BRITISH STANDARD

BS EN 60793-1-33:2002
IEC 60793-1-33:2001

Optical fibres —

Part 1-33: Measurement methods and test procedures — Stress corrosion susceptibility

The European Standard EN 60793-1-33:2002 has the status of a British Standard

ICS 33.180.10

National foreword

This British Standard is the official English language version of EN 60793-1-33:2002. It is identical with IEC 60793-1-33:2001.

The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/1, Optical fibres and cables, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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

From 1 January 1997, all IEC publications have the number 60000 added to the old number. For instance, IEC 27-1 has been renumbered as IEC 60027-1. For a period of time during the change over from one numbering system to the other, publications may contain identifiers from both systems.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

This British Standard, having been prepared under the direction of the Electrotechnical Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 16 May 2002

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 38, an inside back cover and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments

ISBN 0 580 39618 5

EUROPEAN STANDARD **EN 60793-1-33**

NORME EUROPÉENNE

EUROPÄISCHE NORM April 2002

ICS 33.180.10

English version

Optical fibres
Part 1-33: Measurement methods and test procedures - Stress corrosion susceptibility
(IEC 60793-1-33:2001)

Fibres optiques Partie 1-33: Méthodes de mesure et procédures d'essai - Résistance à la corrosion sous contrainte (CEI 60793-1-33:2001)	Lichtwellenleiter Teil 1-33: Messmethoden und Prüfverfahren - Spannungskorrosionsempfindlichkeit (IEC 60793-1-33:2001)

This European Standard was approved by CENELEC on 2002-03-05. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC
European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Ref. No. EN 60793-1-33:2002 E

Foreword

The text of document 86A/688/FDIS, future edition 1 of IEC 60793-1-33, prepared by SC 86A, Fibres and cables, of IEC TC 86, Fibre optics, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60793-1-33 on 2002-03-05.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2002-12-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2005-03-01

Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annexes A, B, C, D, E and ZA are normative and annexes F, G and H are informative.
Annex ZA has been added by CENELEC.

Compared to IEC 60793-1:1989 and IEC 60793-2:1992, IEC/SC 86A has adopted a revised structure of the new IEC 60793 series: The individual measurement methods and test procedures for optical fibres are published as "Part 1-XX"; the product standards are published as "Part 2-XX".

The general relationship between the new series of EN 60793 and the superseded European Standards of the EN 188000 series is as follows:

EN	Title	supersedes
EN 60793-1-XX	Optical fibres -- Part 1-XX: Measurement methods and test procedures	Individual subclauses of EN 188000:1992
EN 60793-2-XX	Optical fibres -- Part 2-XX: Product specifications	EN 188100:1995 EN 188101:1995 EN 188102:1995 EN 188200:1995 EN 188201:1995 EN 188202:1995

EN 60793-1-3X consists of the following parts, under the general title: Optical fibres:

- Part 1-30: Measurement methods and test procedures – Fibre proof test
- Part 1-31: Measurement methods and test procedures – Tensile strength
- Part 1-32: Measurement methods and test procedures – Coating strippability
- Part 1-33: Measurement methods and test procedures – Stress corrosion susceptibility
- Part 1-34: Measurement methods and test procedures – Fibre curl

Endorsement notice

The text of the International Standard IEC 60793-1-33:2001 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INTRODUCTION

Publications in the IEC 60793-1 series concern measurement methods and test procedures as they apply to optical fibres.

Within the same series several different areas are grouped, as follows:

- parts 1-10 to 1-19: General
- parts 1-20 to 1-29: Measurement methods and test procedures for dimensions
- parts 1-30 to 1-39: Measurement methods and test procedures for mechanical characteristics
- parts 1-40 to 1-49: Measurement methods and test procedures for transmission and optical characteristics
- parts 1-50 to 1-59: Measurement methods and test procedures for environmental characteristics.

OPTICAL FIBRES –

Part 1-33: Measurement methods and test procedures – Stress corrosion susceptibility

1 Scope and object

This part of IEC 60793 contains descriptions of the five main test methods concerning the determination of stress corrosion susceptibility parameters.

The object of this standard is to establish uniform requirements for the mechanical characteristic stress corrosion susceptibility. Dynamic fatigue and static fatigue tests are used in practice to determine stress corrosion susceptibility parameters, dynamic *n*-value and static *n*-value.

Any fibre mechanical test should determine fracture stress and fatigue properties under conditions that model the practical application as close as possible. Some appropriate test methods are available:

- A: Dynamic *n* value by axial tension (see annex A);
- B: Dynamic *n* value by two-point bending (see annex B);
- C: Static *n* value by axial tension (see annex C);
- D: Static *n* value by two-point bending (see annex D);
- E: Static *n* value by uniform bending (see annex E).

These methods are appropriate for types A1, A2 and A3 multimode and type B1 single-mode fibres.

Static and dynamic fatigue test methods show comparable results if both tests are performed in the same effective measuring time. For dynamic fatigue tests this means a measuring time which is (n + 1) times larger than the measuring time of static fatigue tests.

When using static fatigue test methods, it has been observed that for longer measuring times and consequently lower applied stress levels, the *n*-value increases. The range of measuring times of the static fatigue tests, given in this standard, approaches the practical situation better than that of the dynamic fatigue tests, which in general are performed in relatively short time-frames.

These tests provide values of the stress corrosion parameter, *n*, that can be used for reliability calculations according to IEC 62048.

2 Normative references

The following referenced documents are indispensable for the application 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.

IEC 62048, *The law theory of optical fibre reliability* [1]

---

[1] To be published.

3 Apparatus

See annexes A, B, C, D, and E for each of the layout drawings and other equipment requirements for each of the methods respectively.

4 Sampling and specimens

These measurements are statistical in nature. A number of specimens or samples from a common population are tested, each under several conditions.

Failure stress or time statistics for various sampling groups are used to calculate the stress corrosion susceptibility parameters.

4.1 Specimen length

Specimen length is contingent on the test procedure used. See the respective annexes A, B, C, D and E for the length required for the test method. For tensile tests, the length ranges from 0,5 m to at most 5 m. For two-point bending tests, the actual length tested is less than 1 cm and for uniform bending tests about 1 m.

4.2 Specimen preparation and conditioning

All of the test methods shall be performed under constant environmental conditions. Unless otherwise specified in the detail specification, the nominal temperature shall be in the range of 20 °C to 23 °C with a tolerance of ±2 °C for the duration of the test. Unless otherwise specified in the detail specification, the nominal relative humidity (RH) shall be in the range of 40 % to 60 % with a tolerance of ±5 % for the duration of the test.

Unless otherwise specified, all specimens shall be pre-conditioned in the test environment for a minimum period of 12 h.

The use of stress corrosion susceptibility (and proof stress) parameters for reliability estimates is still under consideration. A method for extrapolating such parameters to service environments different from the default environment specified above has not been developed.

It has been observed that the value of n produced by these tests can change after even brief exposure of the fibre to elevated temperature and humidity. A guide for the use of these methods is documented in IEC 62048.

The observed value of stress corrosion susceptibility parameter, n, may differ between fatigue test methods. Influences on the results have been observed concerning the measuring time and the applied stress level. Care should be taken in the choice of test method. This should be agreed between the user and manufacturer.

5 Reference test method

Method A is the reference test method and shall be used to resolve disputes because it yields minimal values compared to the others and may be completed in a duration practical for dispute resolution.

6 Procedure

See annexes A, B, C, D and E, respectively, for the individual test methods.

Each of several samples (consisting of a number of specimens) is exposed to one of a number of stress conditions. For static fatigue tests, a constant stress is applied from sample to sample and time to failure is measured. For dynamic fatigue tests, the stress rate is varied from sample to sample and the failure stress is measured.

The following is an overview of the procedures common to all methods:

- complete pre-conditioning;
- divide the specimens into sample groups;
- apply the specified stress conditions to each sample group;
- measure time or stress at failure;
- complete calculations

7 Calculations

The calculations for each individual test method are found respectively in annexes A, B, C, D and E.

8 Results

8.1 The following information shall be reported with each test:

- fibre identification;
- test date;
- stress corrosion susceptibility parameter;
- test method.

8.2 The following information shall be provided upon request:

- specific information as required by the test method;
- any special pre-conditioning.

Clauses A.5, B.5, C.5, D.5, and E.5 have results that apply respectively for each specific method.

9 Specification information

The detail specification shall specify the following information:

- information to be reported;
- any deviations to the procedure that apply;
- failure or acceptance criteria.

Annex A

(normative)

Dynamic *n* value by axial tension

This method is designed for determining the dynamic stress corrosion susceptibility parameter (dynamic *n* value, n_d) of optical fibre at specified constant strain rates.

This method is intended only to be used for use with those optical fibres of which the median fracture stress is greater than 3 GPa at the highest specified strain rate. For fibres with median fracture stress less than 3 GPa, the conditions herein have not demonstrated sufficient precision.

This method is intended to test fatigue behaviour of fibres by varying the strain rate. The test is applicable to fibres and strain rates for which the logarithm of fracture stress versus the logarithm of strain rate behaviour is linear.

A.1 Apparatus

This clause describes the fundamental requirements of the equipment used for dynamic fracture stress testing. There are several configurations that meet these requirements. Examples are presented in figures A.1 to A.3. Unless otherwise specified in the detail specification, use a gauge length of 500 mm for tensile test specimens.

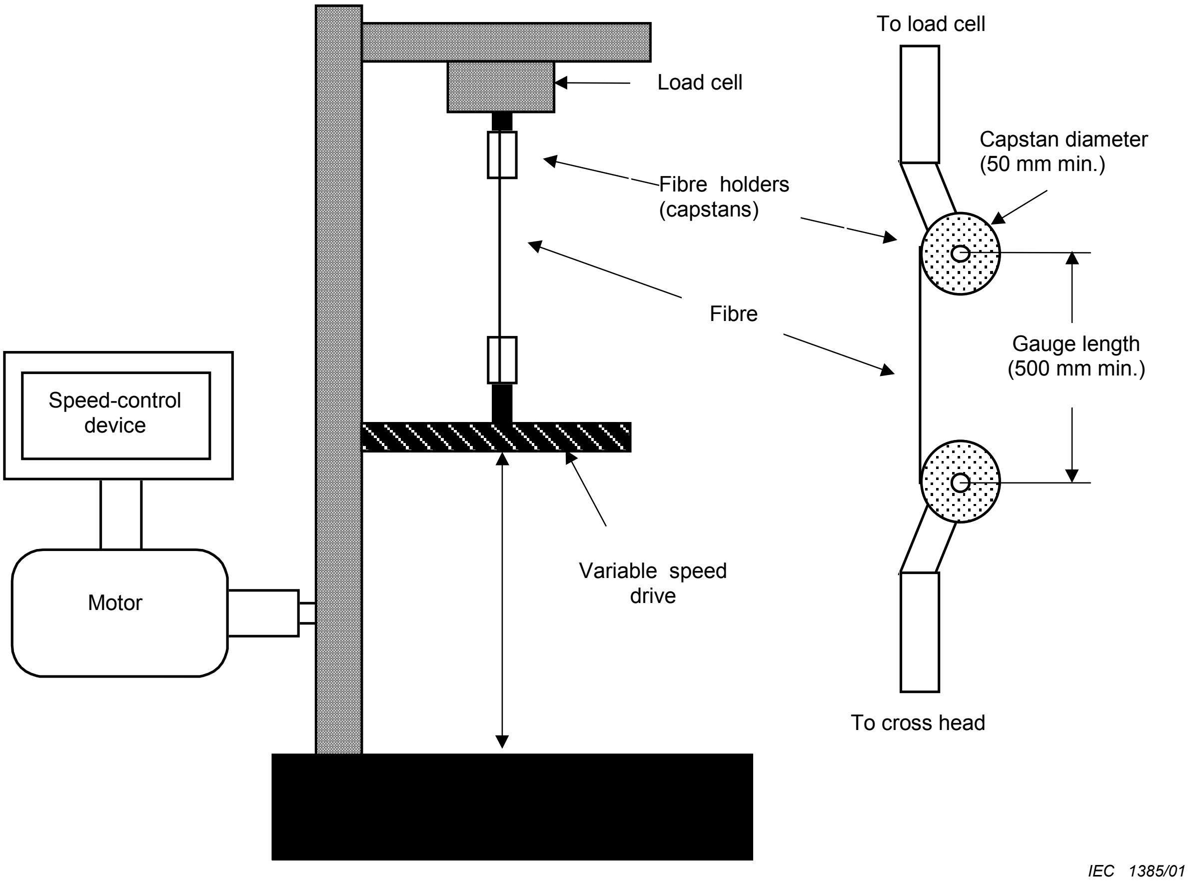


Figure A.1 – Schematic of translation test apparatus

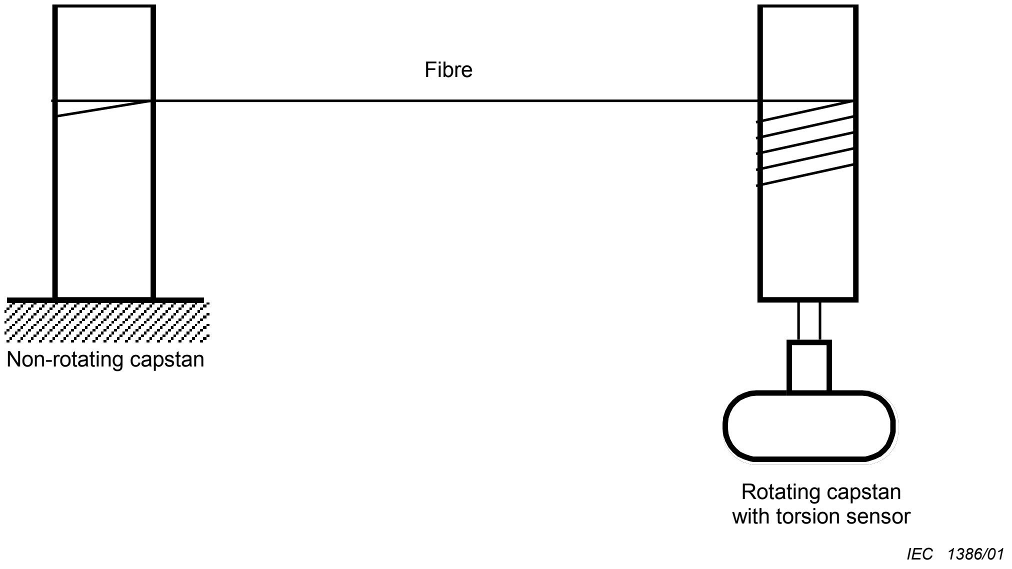


Figure A.2 – Schematic of rotational test apparatus

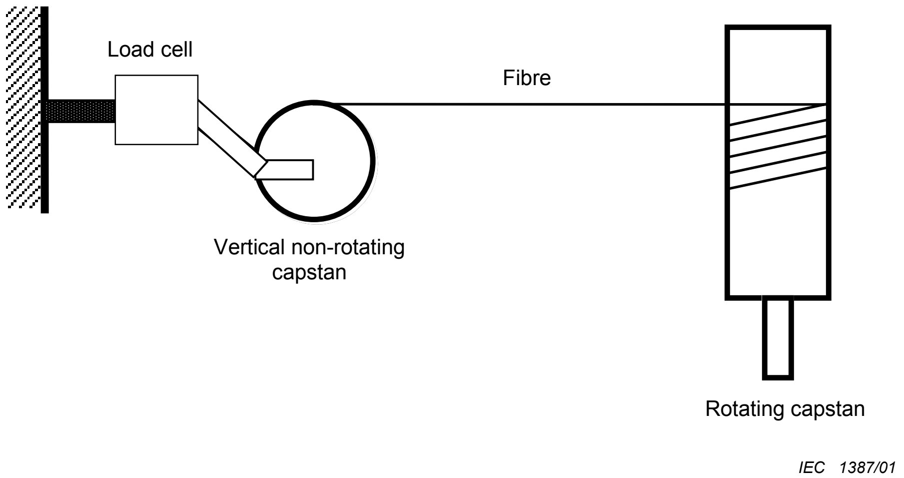


Figure A.3 – Schematic of rotational test apparatus with load cell

A.1.1 Support of the specimen

Grip the fibre length to be tested at both ends and subject the fibre to tension until fracture occurs in the gauge length section of the fibre. Minimize the fibre fracture at the grip by providing a surface friction that prevents excessive slippage.

Do not include breaks that occur at the grip in the sample or use them in the calculations.

Use a capstan, optionally covered with an elastomeric sheath, to grip the fibre. Wrap a section of the fibre that will not be tested around the capstan several times and secure it at the end with, for example, an elastic band or masking tape. Wrap the fibre with no crossovers. The gauge length is the length of fibre between the axes of the gripping capstans before it is stretched.

Use a capstan and pulley diameter so that the fibre is not subjected to a bending stress that causes the fibre to break on the capstan. For typical silica based fibres, the bending stresses shall not exceed 175 MPa when the fibre is wrapped as shown in the figures or traverses a pulley. (For 125/250 μm – cladding/coating – silica fibre, the minimum capstan diameter is then 50 mm.) Provide a capstan surface tough enough that the fibre does not cut into it when fully loaded. This condition can be determined by pre-testing.

A.1.2 Stressing application

Elongate the fibre at a fixed strain rate until it breaks. The rate of elongation is expressed as percentage per minute, relative to the gauge length. Two examples for doing this are as follows:

a) increase the separation between the gripping capstans by moving one or both of the capstans at a fixed rate of speed, with the starting separation equal to the gauge length (figure A.1); or
b) rotate one or both of the gripping capstans, to take up the fibre under test (see figures A.2 and A.3).

The strain rate is the change in length between the two locations, in per cent, divided by the time.

If method b) is used, ensure that the fibre on the capstan does not cross over itself as it is wrapped.

If fibres are tested simultaneously, protect each fibre from adjacent fibres so that whiplash at fracture does not damage other fibres under test.

A.1.3 Fracture force measurement

Measure the tensile stress during the test and at fracture for each test fibre by a load cell, calibrated to within 0,5 % (0,005) of the fracture or maximum load, for each range of fracture stress. Calibrate the load cell while oriented in the same manner as when testing the fibre under load. For method b), use a light, low-friction pulley (or pulleys) in place of the non-rotating capstan (see figure A.2), or the rotating capstan (see figure A.3), when calibrating load cells with a string and calibration weight.

Use a string, attached at one end to the load-measuring device (or its capstan), to duplicate the direction of an actual test fibre and be of a thickness or diameter comparable to that of a test fibre. A minimum of three calibration weights are recommended for load cell calibration which bracket the typical fracture or maximum load (50 % below maximum, maximum and 50 % above maximum).

Recording the maximum tensile load at the time of fracture may be obtained for example by a strip chart recorder. The response time shall be sufficient to report the fracture stress within 1 % of the actual value.

NOTE Frictional effects from the pulleys can lead to substantial errors in the load cell calibration of rotating capstan testers for horizontally mounted fibre.

A.1.4 Strain rate control

Determine the setting for the speed control unit by trial in order to meet the specified strain rates. Express the strain rate as a percentage of gauge length per unit time. Unless otherwise specified in the detail specification, the maximum strain rate shall be equal to or less than 100 %/min. Select the actual maximum strain rate by taking into account aspects of the test method such as equipment considerations, material properties of the samples, etc. In addition to the maximum rate, use three additional strain rates, each reduced sequentially by roughly a power of 10 from the maximum.

It is possible to minimize test duration by using a faster strain rate in conjunction with a reduced load. For example, if a strain rate of 0,025 %/min is specified, test some specimens at the next fastest rate (0,25 %/min) to establish a range of fracture stress. Then pre-load to a level equal to or less than 80 % of the lowest fracture stress found for the initial trial specimens at the next fastest rate.

A.1.5 Stress rate characterization

The stress rate may vary with fibre type, equipment, breaking stress, fibre slippage, and strain rate. Characterize the stress rate, $\dot{\sigma}_\mathrm{a}$, at each strain rate used in the fatigue calculation according to:

$$\dot{\sigma}_\mathrm{a} = \frac{0{,}2 \times \sigma_\mathrm{f}}{t\,(\sigma_\mathrm{f}) - t\,(0{,}8 \times \sigma_\mathrm{f})} \tag{A.1}$$

where

σ_f is the fracture stress;

$t(\sigma_\mathrm{f})$ is the time to fracture;

$t(0{,}8 \times \sigma_\mathrm{f})$ is the time at 80 % of the fracture stress.

A.2 Test sample

A.2.1 Sample size

Because of the variability of test results, test a minimum of 15 specimens for each strain rate, and drop the lowest breaking fracture stress data point for each strain rate. Alternatively, if the standard error of estimate of slope σ_f vs. $\dot{\sigma}_\mathrm{a}$ is 0,0017 or greater (as explained in F.2), test a minimum of 30 specimens for each strain rate and drop the lowest two breaking fracture stress data points for each strain rate.

A.2.2 Sample size (optional)

As explained in clause A.2.1, additional specimens may be required for some applications in which the confidence interval on the estimate of the dynamic (tension) stress corrosion susceptibility parameter, n_d needs to be known. Refer to table F.1 for various sample sizes, depending upon the expected dynamic Weibull slope, m_d. Appropriate use of the algorithm in clause F2 is restricted to tests in which the same sample size is specified for each strain rate.

A.3 Procedure

This procedure describes how to obtain fibre fracture stress on a given sample set tested at a given strain rate. Calculations of population statistics are presented in clause F.2.

A.3.1 Set and record the gauge length (see A.1.2).

A.3.2 Set and record the strain rate (see A.1.4).

A.3.3 If method a) of A.1.4 is used, return the gripping capstans to the gauge length separation.

A.3.4 Load the test specimen in the grips, one end at a time. The tangent point of the fibre shall be in the same location as that for the load calibrations. Guide each specimen so that the fibre makes at least the required number of turns around the capstan without crossing over itself.

A.3.5 Re-set the load recording instrument.

A.3.6 Start the motor to stress the fibre. Record the stress vs. time until the fibre breaks. Stop the motor.

A.3.7 Repeat steps A.3.3 through A.3.6 for all fibres in the sample set.

A.3.8 Calculate the fibre fracture stress, σ_f, for each break. Use equation (A.2).

A.3.9 Calculate the stress rate, $\dot{\sigma}_a$.

A.3.10 Complete the required population statistic calculations. Use equations (A.3) to (A.6).

A.4 Calculations

A.4.1 Fracture stress

The following method can be used to calculate the fracture stress, σ_f, when the coating contribution is negligible (less than 5 %), such as on common 125 µm diameter fibre with a coated diameter of 250 µm (polymer coating):

$$\sigma_f = T/A_g \tag{A.2}$$

where

T is the force (tension) experienced by the composite specimen at fracture;

A_g is the nominal cross-sectional area of the glass fibre.

A more complete method is given in clause F.3 for use when the coating contribution is important.

A.4.2 Fracture stress at a given strain rate

The following steps are required to form a Weibull plot characterizing the population.

a) Sort the fracture stresses from minimum to maximum. Assign a rank, *k,* to each. Rank is the order, e.g. first is the weakest, second is the next weakest, etc. Assign a different rank to each break, even if several breaks have the same fracture stress.

b) Calculate the cumulative probability of failure, F_k, for each break:

$$F_k = (k - 0{,}5)/N, \qquad k = 1, 2, \ldots N \tag{A.3}$$

where N is the sample size.

c) Graph ln [–ln (1 – F_k)] vs ln (σ_f) to form the Weibull plot.

NOTE Special Weibull graph paper is available for this.

d) Label the plot with the required information.

For a given gauge length and diameter, the dynamic fatigue Weibull plot is associated with the following cumulative probability function:

$$F_k = 1 - \exp\left[-(\sigma_f/\sigma_o)^{md}\right] \qquad \text{(A.4)}$$

Let $k(P) = P \times N + 0{,}5$ define a rank associated with a given probability, P.

If $k(P)$ is an integer, let $\sigma_f\ (P) = \sigma_{fk}\ (P)$, the fracture stress of the $k(P)^{th}$ rank. If $k(P)$ is not an integer, let k_1 be the integer below $k(P)$ and $k_2 = k_1 + 1$.

Then, let $\sigma_f\ (P) = (\sigma_{fk1} \times \sigma_{fk2})^{1/2}$.

The median fracture stress is σ_f (0,5). The Weibull slope is:

$$m_d = \frac{2{,}46}{\ln\left[\sigma_f(0{,}85)\right] - \ln\left[\sigma_f(0{,}15)\right]} \qquad \text{(A.5)}$$

The Weibull parameter is:

$$\sigma_o = \exp\left[\frac{0{,}3665}{m_d} + \ln\left[\sigma_f(0{,}5)\right]\right] \qquad \text{(A.6)}$$

Graph the Weibull plot for each stress rate, and determine the median fracture stress σ_f (0,5) for each stress rate.

A.4.3 Dynamic (tension) stress corrosion susceptibility parameter, n_d

The median fracture stress σ_f (0,5) as defined in A.4.2, will generally vary with constant stress rate, as follows:

$$\log\sigma_f \frac{\log\dot{\sigma}_a}{1+n_d} + \text{intercept} \qquad \text{(A.7)}$$

where intercept is the log of fracture stress at a stress rate of unity as shown in figure A.4.

Intercept can be calculated from the following:

$$\text{intercept} = \overline{Y} - (\text{slope}) \times \overline{X} \qquad \text{(A.8)}$$

Unless otherwise specified, use the algorithm in clause F.2 to calculate $\overline{X}$, $\overline{Y}$, the estimate of n_d, and the 95 % confidence interval for the test. Unless otherwise specified, the standard error of estimate of slope log σ_f vs. $\dot{\sigma}_a$ shall be less than 0,0017. Refer to clause F.2 to determine the standard error of estimate of slope.

A.5 Results

The following data shall be provided upon request:

- strain rates;
- sample size per strain rate;
- standard error of estimate;
- $\overline{X}$ and $\overline{Y}$;
- gauge length;
- test environment;
- environmental pre-conditioning time;
- fracture stress calculation method;
- Young's modulus of fibre (if taken into account);
- Young's modulus of coating(s) (if taken into account);
- Weibull plots for all strain rates (if used);
- method of calculating the stress rate.

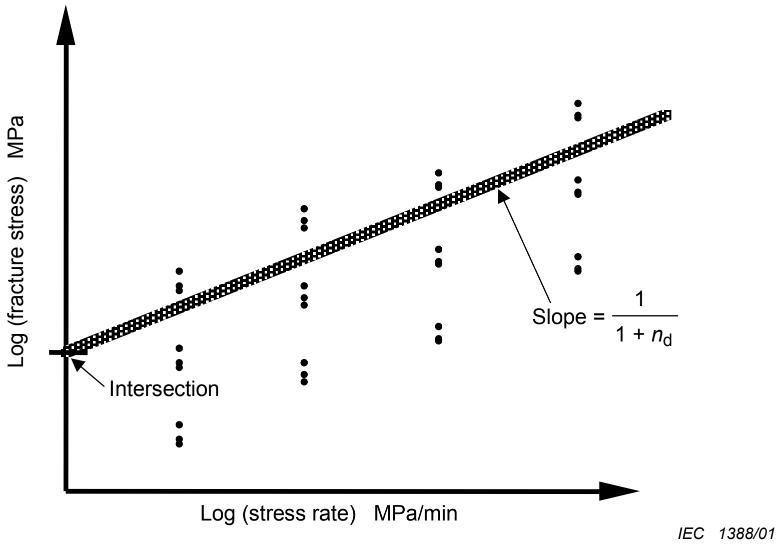


Figure A.4 – Representation of dynamic fatigue graph

Annex B
(normative)

Dynamic *n* value by two-point bending

This procedure provides a method for measuring the dynamic fatigue parameters (dynamic *n* value, n_d) of optical fibre in two-point bending at a constant platen velocity. This method is intended to test fatigue behaviour of fibres by varying the platen velocity. The test is applicable to fibres and platen velocities for which the logarithm of fracture stress versus the logarithm of platen velocity behaviour is linear.

B.1 Apparatus

A possible test apparatus is schematically shown in figure B.1. This equipment is designed to measure the strain/stress required to break an optical fibre in a two-point bending geometry by measuring platen separation at fracture. This technique is readily amenable to various test environments.

B.1.1 Stepper motor control

This device allows accurate, reliable, repeatable motorized control of the linear table. A maximum step length of 1 µm shall be used. A step length of 0,1 µm could be used for higher accuracy.

B.1.2 Stepper-motor-driven moving platen

The moving platen converts the stepper motor rotation to linear translation by means of a lead screw.

B.1.3 Stationary platen

This device holds the fibre against the moving platen.

B.1.4 Platen velocity

Place the fibre between two platens that are brought together by a computer controlled stepper motor at a specified constant platen velocity (V = constant) until the fibre breaks. Unless otherwise specified in the detail specification, use velocities 1 µm/s, 10 µm/s, 100 µm/s, 1 000 µm/s, each accurate to ±10 %.

B.1.5 Fibre fracture detecting system

One of the following techniques may be used to detect fibre fracture.

B.1.5.1 Method 1

Use an acoustic emission detector or transducer and computer to sense the fibre break and platen position at time of break. The computer then stops the platen and displays the platen separation at the time of the break.

B.1.5.2 Method 2

Incorporate a force (pressure) transducer into the stationary platen and connect it to a suitable signal conditioning equipment to measure force exerted on the fibre during the test. When the fibre breaks the force drops to zero, providing a means of detecting the break.

B.1.5.3 Method 3

Launching light through a fibre during the test and monitoring the output signal is another technique for detecting fibre fracture. When the fibre breaks, the transmission is lost.

With all of the techniques above calculate the platen separation at fracture *d* as:

$$d = \text{platen starting position} - \text{platen travel} \qquad \text{(B.1)}$$

B.2 Test sample

The test sample is a length of coated optical fibre approximately 30 mm to 120 mm long. The glass diameter shall be known to ±1 µm and coating diameter shall be known to ±5 µm. Unless otherwise specified in the detail specification, the sample size for each velocity shall be at least 15 specimens.

B.3 Procedure

B.3.1 The following is one example of a calibration procedure. Set the distance between the platen to zero when the faces of the platen are completely touching. When contact is made, the readout on the stepper motor controller should be zero. The platen separation value *d* when the fibre breaks may be verified by checking the distance with a gauge block. The zero position should be repeatable to ±5 µm.

NOTE The surfaces of the platen should be carefully cleaned before they are run together for touching.

B.3.2 Unless otherwise specified in the detail specification, set the initial fibre platen opening gap to 12,00 mm including groove depths.

B.3.3 Before a population of fibres for a given platen velocity is tested, break an identical fibre from the same group to determine the platen separation at fibre fracture. This platen separation *d* is used to calculate the breaking stress (equation (B.2), (B.3) and B.4)). An initial (starting) platen separation can be determined from equations (B.2), (B.3), (B.4) and (B.5) using a value of stress equal to 50 % of the breaking stress. This will allow the duration of the test to be reduced and the highest platen velocities to be achieved, since the maximum stepper motor speed may limit the maximum obtainable platen velocities.

It is possible to minimize test duration by using a faster platen velocity in conjunction with a reduced load. For example, if a platen velocity of 1 µm/s is specified, test some specimens at the next fastest rate (10 µm/s) to establish a range of fracture stresses. Then preload to a level equal to or less than 80 % of the lowest fracture stress found for the initial trial specimens at the next fastest rate.

B.3.4 Carefully grasp both ends of the test specimen, bend it carefully, and insert it between the platen, then pull it upwards to position it as shown in figure B.2. Do not touch the bent fibre (gauge length) with fingers when handling or loading fibres. The apex of the fibre should always be at the same position in the fixture. This minimizes the effect of a non-parallel platen. Fibre orientation, whether up or down, does not matter.

B.3.5 After the specimen has broken, brake the stepper-motor to a stop and record the platen separation at the break.

B.3.6 Repeat steps B.3.1 to B.3.5 for each fibre sample at the specified load rate, and for all samples at the other specified load rates.

B.3.7 Calculate the fibre fracture stress, σ_f, for each break, using equations (B.2) to (B.4).

B.3.8 Complete the required population statistic calculations, using equations (B.5) to (B.6).

B.4 Calculations

B.4.1 Fracture stress

Calculate the fracture stress of each fibre by:

$$\sigma_f = E_o \times \varepsilon_f \left(1 + 0{,}5 \times \alpha' \times \varepsilon_f\right) \tag{B.2}$$

$$\varepsilon_f = 1{,}198 \frac{d_f}{d - d_c + 2d_g} \tag{B.3}$$

$$\alpha' = 0{,}75 \times \alpha - 0{,}25 \tag{B.4}$$

where

σ_f is the fracture stress in GPa;

E_o is the Young's modulus (72 GPa);

ε_f is the fracture strain at the apex of the fibre;

α is the correction parameter for non-linear stress/strain behaviour (typical value for α is 6);

d_f is the glass fibre diameter in μm;

d is the distance between platen at fibre fracture in μm;

d_c is the overall fibre diameter including any coating in μm;

$2d_g$ is the total depth of both grooves in μm (see figure B.2).

B.4.2 Dynamic (two-point bending) stress corrosion susceptibility parameter, n_d

The median fracture stress, σ_f (0,5), will generally vary with constant platen velocity, V, according to:

$$\mathrm{Log}\,\sigma_f(0{,}5) = \frac{1}{n_d - 1} \times \log \frac{V}{r} + \text{intersection} \tag{B.5}$$

where

r is the radius of glass fibre;

intercept is the logarithm of fracture stress at a constant platen velocity of unity as shown in figure B.3.

Intercept can be calculated from:

$$\text{intersection} = \overline{Y} - (\text{slope}) \times \overline{X} \qquad \text{(B.6)}$$

Unless otherwise specified, use the algorithm in F.2 to calculate $\overline{X}$, $\overline{Y}$, the estimate of n_d, and the 95 % confidence interval for the test. Unless otherwise specified, the standard error of estimate of slope log σ_f vs. log V shall be less than 0,0017. Refer to F.2 to determine the standard error of estimate.

B.5 Results

The following data shall be provided upon request:

- platen velocities;
- sample size for each platen velocity;
- the standard error of estimate;
- test environment;
- environmental pre-conditioning time;
- Young's Modulus of fibre glass (if assumed other than what is given in F.3);
- Weibull plots for all platen velocities (if used);
- $\overline{X}$ and $\overline{Y}$;
- fibre (glass) diameter.

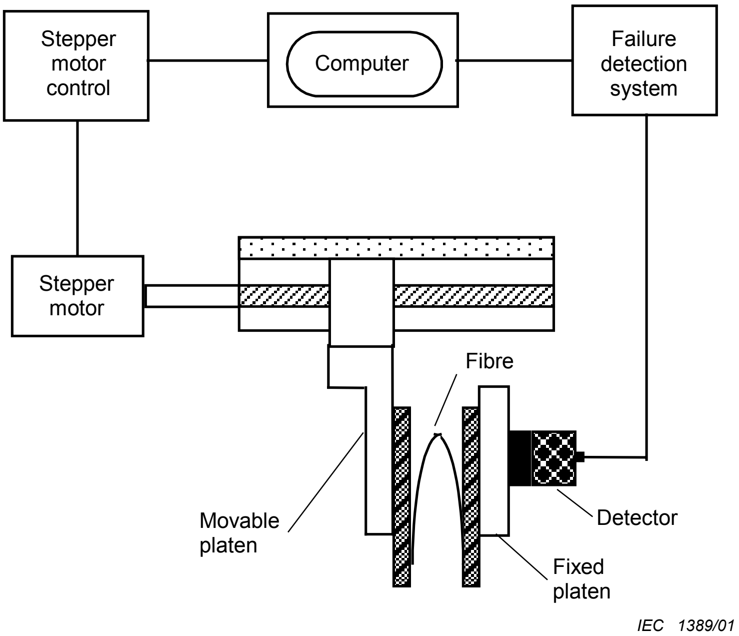
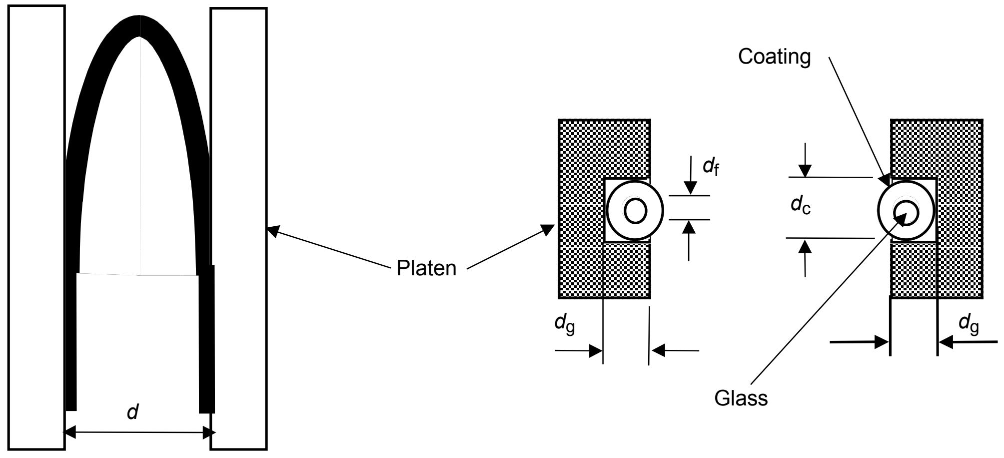


Figure B.1 – Schematic of two-point bending unit



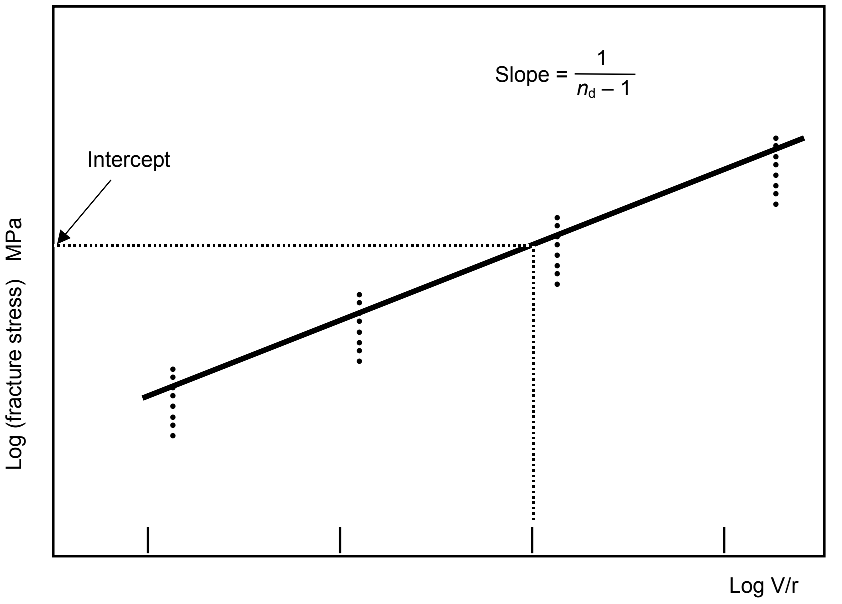
IEC 1390/01

IEC 1391/01

(a)

(b)

Figure B.2 – Schematic of surface platen



IEC 1392/01

Figure B.3 – Dynamic fatigue data schematic

Annex C
(normative)

Static *n* value by axial tension

This method is designed for determining the static fatigue parameters (dynamic *n* value, n_s) of individual optical fibre lengths under tension. This method is intended to test static fatigue behaviour of fibres by varying the applied stress levels.

C.1 Apparatus

Possible arrangements of test equipment are schematically shown in figure B.2. Each arrangement consists of a means of applying stress to a fibre and monitoring time to fracture. Unless otherwise specified in the detail specification, the gauge length, i.e. the distance between the capstans, shall be 500 mm.

C.1.1 Gripping the fibre at both ends

See A.1.1.

C.1.2 Stressing the fibre

The stress is applied on the fibre by hanging a known weight on one capstan (see figure C.1). Several specimens are tested at a given nominal stress level. The range of actual stress levels for a given nominal level can influence the quality of the measurement. For the simple median computation method, the range of stress levels for a given nominal shall be within ±0,5 % of the nominal. For the homologous method and the maximum likelihood estimate method, the individual stress levels for each specimen shall be recorded for use in the computation. See C.4.2.

C.1.3 Measuring time to fracture

There are many techniques to monitor time to fracture which can meet the requirements of this test method. One way to monitor the time to fracture is to set up timers underneath the hanging weights used to apply the stress on the fibre.

C.2 Test sample

C.2.1 Sample size for each nominal stress level

Unless otherwise specified in the detail specifications, use the sample size for each nominal stress level of at least 15.

C.3 Procedure

Test a minimum of five different nominal applied stress levels, σ_a. Choose the nominal stresses such that the median times to fracture range from about 1 h to about 30 days in roughly equal distance on the logarithmic scale. The loads necessary to achieve this for standard silica fibres are in the range of 30 N to 50 N.

Since the time to fracture is dependent on both the fracture stress of the fibre and the fatigue parameter, the actual nominal stress levels applied and the number that are applied can be determined iteratively. Alternatively, a broad range of levels may be applied at the beginning of a measurement. Data from test sets that break too soon or take too long to break may be discarded.

Upon completion of pre-conditioning, load the fibres into the unit. Monitor and record the time to fracture for each fibre fracture. When testing a sample set for a given nominal stress level, as soon as the median specimen has broken the test may be terminated early. That is, if more than half of the samples have broken, the computation can be carried out and a median time to fracture determined before all the remaining samples fail. The standard error of the estimate shall be computed and reported for each measurement. Unless otherwise specified in the detail specification, the standard error of the estimate shall be less than 1.

C.4 Calculations

C.4.1 Fracture stress

See A.4.1.

C.4.2 Static (tension) stress corrosion susceptibility parameter, n_s

Unless otherwise specified, the following method shall be used to determine n_s. Alternatively, other methods, for example homologous or maximum likelihood estimate, can be used to determine n_s (see A.4).

C.4.3 Simple median

This method does not require an assumption of linearity of the Weibull slope. Since all the data are not used, it can produce a larger standard error of the estimate than others. For each nominal stress level, σ_i, the median time to fracture, t_i, is determined. Fit the data to the following linear regression model by minimizing the sum of squared errors:

$$-n_s \ln(\sigma_i) + \text{intercept} = \ln(t_i) \tag{C.1}$$

The standard error of the estimate for n_s is reported by most statistical packages. The median of $\ln(\sigma_i)$ and the median of the $\ln(t_i)$ are also reported. The value of intercept in the above equation is as follows:

$$\text{intercept} = \text{median}\,[\ln(t_i)] + n_s\,\text{median}\,[\ln(\sigma_i)] \tag{C.2}$$

C.5 Results

The following data shall be reported:

- fibre identification;
- test date;
- static (tension) stress corrosion susceptibility parameter, n_s (other parameters are under consideration).

The following data shall be provided upon request:

- fibre diameter;
- coating diameter (if it is taken into account);
- test environment;
- gauge length;

- initial sample size for each nominal stress level and the number of nominal stress levels;
- environmental pre-conditioning time, where applicable;
- fracture stress calculation method. If the method of clause A.3 is used, Young's modulus of the coating and the glass shall be reported;
- nominal stress levels.

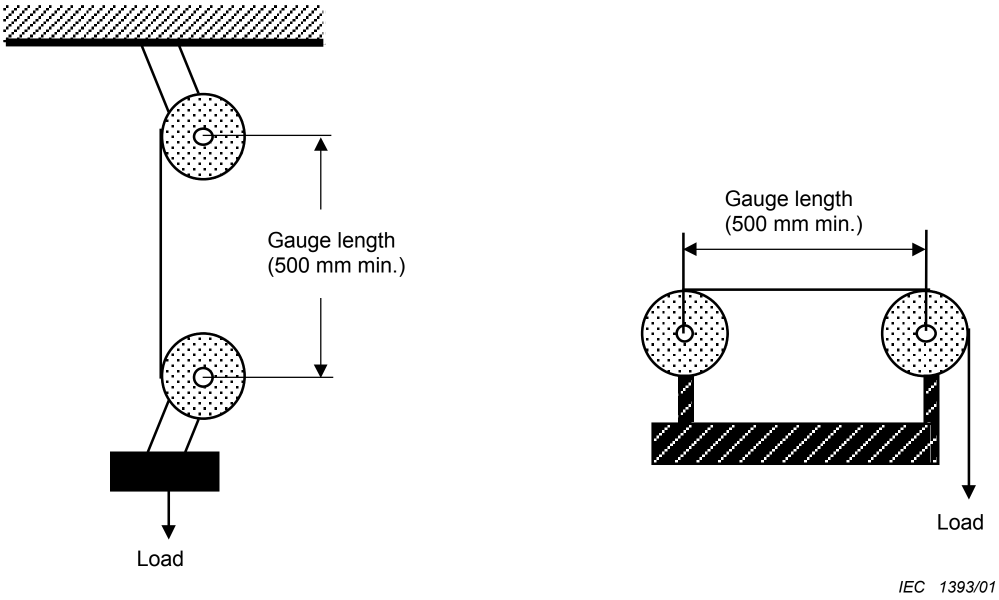


Figure C.1 – Schematic of possible static fatigue (tension) apparatus

Annex D
(normative)

Static *n* value by two-point bending

This procedure provides a method for determining the static fatigue parameters (static *n* value, n_s) of optical fibres in two-point bending.

D.1 Apparatus

D.1.1 Test equipment

A possible test equipment schematic is shown in figure D.1. The grooved, parallel plates and the spacers shall be made of thermally stable materials (e.g., stainless steel). (The spacers are used to create a required gap between platen.) Precision-bore glass tubes or precision-reamed metal plates may be used in place of the parallel plates shown in figure D.1. In this case, the walls of the tubes serve the same function as the parallel plates.

D.1.2 Fibre fracture detection

An acoustic sensor, and an appropriate monitor for output voltage, may be used for fibre fracture detection. Other methods of sensing breaks, such as launching light down the optical fibre, may also be used. The sensing equipment shall be capable of measuring the time to break with a precision equal to or better than 1 % of the elapsed time.

D.2 Test sample

The test sample is a length of coated optical fibre approximately 30 mm to 120 mm long. The glass diameter shall be known to ±1 µm and coating diameter must be known to ±5 µm. Unless otherwise specified in the detail specification, a sample size of at least 15 shall be used for each nominal stress level.

D.3 Procedure

Test a minimum of five different nominal stress levels. Choose the nominal stresses so that the median times to fracture range from about 1 h to about 30 days.

Assemble the two-point bending fixture, using spacers of appropriate height to produce the desired maximum stress at the apex of the fibre bend. To calculate the spacer height which will produce the desired value of applied stress use equations (B.2), (B.3) and (B.4). If precision-bore tubing or precision-reamed metal is used, d_g in equation (B.3) is equal to zero (0). Upon completion of pre-conditioning, load the fibres into the fixture. Record the time to fracture for each break using a detector. Ensure that the detector did not register false breaks or fail to register true breaks.

D.4 Calculations

D.4.1 Fracture stress

See B.4.1.

D.4.2 Static (two-point bending) stress corrosion susceptibility parameter, n_s

See C.4.2.

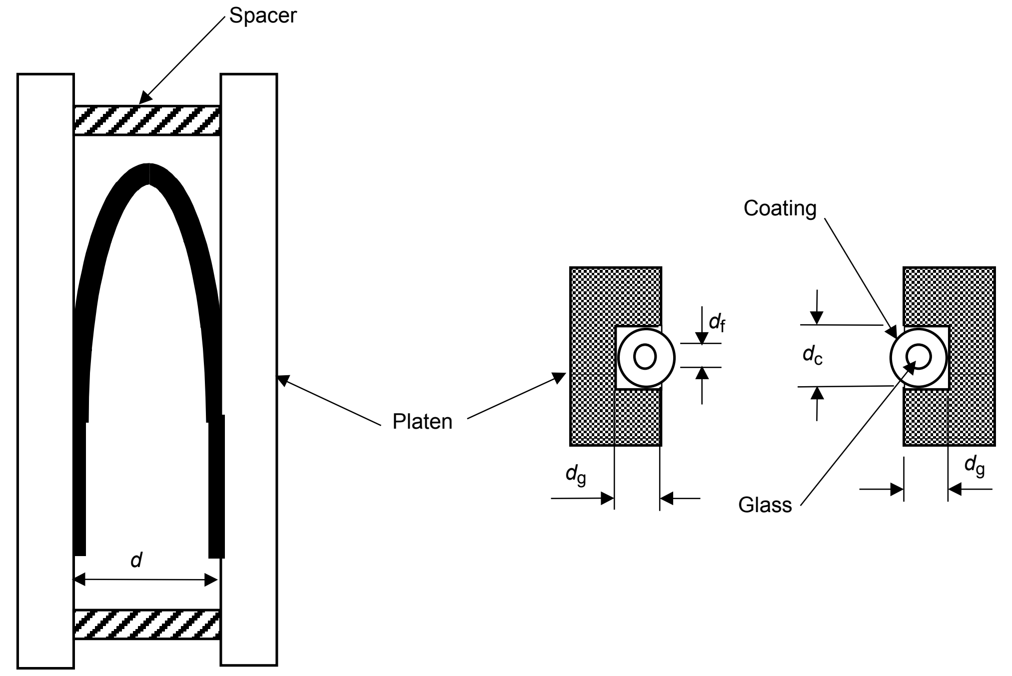
D.5 Results

The following data shall be reported:

- fibre identification;
- test date;
- static (tension) stress corrosion susceptibility parameter, n_s (other parameters are under consideration).

The following data shall be provided upon request:

- fibre (glass) diameter;
- coating diameter;
- test environment;
- modulus of elasticity of the fibre;
- initial sample size for each nominal stress level and the number of nominal stress levels;
- method of computation of n_s;
- the Weibull shape parameter, m_s, from G.2, for each strain value tested;
- the standard error of the estimate of n_s;
- nominal stress levels.



IEC 1394/01

IEC 1395/01

Figure D.1a – Plan **Figure D.1b – Section**

Figure D.1 – Schematic of possible static fatigue (two-point bending) apparatus

Annex E
(normative)

Static *n* value by uniform bending

This procedure describes a method for determining the static fatigue parameters (static *n* value, n_s) of individual optical fibre lengths in uniform bending.

E.1 Apparatus

The proposed test equipment for bending stress consists of precision mandrels of different diameters. Fibres are subjected to bending stresses by winding around a mandrel (see figure E.1).

E.1.1 Support of the sample

Grip the fibre length to be tested at both ends. The fibres can be fixed using, for example, rubber rings or glue or tape at the ends of the mandrel. Use a grip that does not allow the fibre to slip prior to fracture, and minimizes fibre fracture at the grip. Record breaks that occur at the grip, but do not consider it as part of the sample or use it in subsequent calculations.

A winding mechanism is needed to wind the test fibre on the mandrel. Wind the fibre with minimum pitch and without crossovers. Take care to avoid introducing unwanted tensile stress during winding. Sufficient winding force is needed to ensure that the fibre touches the mandrel throughout its entire length, for example 0,25 N.

E.1.2 Stressing the fibre

The stress level can be varied by the proper choice of the mandrel size. Several specimens are tested at a given nominal stress level. For the simple median computation method, use a range of mandrel diameters for a given stress level within ±0,5 % of the nominal. For the homologous method and the maximum likelihood estimate method, record the individual stress levels for each specimen for use in the computation.

E.1.3 Measuring time to fracture

There are many techniques to monitor time to fracture which meet these requirements. One way is to use an acoustic emission detector or transducer to sense the fibre break and signal the computer at the time of fracture. Another method is optical detection of the presence of the mandrel in a special holder. When the fibre breaks, the mandrel is pushed out of the holder. Optical detection of transmitted light through the fibre is yet another technique.

E.2 Test sample

Unless otherwise specified in the detail specification, use a sample size for each nominal stress level of at least 15 and a fibre length of 1 m for each test. The glass diameter shall be known to ±1 µm and coating diameter shall be known to ±5 µm.

E.3 Procedure

Test a minimum of five different nominal stress levels. Choose nominal stresses such that the median times to fracture range from about 1 h to about 30 days.

E.4 Calculations

E.4.1 Fracture stress

Calculate the fracture stress of each fibre using the following equation :

$$\sigma_\mathrm{f} = E_\mathrm{o} \times \varepsilon_\mathrm{f}(1 + 0{,}5 \times \alpha'' \times \varepsilon_\mathrm{f}) \tag{E.1}$$

$$\varepsilon_\mathrm{f} = \frac{d_\mathrm{f}}{D + d_\mathrm{c}} \tag{E.2}$$

$$\alpha'' = 0{,}75\ \alpha \tag{E.3}$$

where

σ_f is the fracture stress in GPa;

E_o is the Young's modulus (72 GPa);

ε_f is the fracture strain;

α is the correction parameter for non-linear stress/strain behaviour (typical value for α is 6);

d_f is the glass fibre diameter in µm;

D is the mandrel diameter in µm;

d_c is the overall fibre diameter including any coating in µm.

E.4.2 Static (uniform bending) stress corrosion susceptibility parameter, n_s

See C.4.2.

E.5 Results

The following data shall be provided upon request :

- fibre (glass) diameter;
- coating diameter;
- mandrel diameters;
- test environment;
- the standard error of the estimate of n_s;
- length of fibre wound on mandrels;
- winding force;
- initial sample size for each test set and the number of test sets;
- number of mandrels in each batch of mandrel diameters.

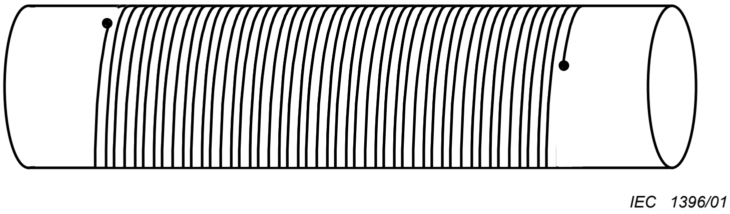


Figure E.1 – Schematic of possible static fatigue (uniform bending) apparatus

Annex F
(informative)

Considerations for dynamic fatigue calculations

F.1 Specimen size and sample size

F.1.1 Specimen size

Fracture stress testing is statistical in nature. Many individual fibres, each of which is representative of a given population, shall be tested for fracture stress. The result is reported for the population as a whole, as a probability distribution.

The product sample size and gauge length determines the extent to which the population is represented and the range of measured probability. The gauge length also affects the result since, in general, the measured fracture stress decreases as the gauge length increases.

F.1.2 Sample size

In practice, identical flaws cannot be pre-selected for testing at each of the strain rates. Instead, sampling is required to estimate the behaviour of the mean flaw. The confidence interval width of the test is governed by the lack of similarity of flaws tested at different strain rates. That is, the confidence interval is a measure of the fatigue test precision, not a direct measure of a fibre attribute.

Table F.1 gives a typical confidence interval for various combinations of dynamic stress corrosion susceptibility parameter, n_d, the Weibull slope, m_d and the sample size per strain rate. These results are from Monte Carlo simulation of an ideal Weibull distribution in conjunction with fatigue behaviour defined by equation (A.1). Four strain rates, each separated by an order of magnitude, are used in the simulation.

Table F.1 – 95 % confidence interval for n_d

Actual n_d	m_d	Sample size per strain rate			
		15	30	45	60
10	15	8,7 – 11,0	9,3 – 10,8	9,5 – 10.5	9,5 – 10.5
"	30	9,5 – 10,5	9,6 – 10,4	9,7 – 10,3	9,8 – 10,3
"	60	9,7 – 10,3	9,8 – 10,2	9,9 – 10,2	9,9 – 10,1
"	90	9,8 – 10,2	9,9 – 10,1	9,9 – 10,1	9,9 – 10,1
20	15	16,7 – 24,0	17,6 – 23,2	18,3 – 22,6	18,4 – 22,0
"	30	18,2 – 22,0	18,9 – 21,6	19,5 – 22,6	19,2 – 21,0
"	60	19,1 – 21,1	19,5 – 20,9	19,8 – 20,5	19,6 – 20,5
"	90	19,5 – 20,8	19,6 – 20,7	19,8 – 20,5	19,8 – 20,4
30	15	22,8 – 39,2	24,9 – 37,1	26,2 – 35,5	26,6 – 34,4
"	30	26,0 – 34,1	27,3 – 33,3	28,0 – 32,7	28,3 – 32,3
"	60	28,0 – 32,0	29,2 – 31,2	29,4 – 31,0	29,2 – 31,2
"	90	28,7 – 31,4	29,2 – 31,2	29,4 – 31,0	29,3 – 30,8
50	15	33,2 – 80,6	37,5 – 72,3	40,5 – 67,3	41,5 – 63,7
"	30	40,0 – 62,2	43,0 – 59,8	45,0 – 57,7	45,6 – 56,4
"	60	44,6 – 55,8	46,5 – 54,7	48,1 – 53,8	47,9 – 53,3
"	90	46,4 – 53,9	47,8 – 53,3	49,1 – 52,7	49,0 – 52,3
100	15	49,8 – 380,0	60,8 – 258,7	68,5 – 198,0	71,2 – 170,7
"	30	67,1 – 162,3	76,1 – 147,7	81,5 – 135,1	83,9 – 129,7
"	60	81,5 – 125,8	87,2 – 120,7	90,4 – 116,2	92,2 – 114,4
"	90	87,4 – 123,2	91,7 – 113,8	93,9 – 110,8	95,2 – 110,0

F.2 Numeric algorithm for calculation of dynamic stress corrosion susceptibility parameter, n_d

This algorithm calculates the estimate of n_d and the 95 % confidence interval of the estimate with the homologous least squares method. Appropriate use of the algorithm is restricted to tests in which the same sample size is specified for each strain rate.

σ_{ij} is the fracture stress of j^{th} break on the i^{th} strain rate, and

$\dot{\sigma}_a$ is the stress rate for the i^{th} strain rate.

Let $y_{ij} = \log(\sigma_{ij})$ for $i = 1$ to L, the number of strain rates, and

for $j = 1$ to N_j, the number of specimens for each rate.

Let $x_i = \log \dot{\sigma}_a$

Let $N = \Sigma N_i$ Let $\bar{Y} = \sum_{i=1}^{L} \sum_{j=1}^{N_i} \frac{y_{ij}}{N}$ Let $\bar{X} = \sum \frac{(N_i x_i)}{N}$

Let $XX = \left(\sum_{i=1}^{L} N_i x_i^2 \right) - N\bar{X}^2$ Let $YY = \left(\sum_{i=1}^{L} \sum_{j=1}^{N_i} y_{ij}^2 \right) - N\bar{Y}^2$

Let $XY = \left(\sum_{i=0}^{L} \sum_{j=0}^{N_i} X_i Y_{ij} \right) - N\bar{X}\bar{Y}$

$S = \frac{XY}{XX}$ = slope Let SEE $= \sqrt{\frac{(YY - S \times XY)}{(XX \times (N - 2))}}$

where SEE is standard error of estimate S.

Let $S_U = S - 1{,}96 \times \text{SEE}$ Let $S_L = S + 1{,}96 \times \text{SEE}$

then $n_d = \frac{1}{S} - 1$, $n_{dU} = \frac{1}{S_U} - 1$, $n_{dL} = \frac{1}{S_L} - 1$

where n_{dU} and n_{dL} form the 95 % confidence interval on estimate, n_d.
Calculate intercept $= \bar{Y} - (S \times \bar{X})$

where slope is: slope $= \frac{1}{n_d + 1} = S$

F.3 Complete method to calculate fracture stress

Compensation for load sharing by coating:

Calculate the fraction, F, of the tension carried by the protective coating to be

$$F = \frac{E_2(D_2^2 - D_1^2) + E_1(D_1^2 - D_g^2)}{[E_2(D_2^2 - D_1^2) + E_1(D_1^2 - D_g^2)] + E_g D_g^2}$$

where
E_g is Young's modulus of the glass fibre, in Pa;
E_2 is Young's modulus of the second coating layer, in Pa;
E_1 is Young's modulus of the first coating layer, in Pa;
D_g is the nominal diameter of the glass fibre, in µm;
D_2 is the nominal diameter of the second coating layer, in µm;
D_1 is the nominal diameter of the first coating layer, in µm.

Use values for E_2 and E_1 that are consistent with the operating temperature, humidity and strain rate. A worst case overestimate of the coating contribution can be made by replacing the modulus of the inner primary coating by the larger modulus of the outer primary coating. In this way, the diameter and modulus of the inner primary coating need not be known.

Calculate the corrected proof test tension, T_a (N), to be applied to the coated fibre as follows:

$$T_a = \frac{(0{,}0008) D_g^2 \sigma_p}{(1 - F)}$$

where

D_g is the nominal diameter of the glass fibre, in μm;

σ_p is the proof stress, in GPa;

F is the fraction of the load carried by the coating.

Annex G
(informative)

Considerations for static fatigue calculations

G.1 Homologous method

This method uses all the data, but requires an assumption that the Weibull plot of each set is the same and linear. Since it uses all the data, it will often produce a smaller standard error of the estimate.

Let t_{ij} be the time to fracture of the j^{th} specimen in the i^{th} nominal stress level. Let σ_{ia} be the nominal stress level of that specimen. Let N_i be the number of the samples in the i^{th} test set. For each *i, j,* compute the Weibull parameter, w_{ij}:

$$w_{ij} = \ln\{-\ln[1 - (j - 0{,}5)/N_i]\}$$

Fit the data to the following linear regression model by minimizing the sum of squared errors:

$$a \times \ln(t_{ij}) + b \times \ln(\sigma_a) + \text{const} = w_{ij}$$

$n_s = b/a$ is reported as the estimate.

The standard error of the estimate is approximated with the variance and co-variance of *a* and *b*, along with their values. The variance and co-variance terms are reported by most statistical packages.

$$\mathrm{Var}(n) = \mathrm{Var}(a)/a^2 + (b/a^2)^2\ \mathrm{Var}(a) - 2(b/a^2)\ \mathrm{Cov}(a,b)$$

The standard error of the estimate is $[\mathrm{Var}(n)]^{1/2}$.

The median of $\ln(t_{ij})$ and $\ln(\sigma_a)$ are reported.

G.2 Maximum likelihood estimate

This method also requires an assumption that the Weibull plot for each nominal stress level is derived from a single underlying fracture stress distribution and that it is linear. This method gives the best results, but it is the most complicated. The method can accurately treat the case for which data are truncated by way of aborting a test before all samples break. Statistical packages are available to complete the computation. It is based on the following probability model:

$$F = 1 - \exp[-(t_f/t_o)m_s]$$

where

F is the cumulative fracture probability for fracture time t_f;

t_o is the Weibull scaling parameter;

m_s is the static Weibull shape parameter.

Annex H
(informative)

Considerations on stress corrosion susceptibility parameter test methods

H.1 Introduction

The test methods in this standard describe a number of test methods which can be used to determine the stress corrosion susceptibility parameter of an optical glass fibre. This guide is intended to give some background concerning this mechanical parameter and to show the relation between the results of the different test methods.

H.2 Crack growth

A1, A2 and A3c type multimode fibres and B type single-mode fibres are made from silica glass which consists of ring structures of SiO_4 tetrahedrals. The mechanical bonds of these tetrahedrals should result in a fracture stress of 20 GPa (i.e. inert strength, without crack growth). Stress concentration at crack tips causes the fibre to fracture at lower stress levels [1] [2] This stress concentration is characterized by the stress-intensity factor:

$$K_I = Y\sigma\sqrt{a}$$

where

Y is the geometrical factor;

a is the crack depth;

σ is the applied stress.

Fracture occurs when K_I reaches the critical value K_{Ic} of about 0,8 MPa [2], [3]. For a semi-elliptical or semi-circular crack Y = 1,24 [2]. Hence a unique relation exists between crack depth and fracture stress.

In practice, lower fracture stresses are observed than would follow the relation between crack depth and fracture stress. Moreover the fracture stress of optical fibres is dependent on time. This can be explained by crack growth due to a stress chemical reaction, which breaks the bonds. The experimental condition, especially water, is an important factor for this crack growth (da/dt). The stress-induced corrosion of silica glass is usually described by a power law, where the crack growth velocity, v, is equal to Ak_I^n, with A a scale factor for the speed of crack growth and n the stress corrosion susceptibility parameter [1]. In fibre reliability models this power law is often used [5], which shows the importance of determining the n value. This value may depend on specific characteristics of the glass fibre and/or its coating [6], [7], [8], [9].

The test methods described in this standard test only relative short length of fibres, resulting in stress corrosion data of the intrinsic strength distribution.

---

[2] Figures in square brackets refer to the bibliography

In practice the weak flaws in optical fibres (i.e. extrinsic strength distribution, below the intrinsic strength) lead to fibre fracture. It would therefore be appropriate to use also the stress corrosion susceptibility parameter of these weak flaws for lifetime calculations. Because this parameter is very difficult to determine, at present the stress-induced corrosion of the intrinsic strength distribution is used. This is justified by experiments on abraded fibres, which show that this choice reflects even a worst case situation. The n value of abraded fibres has been found higher than those of the intrinsic strength distribution [5], [10], [11], [12], [13].

H.3 Types of stress corrosion susceptibility test methods

The stress corrosion susceptibility parameter obtained for standard optical glass fibres is generally found between 17 and 40, the higher value showing a slower crack growth. These differences can mainly be explained because of differences in measurement techniques. In practice, two families of fatigue tests are used: static tests and dynamic tests. The following tests are described in this standard:

Dynamic tests:

- method 60793-1-33-A: Dynamic n value by tension,
- method 60793-1-33-B: Dynamic n value by two-point bending.

Static tests:

- method 60793-1-33-C: Static n-value by tension,
- method 60793-1-33-D: Static n-value by two-point tension,
- method 60793-1-33-E: Static n-value by uniform bending.

As indicated in the present test methods, these tests are performed in standard room environments. The results from these tests should not be used for reliability estimates which differ from the standard environment.

In order to compare both families of fatigue tests, it is possible for the dynamic fatigue test to translate the loading history into an 'effective' static time-to-fracture, t_{eff} [14].

For tensile testing, t_{eff} is written as

$$t_{\mathrm{eff}} = \frac{\sigma_{\mathrm{d}}}{\dot{\sigma}} \times \frac{1}{(n+1)} = \frac{t_{\mathrm{d}}}{(n+1)}$$

with $\sigma(t) = \dot{\sigma}\, t$, in which $\dot{\sigma}$ is the stress rate and the dynamic fatigue strength $\sigma_{\mathrm{d}} = \dot{\sigma}_{\mathrm{td}}$ with t_{d} the dynamic time-to-fracture.

This equation assumes all the crack growth parameters are constant. For other test methods, where the stress is not directly measured (e.g. fibre exposed to strain or bending), the data should be transformed to stresses (see [14]). In this way, the dynamic fatigue strength can be plotted (log/log) versus the effective time-to-fracture, in the same way as for the static fatigue test.

H.4 Comparison of *n* value obtained with different methods

In a round robin test performed by COST 218 in Europe [14], almost all stress fatigue test methods have been used. The results are shown in figure H.1 and demonstrate a variation in measured fracture stress. Dependent on the test method, the results seem to be shifted vertically upon each other, due to differences in the effective tested glass fibre surface (length and geometry).

Figure H.2 shows the results, corrected for these differences in glass area [8], [14], leading to a reduced scatter in the 'effective' fracture stress. The stress corrosion, described by the power law, results in straight lines (constant *n*) when time-to-fracture and applied stress are plotted on a log/log plot. Figure H.2 indicates that the fracture stress gradually decreases with increasing time-to-fracture; simultaneously the slope decreases (*n* increases). This effect is probably due to a time effect of the glass surface; it may be caused by crack blunting [13], [15], which competes with stress corrosion [16]. Some investigators even expect a fatigue limit [12], [17].

The two basic families of test methods, the dynamic and the static tests, can be recognized in figure H.2. The dynamic fatigue test methods generally operate in small time frames, reduced to even smaller effective time frames, in combination with a high failure strength. These tests show in general a smaller stress corrosion susceptibility parameter (n_d). The static test methods can operate in somewhat longer measurement times and consequently at lower applied stress levels; larger n_s values are obtained.

H.5 Conclusion

In comparing the results between different fatigue tests one can translate between dynamic time-to-fracture and effective static time-to-fracture. Furthermore, the fracture stress level needs to be corrected for the effective glass area under test.

Having made these corrections, the stress corrosion susceptibility parameter is shown not to be constant with varying effective time-to-fracture (see figure H.2). This explains in general the different rules between dynamic and static fatigue test methods.

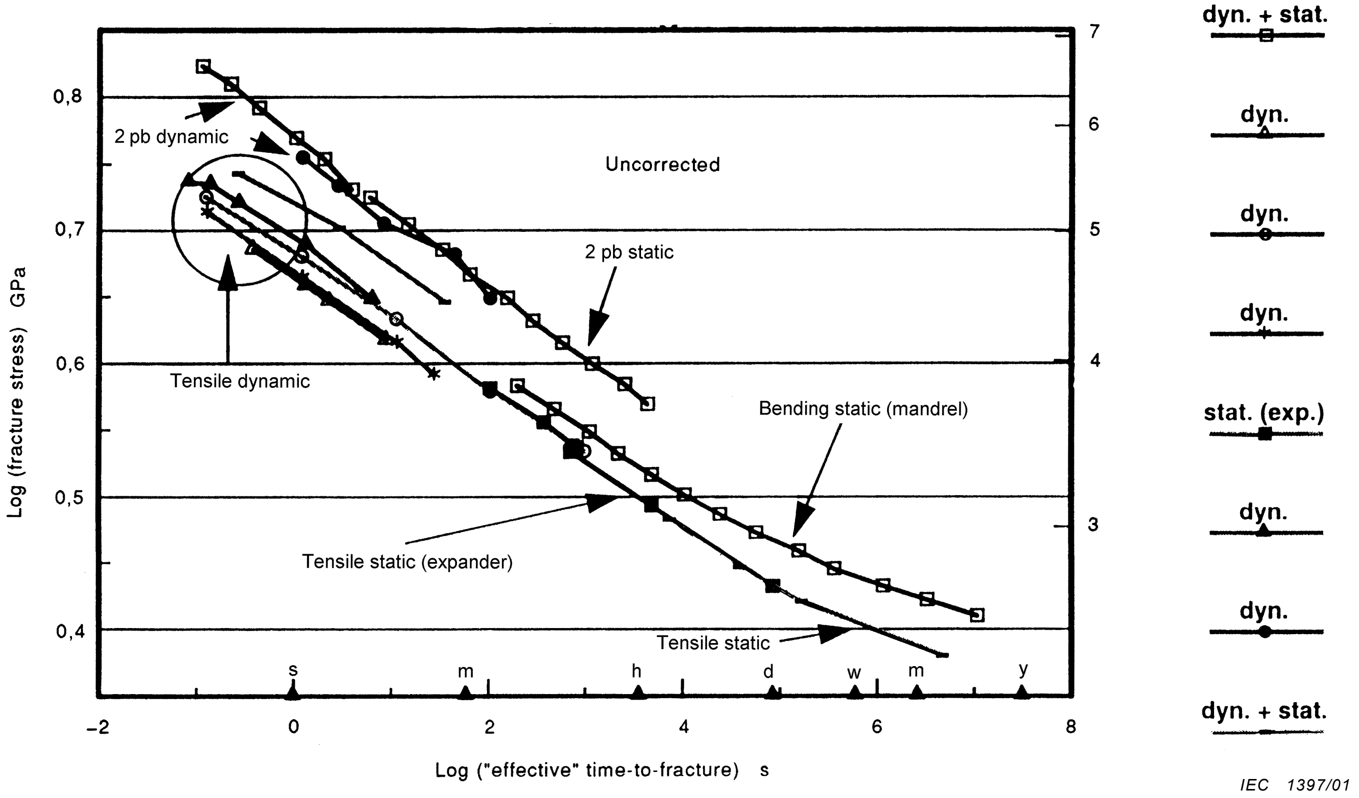


Figure H.1 – The results of the round robin fracture strength versus time

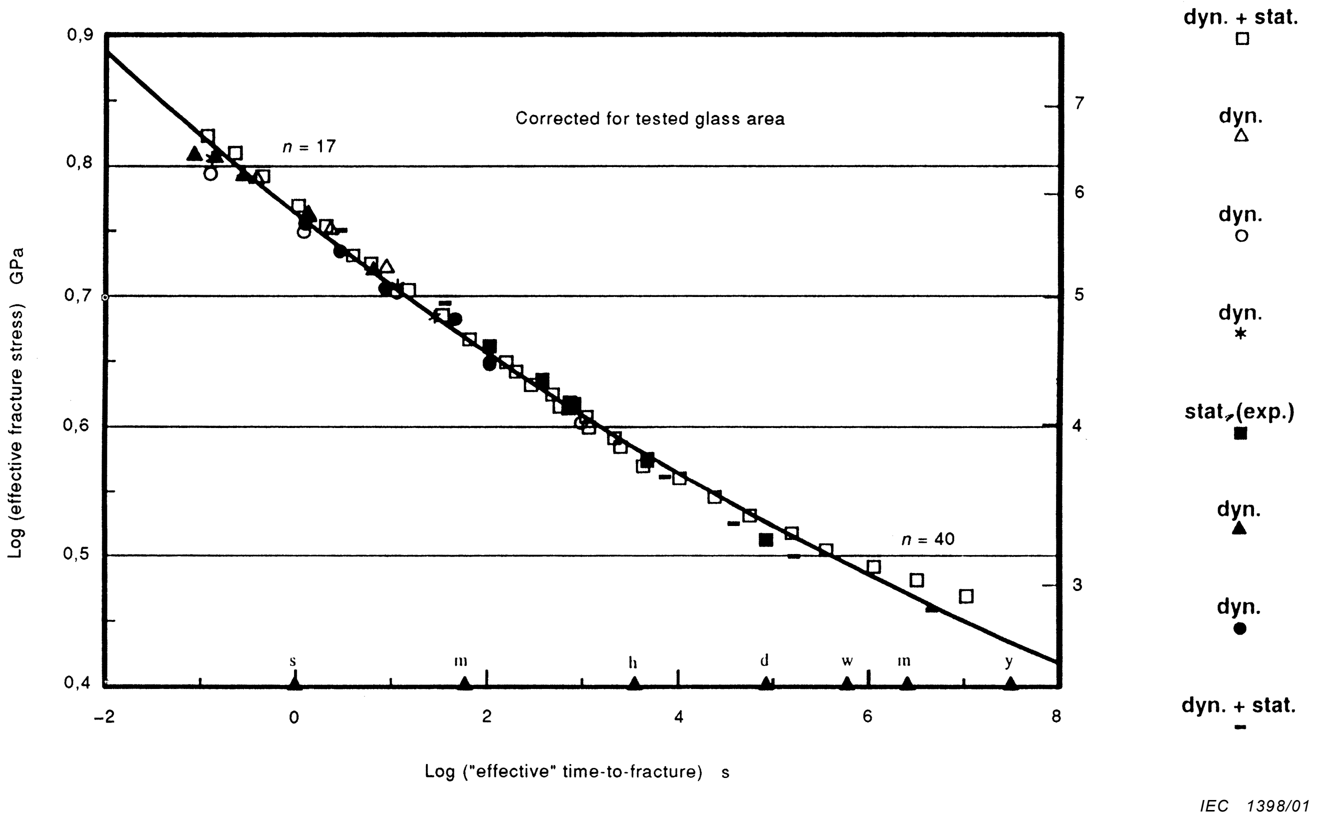


Figure H.2 – The results of the round robin fracture strength versus time

Bibliography

[1] EVANS, AG. and WIEDERHORN, SM. Proof testing of ceramic materials – an analytical basis for failure prediction. *Int. J. Fract.*, 1974, 10, p. 379-392.

[2] KALISH, D. and TARIYAL, BK. Static and dynamic fatigue of a polymer-coated fused silica optical fiber. *J. Am. Ceram, Soc.* (USA), 1981, 61, p. 518-523.

[3] BOGATYRJOV, VA., BUDNOV MM., DIANOV EM., RUMYANTZEV SD., SEMJONOV SI. Mechanical reliability of polymer coated and hermetically coated optical fibers based on proof testing. *Optical Engineering*, June 1991, vol. 30, no. 6, p. 690 – 699.

[4] *Power Law Theory of Optical Fibre Reliability*, TIA TSB-61, August 1994.

[5] GRIFFIOEN, W., BREULS, T., COCITO, G., DODD, S., FERRI, G., HASLOV, P., OKSANEN, L., STOCKTON, D., SVENSSON T. COST 218 evaluation of optical fibre lifetime models. SPIE Vol. 1791, *Optical Materials Reliability and Testing*, 8-9 September 1992, Boston, MA, USA.

[6] GULATI ST., HELFINSTINE, JD., GLAESEMANN, GS., ROBERTS, DR., CUELLER, E., MIDDLEMAN, LM. Improvements in optical fiber reliability via high fatigue resistant composition. SPIE Vol. 842, *Fiber Optics Reliability: Benign and Adverse Environments*, 1987, p. 22-31.

[7] BOGATYRJOV, VA., BUBNOV, MM., GURYANOV, AN., VECHKANOV NN., DEVYATYKH, GG., DIANOV, EM., SEMJONOV, SL. Influence of various pH solutions on strength and dynamic fatigue of silicon-resin-coated optical fibres. *Eletr. Letters*, 11th Sept. 1986, Vol. 22, No. 18, p. 1013-1014.

[8] MATTHEWSON, MJ., KURKJIAN, CR., GULATI, ST. Strength Measurement of optical fibers by bending, *J. Am. Ceram. Soc.*, 69 [11], 1986, p. 815-821.

[9] LECLERCQ, JW. and BREULS, AHE*. Influence of adhesion promoters on the aging characteristics of optical fibers in water*. Submitted to SPIE int. symposium on optics, imaging, and instrumentation (fiber optic materials and components), 24-29 July 1994, San Diego.

[10] CRAIG, SP., DUNCAN, WJ., FRANCE, PW., SNODGAS, JE. The strength and fatigue of large flaws in silica optical fibre. ECOC, 1982, p. 205-208.

[11] GLAESEMANN, GS., ESTEP, MG., HELFINSTINE, JD., CARR, JJ*. Examining the mechanical behavior of intrinsic and extrinsic flaws in optical glass fiber.* 94th annual meeting of the Am. Cer. Soc., 4-JXVI-92, April 1992, Minneapolis.

[12] BREULS, A. and SVENSSON, T. Strength and fatigue of zirconia induced weak spots in optical fibre. SPIE, September 1993, Boston.

[13] YUCE, HH., KEY, PL., CHANDAN, HC. Aging behavior of low strength fused silica fibres. SPIE. Vol. 1366, *Fiber optics reliability benign and adverse environments IV*, 1990, p. 120-128.

[14] BREULS, A. *A COST 218 comparison of n-values obtained with different techniques*. Proceedings of OFMC'93, 1993, Torino, p. 9-12.

[15] GULATI, S. Reliability considerations for long length optical fibres. 4th IWCS, 1992, p. 612-621.

[16] GRIFFIOEN, W. Effects influencing measurements of optical fibre corrosion susceptibility. Proceedings of OFMC'93, 1993, Torino, p. 13-16.

[17] KURKJIAN, C. *et al.* Current issues in mechanical reliability of optical fibres. 41th IWCS, 1992, p. 599-604.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC/TR 62048	- [1]	The law theory of optical fibre reliability	-	-

---

[1] To be published.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001.
Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001.
Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

Details and advice can be obtained from the Copyright & Licensing Manager.
Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553.
Email: copyright@bsi-global.com.

BSI
389 Chiswick High Road
London
W4 4AL