IEC 60793-1-31

Edition 3.0 2019-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical fibres –
Part 1-31: Measurement methods and test procedures –Tensile strength

Fibres optiques –
Partie 1-31: Méthodes de mesure et procédures d'essai –Résistance à la traction

IEC 60793-1-31:2019-02(en-fr)

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INTERNATIONAL
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COMMISSION

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OPTICAL FIBRES –

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FOREWORD

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International Standard IEC 60793-1-31 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition published in 2010. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) correction of Formulae (3b) and (4b) and renumbering of formulae.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
86A/1908/FDIS	86A/1926/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60793 series, published under the general title *Optical fibres*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Failure stress distributions can be used to predict fibre reliability in different conditions. IEC TR 62048 shows mathematically how this can be done. To complete a given reliability projection, the tests used to characterize a distribution are controlled for the following:

- population of fibre, for example coating, manufacturing period, diameter;
- gauge length, i.e. length of section that is tested;
- stress or strain rates;
- testing environment;
- preconditioning or aging treatments;
- sample size.

This method measures the strength of optical fibre at a specified constant strain rate. It is a destructive test, and is not a substitute for proof-testing.

This method is used for those typical optical fibres for which the median fracture stress is greater than 3,1 GPa (450 kpsi[1]) in 0,5 m gauge lengths at the highest specified strain rate of 25 %/min. For fibres with lower median fracture stress, the conditions herein have not demonstrated sufficient precision.

Typical testing is conducted on "short lengths", up to 1 m, or on "long lengths", from 10 m to 20 m with sample size ranging from 15 to 30.

The test environment and any preconditioning or aging are critical to the outcome of this test. There is no agreed upon model for extrapolating the results for one environment to another environment. For failure stress at a given stress or strain rate, however, as the relative humidity increases, failure stress decreases. Both increases and decreases in the measured strength distribution parameters have been observed as the result of preconditioning at elevated temperature and humidity for even a day or two.

This test is based on the theory of fracture mechanics of brittle materials and on the power-law description of flaw growth (see IEC TR 62048). Although other theories have been described elsewhere, the fracture mechanics based on power-law theory is the most generally accepted.

A typical population consists of fibre that has not been deliberately damaged or environmentally aged. A typical fibre has a nominal diameter of 125 μm, with a 250 μm or less diameter acrylate coating. Default conditions are given for such typical populations. Non-typical populations might include alternative coatings, environmentally aged fibre, or deliberately damaged or abraded fibre. Guidance for non-typical populations is also provided.

1 kpsi = kilopounds per square inch.

OPTICAL FIBRES –

Part 1-31: Measurement methods and test procedures – Tensile strength

1 Scope

This part of IEC 60793 provides values of the tensile strength under dynamic loading of optical fibre samples. The method tests individual lengths of uncabled and unbundled glass optical fibre. Sections of fibre are broken with controlled increasing stress or strain that is uniform over the entire fibre length and cross section. The stress or strain is increased at a nominally constant rate until breakage occurs.

The distribution of the tensile strength values of a given fibre strongly depends on the sample length, loading velocity and environmental conditions. The test can be used for inspection where statistical data on fibre strength is required. Results are reported by means of statistical quality control distribution. Normally, the test is carried out after temperature and humidity conditioning of the sample. However, in some cases, it can be sufficient to measure the values at ambient temperature and humidity conditions.

This method is applicable to categories A1, A2, and A3, and classes B and C optical fibres.

The object of this document is to establish uniform requirements for the mechanical characteristic: tensile strength.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-1-20, *Optical fibres – Part 1-20: Measurement methods and test procedures – Fibre geometry*

3 Terms and definitions

No terms and definitions are listed in this document.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Hazards

This test involves stretching sections of optical fibre until breakage occurs. Upon breakage, glass fragments can be distributed in the test area. Protective screens are recommended. Safety glasses shall be worn at all times in the testing area.

5 Apparatus

5.1 General

Clause 5 specifies the fundamental requirements of the equipment used for dynamic strength testing. There are many configurations that can meet these requirements. Some examples are presented in Annex A. The choice of a specific configuration will depend on such factors as

- the gauge length of a specimen,
- the stress or strain rate range,
- the environmental conditions, and
- the strength of the specimens.

5.2 Gripping the fibre at both ends

Grip the fibre to be tested at both ends and stretch it until failure occurs in the gauge length section. The grip shall not allow the fibre to slip out prior to failure and shall minimize failure at the grip.

Record a break that occurs at the grip, but do not use it in subsequent calculations. Since fibre strain is increasing during the test, some slippage occurs at the grip. At higher stress levels, associated with short gauge lengths, slippage can induce damage and cause gripping failures that are difficult to ascertain. The frequency of such failures can often vary with stress or strain rate. Careful inspection of the residual fibre pieces, or other means, is required to prevent the possibility of including gripping failures in the analysis.

Use a capstan, typically covered with an elastomeric sheath, to grip the fibre (see Figure A.1). Wrap a section of fibre that will not be tested around the capstan several times and secure the fibre at the ends with, for example, an elastic band. Wrap the fibre with no crossovers. The capstan surface shall be tough enough so that the fibre does not cut into it when fully loaded. The amount of slippage and capstan failures depends on the interaction of the fibre coating and the capstan surface material, thickness, and number of wraps. Careful preliminary testing is required to confirm the choice of a capstan surface.

Design the diameter of the capstan and pulley so that the fibre does not break on the capstan due to bend stress. For typical silica-clad fibres, the bend stresses shall not exceed 0,175 GPa.

EXAMPLE For a typical 125 µm cladding/250 µm coating silica fibre, the minimum capstan diameter is 50 mm.

A particular gripping implementation is given in Annex B.

5.3 Sample support

Attach the specimen to the two grips. The gauge length is the length of fibre between the axes of the gripping capstans before it is stretched. To reduce the space required to perform the test on long gauge lengths, one or more pulleys may be used to support the specimen (see Figure A.4). The pulleys shall be designed, and their surfaces kept free of debris, so the fibre is not damaged by them. The remainder of the fibre, away from pulleys and capstans, shall not be touched.

When multiple fibres are tested simultaneously, as in Figure A.5, a baffle arrangement is required to prevent a broken fibre from snapping into, or otherwise perturbing the other fibres under test.

5.4 Stretching the fibre

Stretch the fibre at a fixed nominal strain rate until it breaks. The nominal strain rate is expressed as the percent increase in length per minute, relative to the gauge length.

There are two basic alternatives for stretching the fibre.

– Method A: Increase the separation between the gripping capstans by moving them apart at a fixed rate of speed, with the starting separation equal to the gauge length (Figure A.2).
– Method B: Rotate a capstan at a fixed rate to take up the fibre and strain the section between capstans (Figures A.3 to A.5). The rotation shall not result in crossovers on the capstan.

Calibrate the strain rate to within ±10 % of the nominal strain rate. Some equipment configurations are computer-controlled and allow dynamic control of the capstan motion to produce a constant stress rate. A particular implementation of this is given in Annex C.

The strain rate shall be agreed between customer and supplier. A strain rate range of either 2,5 % to 5 % or 15 % to 25 % is typically used.

5.5 Measuring the force at failure

Measure the tensile load (force in tension) at failure for each specimen by a calibrated load cell, to within ±1 % of the actual load. This can be done with a variety of methods:

- strip chart recorder;
- peak and hold meter;
- computer sampling.

Provide a means of measuring the tensile load as a function of time to determine the stress rate. This is not required for each individual test, but shall be done occasionally.

Calibrate the load cell to within 0,5 % of the failure, or maximum load, for each range of failure loads, while it is oriented in the same manner as when testing a fibre. Do this by substituting a string attached to a known weight for the test specimen. For method B, a light, low-friction pulley can be used in place of the capstan that is not attached to the load cell. The string, with one end attached to the load cell capstan and the other end attached to a known weight, shall duplicate the direction of a test specimen and be of a diameter comparable to that of a test specimen. A minimum of three calibration weights, bracketing the typical failures, is recommended.

5.6 Environmental control equipment

Measured failure stress and fatigue characteristics are known to vary with temperature and humidity of the fibre, both of which shall be controlled during both preconditioning and test. Many equipment configurations can be used to provide the required controls, including controls on the entire room in which testing is conducted.

The following are the typical control requirements:

- temperature: 23 °C ± 2 °C;
- relative humidity: 50 % ± 5 %.

Alternative test environments, such as high non-precipitating humidity, can be achieved by enclosing the test specimen and injecting water vapour into the enclosure. Figure A.5 shows a ganged tester that includes an enclosure over a circulating water bath.

6 Sample preparation

6.1 Definition

A sample is one or more fibres from a population. Each sample provides a result by cutting it into smaller lengths called specimens. Testing results on these specimens are combined to yield an overall result for the sample. The term "sample size" is used to indicate the number of specimens tested in the rest of the document.

For ribbonized fibre, select the specimens uniformly across the ribbon structure. Exercise caution in removing fibre from the ribbon to avoid inadvertent strength reduction.

6.2 Sample size and gauge length

The result of testing is a statistical distribution of failure stress values. Hence all reported parameters are statistical in nature, with inherent variability that is a function of the sample size and the variability of the flaw size within the sample. The weakest site, or largest flaw, within a specimen will fail, and the typical failure stress decreases as gauge length increases.

A given population can have flaws generated from multiple causes. An example is a bi-modal aggregate distribution as shown in the Weibull plot of Figure 1 (see also 8.2) obtained for a 20 m gauge length set-up. The narrow near vertical distribution on the right (around 5 GPa) is called the intrinsic region; the wider distribution below this 5 GPa is the extrinsic region.

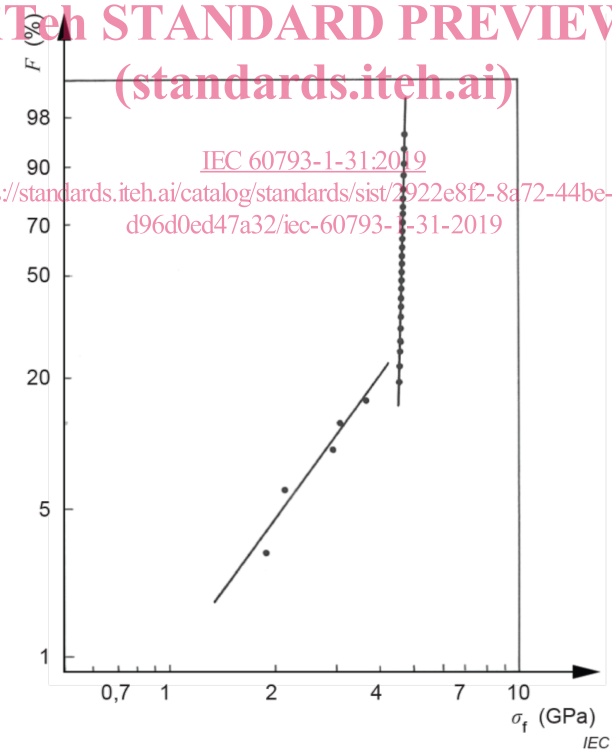

Figure 1 – Bimodal tensile strength Weibull plot for a 20 m gauge length test set-up at 5 %/min strain rate

Testing on gauge lengths of 0,5 m does not typically result in measuring flaws from the extrinsic region. From time to time, however, the failure stress of an extrinsic flaw is measured and appears as an "outlier". If the outlier is included in the data analysis, errors in the parameters will occur. For typical testing, uniform outlier removal techniques are recommended.

For tests which are designed to measure the characteristics of the extrinsic region, large sample sizes (hundreds of specimens) and long gauge lengths (20 m) are recommended. For characterization of the intrinsic region as per this document, a gauge length of 0,5 m is often used. For the dynamic strength, a sample size of 30 is often used. Any deviation from these values is to be specified in the detail specification.

Statistical analysis can be performed to determine whether a given precision has been achieved.

6.3 Auxiliary measurements

Failure stress calculations require a conversion of tensile load to the stress on the cross section of the glass portion of the fibre. The cladding diameter, as measured by IEC 60793-1-20, shall be used in this calculation to compute the cross sectional area. The coating also bears part of the tensile load that decreases the stress on the glass cross section. Subclause 8.1 contains formulae for stress calculations.

The coating correction factor is a function of the coating thickness, measured by IEC 60793-1-21 and Young's modulus of each coating layer and the modulus of the glass. The modulus of cured coating is often characterized by the manufacturer. For typical fibre, the contribution of coating effects is less than 5 % of total load, and compensation (hence measurement) for coating is not required (see 8.1). When this is done, the reported failure stress is larger than the actual by a fixed percentage. When coating effects are compensated, average or nominal values may be used for all specimens. The contribution of the coating modulus to failure stress can change with the stress or strain rate. If the contribution at any stress or strain rate is greater than 5 % of the total load, then the coating effect shall be included in the computation.

6.4 Environment

There are two key environmental considerations: aging environment and test environment.

Fibre aging is sometimes required. Even brief accelerated aging can produce increases or decreases in the measured strength of some fibres. The causes of these phenomena are not well understood. As a consequence, extrapolation methodologies from accelerated aging environments to other environments are under study.

After extensive aging, the coating surface friction can be altered. After any aging and before any testing, fibre specimens should be pre-conditioned in the test environment for at least 12 h.

The typical test environment is 23 °C ± 2 °C and 50 % ± 5 % RH. Alternative environments, such as high non-precipitating relative humidity, can yield significantly different failure stress values.

7 Procedure

7.1 Preliminary steps

1) Age the specimens if required.
2) Precondition the specimens.

7.2 Procedure for a single specimen

1) Mount the specimen in the capstans, making sure the fibre does not cross over itself or become damaged in the gauge length by mounting.
2) Verify equipment settings for the desired nominal strain rate.
3) Reset the tension recording display.

4) Begin capstan motion. For nominal strain rates of 0,03 %/min or less, the specimen may be pre-loaded at 0,3 %/min to about half of the expected failure stress at the slower rate. The expected failure stress may be projected from results at higher strain rates. When testing damaged fibre, pre-loading is not recommended unless the expected time to failure is in excess of 4 h.
5) At failure, stop the capstan and record the failure load and, if necessary, the stress rate.
6) Verify that the break did not occur on the capstan. If it did, mark the measurement so it will not be used in calculations.
7) Remove the residual fibre from the capstans and complete any auxiliary measurements, if necessary, as in 6.3.

7.3 Procedure for completing all samples for a given nominal strain rate

1) Record the nominal strain rate and any population identifications.
2) Determine if coating effects will be compensated. If so, record the appropriate coating parameters (see 8.1). Record the nominal cladding diameter if the nominal value is used to compute stress.
3) Complete 5.2 for each specimen.
4) Using 8.1, compute the failure stress for each specimen, and sort in increasing order.
5) Complete the Weibull plot (see Figure 1), if required, using 8.2. If required, compute the Weibull parameters, m_d and S_0, using 8.3.
6) If required for handleability requirements, compute the median failure stress σ_{50} and the 15-percentile failure stress σ_{15} according to 8.2.

8 Calculations

8.1 Conversion of tensile load to failure stress

The following symbols and units are used:

- fibre dimensions: mm;
- gauge length: m;
- stress σ and failure stress σ_f: GPa;
- tension T and failure tension T_f N.

Method A

When the load is substantially aligned with the tension T and D_g is the cladding diameter, Formula (1) provides the stress without compensating for the coating:

$$\sigma = \frac{4 \times 10^3 T}{\pi D_g^2} \text{ in GPa} \tag{1}$$

Method B

When coating is compensated, the following formulae are used. Calculate the fraction

$$R = \frac{E_0 A_0}{E_0 A_0 + \sum_{j=1}^{N} E_j A_j} , \tag{2}$$

where

E_0 is Young's modulus of the glass, typically 70,3 GPa for silica;

A_0 is the cross sectional area of the glass fibre.

For N coating layers indexed with j, E_j and A_j are the Young's modulus and layer cross sectional area, for each layer, respectively.

The coating compensated stress is given by

$$\sigma_c = \sigma R \tag{3}$$

8.2 Preparation of a Weibull plot

Figure 1 shows a typical Weibull plot, where the line drawn through the data represents an ideal Weibull distribution. While Weibull plots are typically used to display the data for a given nominal strain rate, the actual distribution may not be Weibull.

1) Sort the failure stress values in order of increasing value.
2) Let k represent the rank of a given failure stress, for example, k = 1, 2, 3..., N, and σ_{fk} be the k^{th} failure stress.
3) Let

$$x_k = \ln \sigma_{fk} \tag{4}$$

and

$$y_k = \ln\left(-\ln\left[1-\frac{k-0{,}5}{N}\right]\right) \tag{5}$$

4) Plot y_k versus x_k. Label the axes with the associated probability levels and failure stress values.

NOTE The median failure stress σ_{50} and the 15-percentile failure stress σ_{15} are calculated if applicable.

If 0,5N + 0,5 is an integer, $\sigma_{50} = \sigma_{0,5N+0,5}$. Otherwise, σ_{50} is determined by an appropriate interpolation between $\sigma_{0,5N}$ and $\sigma_{0,5N+1}$.

If 0,15N + 0,5 is an integer, $\sigma_{15} = \sigma_{0,15N+0,5}$. Otherwise, σ_{15} is determined by an appropriate interpolation between $\sigma_{[0,15N+0,5]}$ and $\sigma_{[0,15N+0,5]+1}$, where square brackets stand for the greatest integer function.

8.3 Computation of Weibull parameters

The Weibull distribution cumulative frequency function is given by:

$$F = 1-\exp\left[-\left(\frac{\sigma}{S_0}\right)^{m_d}\right] \tag{6}$$

where F corresponds to $\frac{k-0{,}5}{N}$ of Formula (5). Consequently,

$$y_k = m_d \ln\left(\frac{\sigma_{fk}}{S_0}\right) \tag{7}$$