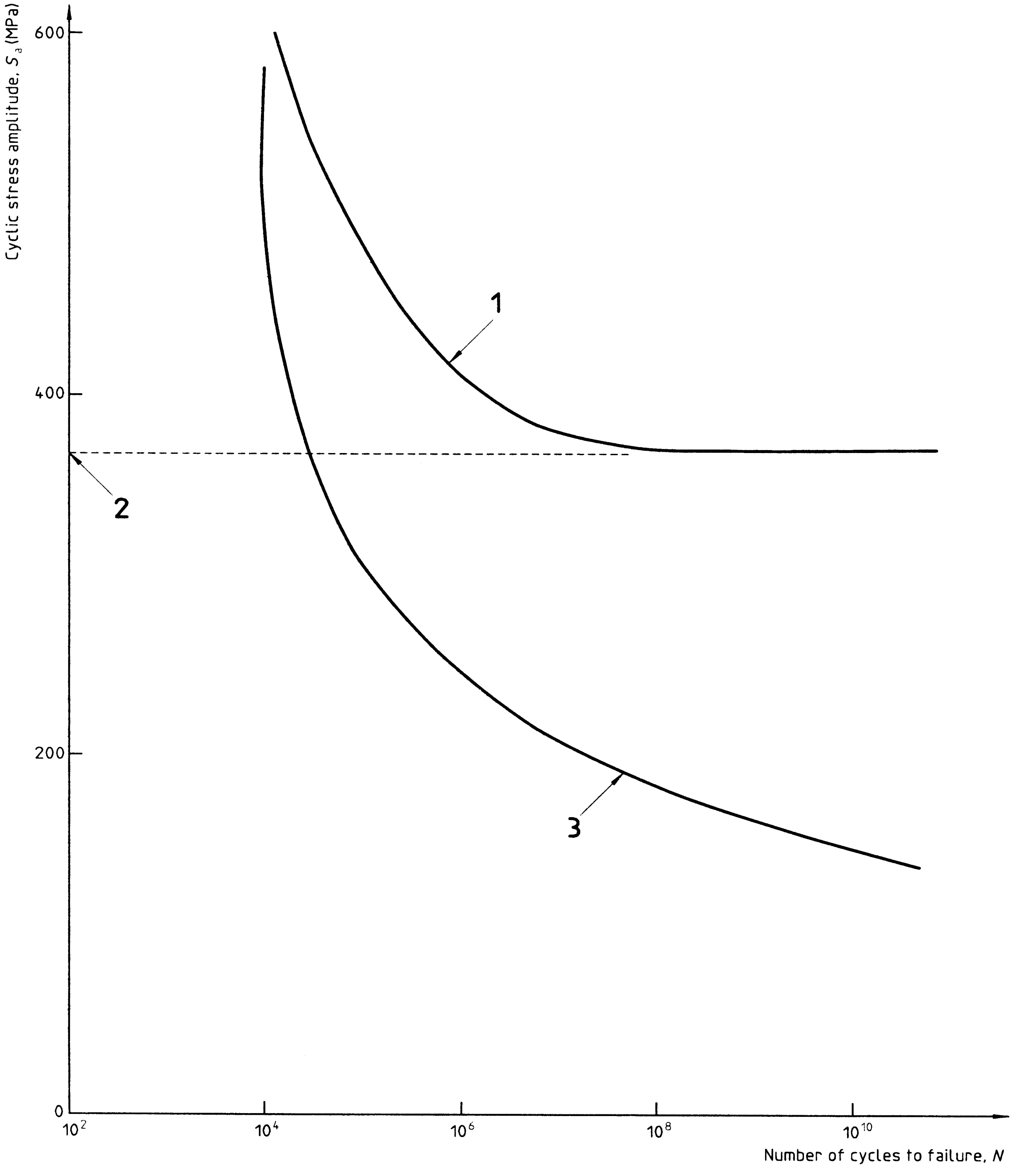
$q = 1$ for a material where the notch exerts its full theoretical effect.

If the standard size cannot be met other specimen configurations can be used with appropriate caution.

4.2.5 *Specimen size effects*

Size effects can be important in fatigue for several reasons which include residual stress distribution, variations in stress gradient across the diameter (plain or notched specimens in bending or tension and notched specimens in axial tension-compression loading), variations in surface area, variations in hydrogen concentration gradient (in appropriate environmental conditions). There is a tendency for the fatigue strength to decrease as the specimen size increases but this may not always be the case.

The size effect means that it can be difficult to predict the fatigue performance of large components directly from the results of laboratory tests on small specimens.



Key

1 Fatigue in air
2 Fatigue limit in air
3 Corrosion fatigue (no fatigue limit)

Figure 1 — Schematic comparison of *S-N* behaviour during fatigue and corrosion fatigue for steel

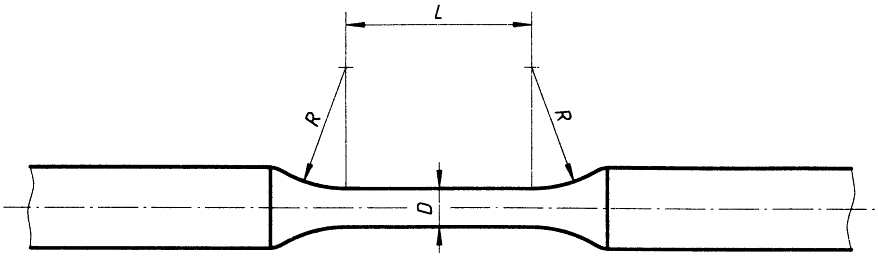


Figure 2 — Specimens with tangentially blending fillets between the test section and the ends

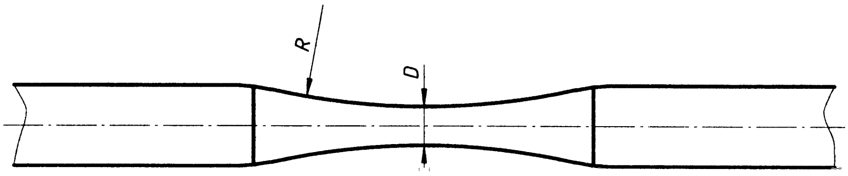


Figure 3 — Specimens with a continuous radius between ends

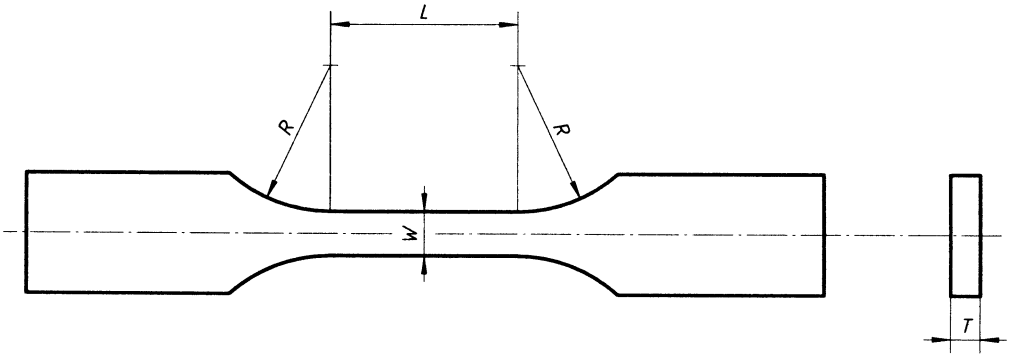


Figure 4 — Specimens with tangentially blending fillets between the uniform test section and the ends

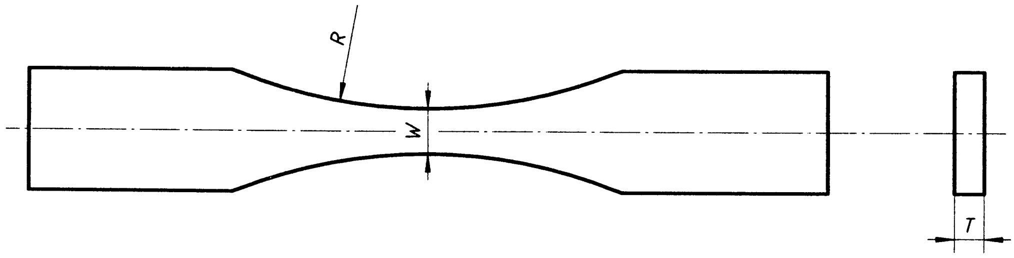


Figure 5 — Specimens with a continuous radius between ends

4.2.6 *Surface effects*

Corrosion fatigue properties can be very sensitive to surface condition since fatigue cracks usually initiate at the surface. The following factors may affect the behaviour of specimens during corrosion fatigue testing.

4.2.6.1 *Surface roughness*

In general, fatigue life increases as the magnitude of the surface roughness decreases. Therefore, attention must be paid to the surface preparation of corrosion fatigue test specimens.

Unless it is required to investigate the behaviour of an as-manufactured surface, it is recommended that a metallographically polished surface free of machining grooves and scratches should be used. The direction of polishing can be important and in axial loading the final surface preparation should involve grinding, or polishing in the longitudinal direction, i.e. in the same direction as the applied stress.

4.2.6.2 *Surface residual stress*

Finishing processes such as machining, grinding and polishing that deform and work harden the surface, or heat treatments that introduce thermal stresses or microstructural phase changes can introduce tensile or compressive residual stresses depending on the conditions employed.

Residual surface stresses can influence the corrosion fatigue behaviour of the specimen.

Compressive residual stresses generally increase fatigue strength while tensile residual stresses tend to exert the opposite effect.

Residual surface stresses may also influence localized corrosion behaviour and hence affect corrosion fatigue crack initiation.

Peening processes which introduce surface compressive stresses may improve corrosion fatigue behaviour, although any benefits may be negated by pitting or where incomplete surface coverage occurs.

Machining, heat treatment and finishing processes employed during specimen preparation should be designed to minimize surface residual stresses unless it is required to simulate a service situation which involves significant residual surface stress.

4.2.6.3 *Microstructural surface effects*

Surface treatment processes to increase the hardness of the surface layer and introduce compressive residual stresses may change corrosion fatigue properties. If relevant to the application of interest, test specimens should be treated similarly.

Hard surface layers introduced by poorly controlled machining, particularly where surface heating causes a phase transformation, can be associated with microcracks and tensile residual surface stresses which can have an adverse influence on corrosion fatigue strength and should therefore be avoided.

4.3 Environmental considerations

Because of the specificity of metal-environment interactions, it is essential that corrosion fatigue cycles to failure tests be conducted under environmental conditions which are closely controlled.

Environmental factors of importance are electrode potential, temperature, solution composition, pH, concentration of dissolved gases, flowrate and pressure. ISO 7539-1 provides useful background information. In relation to gaseous environments a critical factor is purity of the gas.

Tests may be conducted under open circuit conditions in which the electrode potential of the metal is dependent on the specific environmental conditions of the test of which the degree of aeration is an important factor. Alternatively the electrode potential may be displaced from the open circuit value by potentiostatic or galvanostatic methods (see **5.3**). Auxiliary electrodes to apply external current should be designed to produce uniform current distribution on the specimen i.e. the electrode potential should be uniform.

4.4 Stressing considerations

4.4.1 *Cyclic frequency*

Cyclic frequency is of far greater importance when cycles to failure tests are conducted in "aggressive" environments rather than in air where cyclic frequency usually has little, if any, effect. This sensitivity to frequency is due to time-dependent processes associated with the material-environment interaction. In a narrow context this may simply reflect the timescale of overall testing for significant pit development but more broadly the cycle period affects the extent of reaction or transport during a load cycle and consequently the extent of crack advance.

In the presence of an "aggressive" environment the fatigue strength of a metal or alloy generally decreases as the cyclic frequency is reduced. It is important, therefore, that a cyclic frequency relevant to the service application be used during testing.

4.4.2 *Waveform*

In some cases, corrosion fatigue strength is strongly affected by the waveform of the loading cycle. This is particularly so where the cycle incorporates hold times during which time-dependent corrosion or stress corrosion processes may influence crack initiation and growth.

The rate of loading and unloading may also influence environmental effects if these involve, for example, diffusion or repassivation processes. It can be important, therefore, to employ a waveform representative of that encountered during service. Sinusoidal, triangular, sawtooth and square waveforms are often employed to simulate service loading conditions and, where appropriate, hold times can be imposed during the cycle.

The mean load can affect fatigue strength and life and appropriate assessment should be made.

4.4.3 *Variable amplitude loading patterns*

Some practical applications involve exposure to random loading cycles or to well-defined periodic changes in the cyclic loading conditions. While some insight into the influence of these fluctuations may be gained by the summation of the effects observed during a series of tests under different loading conditions, it is preferable to simulate the service conditions by computer control using block or random loading programs.

5 Apparatus

5.1 The fatigue testing machine shall be capable of operation at cyclic frequencies and with waveforms relevant to the application of interest and shall be equipped with adequate cycle counting and load monitoring systems.

5.2 The alignment of the fatigue testing machine shall ensure axiality of the applied load.

5.3 The environmental chamber shall completely enclose the test section of the specimen. Wherever possible, the gripped portions shall be excluded from contact with the solution environment to prevent galvanic effects and crevice corrosion. If this is not possible, appropriate avoidance measures shall be taken through, for example, the use of similar metals, electrical insulation or coatings. An adequate volume of solution to metal area ratio is required (dependent on reaction rates and exposure time) and a circulation system is usually necessary. For conditions of applied potential or applied current a separate compartment for the counter electrode may be necessary to limit any influence of reaction products from this electrode. Non-metallic materials are recommended for the environmental chamber and circulation system where this is practicable. These materials shall be inert. Note that glass and certain plastics are not inert at elevated temperatures. Where metallic chambers are necessary these shall be electrically insulated from the specimens to prevent galvanic interaction.

For tests in gaseous environment an all metal-chamber is preferred.

6 Procedure

6.1 The specimen (degreased and handled with care) shall be mounted in the specimen grips within the environmental chamber, every effort being made to prevent the occurrence of misalignment either due to rotation of the grips or to displacement in their axes of symmetry.

6.2 The environment to be used shall represent the service or an appropriate standard and shall be prepared using analytical reagent grade chemicals. In the case of gases a high-purity laboratory grade shall be used unless it is required to simulate a particular service condition which involves impure gas. In this case, a gas mixture with the same mixture of components at the same composition as the impure gas shall be used.

6.3 The starting procedure, in relation to the relative timescale of introducing the environment and commencement of loading, can have a significant influence on fatigue life. Factors which can be important are the timescale for pit development and for hydrogen charging of the material. Transient effects in corrosion are common: the corrosion potential may change after initial immersion and corrosion product development will also be time-dependent. In view of these factors it may be useful to assess the effect of pre-exposure period on fatigue strength.

6.4 The environment shall be monitored and controlled during the test as required. In unbuffered systems the pH can be maintained constant using an automatic pH control system; otherwise, the effect of any variations in pH on crack growth shall be assessed.

In systems open to the atmosphere, aeration can be maintained by bubbling air through the solution. In closed systems monitoring is required. The pressure of the system shall be controlled where appropriate. The flowrates used in testing shall simulate the range of conditions in service. The orientation of the flow with respect to the specimen configuration can be important. Note that the rotating-bend test is essentially a rotating electrode system which may create its own local hydrodynamics.

It is strongly recommended that the electrode potential be measured with a reference electrode appropriate for the application. Care should be taken to limit potential drop errors in the measurement. Double junction electrodes can be used to avoid contamination of the solution and specialized electrodes exist for high temperature applications.

The temperature of the solution shall be controlled to ± 2 °C.

6.5 Testing shall be continued until the specimen fails or until a predetermined number of cycles has been applied to the specimen. Failure shall be defined as complete separation or by some other agreed criterion.

6.6 It is conventional to determine fatigue strengths by a series of tests at progressively lower stress levels until a stress amplitude is reached at which no failure occurs during the test period. Complementary tests at varying mean stress may be undertaken.

7 Test report

The test report should include the following information:

a) specimen design, dimension, machining processes and surface condition;

b) for notched specimens, details of the notch and its stress concentration factor;

c) description of the test machine, including the method of verification of dynamic load monitoring;

d) test material characterization in terms of, for example, chemical composition, melting and fabrication process, heat treatment, microstructure, grain size, non-metallic inclusion content and mechanical properties; product size and form shall also be identified; the method of stress relief, if applicable;

e) specimen orientation and its location with respect to the parent product from which it was removed;

f) test loading variables, including stress amplitude and stress ratio, fatigue life or cycles to end of test, cyclic frequency and waveform for each specimen;

g) the initial solution composition, pH, degree of aeration (or concentration of other relevant gases), flow conditions, temperature and electrode potential; specification of flowrate shall be in terms of approximate linear rate past the specimen if determined by the recirculation rate; the reference electrode used shall be indicated; the potential shall be reported and referred to an appropriate standard electrode (example: standard hydrogen electrode or saturated calomel electrode at 25 °C);

h) the starting procedure for the test, for example any change in initial electrode potential;

i) transients in the environment or in the loading (including test interruptions) during testing, noting the nature and duration;

j) description of the environmental chamber and all equipment used for environmental monitoring or control;

k) failure criterion;

l) an *S-N* diagram plotting the maximum stress, minimum stress, stress range or alternating stress against the number of cycles to failure; it is conventional to plot fatigue life, *N*, in cycles logarithmically on the abscissa while stress is plotted arithmetically or logarithmically on the ordinate; all data should be plotted in the *S-N* diagram along with a best fit regression analysis line; this procedure develops the *S-N* diagram for 50 % probability of survival when the logarithms of the lives are described by normal distribution.

Annex A (informative)
Bibliography

[1] ISO 7539-2:1989, *Corrosion of metals and alloys — Stress corrosion testing — Part 2: Preparation and use of bent-beam specimens.*

[2] ISO 7539-4:1989, *Corrosion of metals and alloys — Stress corrosion testing — Part 4: Preparation and use of uniaxially loaded tension specimens.*

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