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Fibre-reinforced plastic composites — Determination of laminate through-thickness properties —

Part 1: Direct tension and compression tests

Composites plastiques renforcés de fibres — Détermination des propriétés dans l'épaisseur d'un composite stratifié —

Partie 1: Essais directs de traction et de compression

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 13, *Composites and reinforcement fibres*.

A list of all parts in the ISO 20975 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Through-thickness properties and the methods specified in this document for their measurement are of interest for engineering specifications and design use. The test geometries recommended are suitable for testing thermoset and thermoplastic-based fibre-reinforced composites, although some materials can be difficult to bond to the loading bars when loaded in tension. A through-thickness dimension of 40 mm is recommended.

For the tension method, consideration has been given to the possibility of out-of-plane bending and end effects influencing the measured tensile properties. Specimen geometries have therefore been specified on the basis of minimising these effects, promoting failure away from the specimen ends (i.e. type II and III) and ease of handling (i.e. machining and testing).

For the compression method, consideration has been given to the possibility of Euler buckling and end effects influencing the measured compressive properties. Specimen geometries have therefore been specified on the basis of minimising these effects, promoting failure away from the specimen ends (i.e. type III) and ease of handling (i.e. machining and testing).

Fibre-reinforced plastic composites — Determination of laminate through-thickness properties —

Part 1: Direct tension and compression tests

1 Scope

This document specifies methods for determining the through-thickness properties (i.e. strength, modulus of elasticity, Poisson's ratio and strain-to-failure) of fibre-reinforced plastic composites using either rectangular prism and/or waisted block specimens. The methods are suitable for use with a variety of aligned and non-aligned, continuous, and discontinuous fibre formats, with both thermoset and thermoplastic matrices, ranging from 20 mm to 40 mm in thickness.

Three specimen types are described in this document. These are:

— Type I - fixed rectangular cross-section along length of specimen. It is the preferred specimen for determining elastic properties.

— Type II - waisted rectangular cross-section, variable cross-section along length of specimen. It is only suitable for determining tensile strength values and is the preferred specimen for highly anisotropic and thermoplastic materials.

— Type III - waisted rectangular cross-section, fixed cross-section along the gauge-length of specimen. It is used to provide both elastic and strength property data and is the preferred specimen for generating a full stress-strain response.

Specimen types I and II are also suitable for use with unreinforced plastics but are unsuitable for use with rigid cellular materials and sandwich structures containing cellular materials.

Two testing modes are covered:

— Method A – Tension

— Method B – Compression

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.

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 1268 (all parts), *Fibre-reinforced plastics — Methods of producing test plates*

ISO 2602, *Statistical interpretation of test results — Estimation of the mean — Confidence interval*

ISO 5893, *Rubber and plastics test equipment — Tensile, flexural and compression types (constant rate of traverse) — Specification*

ISO 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
tensile stress
σ_{33T}
tensile force, carried by the test specimen at any particular moment, divided by the initial cross-sectional area of the specimen at the specimen mid-length

Note 1 to entry: It is expressed in megapascals, MPa.

3.2
tensile failure stress or strength
σ_{33TM}
tensile stress (3.1) at the moment of failure, or when the load reaches a maximum value

Note 1 to entry: It is expressed in megapascals, MPa.

3.3
tensile failure strain
ε_{33TM}
through-thickness strain at the tensile failure stress or strength, σ_{33TM} (3.2)

Note 1 to entry: It is expressed as a dimensionless ratio or in percent, %.

3.4
modulus of elasticity (chord) in tension
E_{33T}
chord modulus obtained from the ratio of the stress difference (σ” minus σ') and the corresponding strain difference (ε” = 0,002 5 minus ε' = 0,000 5)

Note 1 to entry: It is expressed in megapascals, MPa.

Note 2 to entry: A ratio of the stress difference (σ” minus σ') and the corresponding strain difference (ε” minus ε') may be used if failure strain, ε_{33TM}, is less than 0,002 5. Where this is the case, ε”, and the corresponding value of σ”, should be taken as the maximum values of strain and stress, respectively, in the linear region of the stress-strain response.

3.5
compressive stress
σ_{33C}
compressive force, carried by the test specimen at any particular moment, divided by the initial cross-sectional area of the specimen at the specimen mid-length

Note 1 to entry: It is expressed in megapascals, MPa.

3.6
compressive failure stress or strength
σ_{33CM}
compressive stress (3.5) at the moment of failure, or when the compressive load reaches a maximum value

Note 1 to entry: It is expressed in megapascals, MPa.

3.7
compressive failure strain
ε_{33CM}
through-thickness strain at the compressive failure stress or strength, σ_{33CM} (3.6)

Note 1 to entry: It is expressed as a dimensionless ratio or in percent, %.

3.8
modulus of elasticity (chord) in compression
E_{33C}
chord modulus obtained from the ratio of the stress difference (σ" minus σ') and the corresponding strain difference (ε" = 0,002 5 minus ε' = 0,000 5),

Note 1 to entry: It is expressed in megapascals, MPa.

Note 2 to entry: A ratio of the stress difference (σ" minus σ') and the corresponding strain difference (ε" minus ε') may be used if failure strain, ε_{33CM}, is less than 0,002 5. Where this is the case, ε", and the corresponding value of σ", should be taken as the maximum values of strain and stress, respectively, in the linear region of the stress-strain response.

3.9
Poisson's ratio
ν
negative ratio of the strain, ε_n, in one of the two axes normal to the direction of loading, to the corresponding strain ε, in the direction of loading, within the initial linear portion of the longitudinal versus normal strain curve

Note 1 to entry: It is expressed as a dimensionless ratio.

3.10
specimen coordinate axes
1, 2, 3
coordinate axes for the material with the fibres preferentially aligned in one direction

Note 1 to entry: The direction parallel with the fibre axes is defined as the "1" direction, the direction perpendicular and in the same plane as the "2" direction, and the direction perpendicular to the 1-2 plane as the "3" direction. For other materials, the "1" direction is normally defined in terms of a feature associated with the production process, such as the long direction for continuous sheet processes. The "2" direction is perpendicular to the "1" direction in the same plane, and the "3" direction is perpendicular to the 1-2 plane. Results for specimens cut parallel with the "3" direction are identified by the subscript "33" (e.g. E_{33T}). See Figure 1.

Note 2 to entry: The "1" direction is also referred to as the 0 degree (0°) or longitudinal directional, the "2" direction as the 90 degree (90°) or transverse direction, and the "3" direction as the through-thickness or out-of-plane direction.

Note 3 to entry: The specimen height corresponds to the through-thickness or out-of-plane direction dimension.

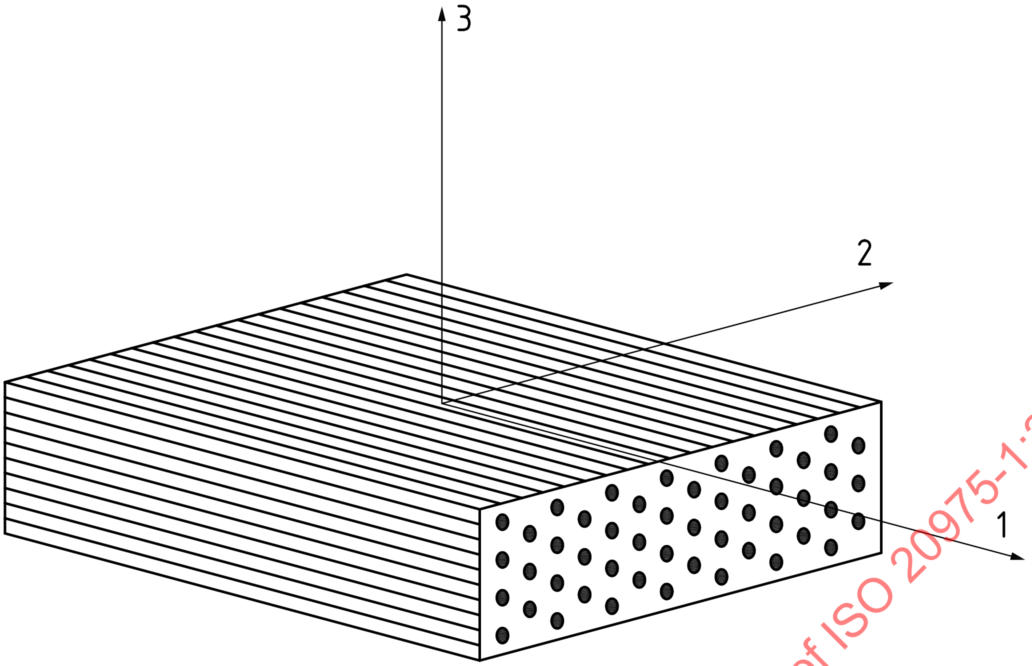


Figure 1 — Aligned fibre-reinforced composite plate element showing specimen coordinate axes

4 Principle

Test specimens are loaded along their major axis at constant speed in tension or compression until the specimen fractures [for type II (tension only) and III specimens], or for type I specimens until the specified strain limit or load is reached. The load and strain (or displacement) are measured depending on the method used.

In tension, the specimens are end-loaded via two metallic (aluminium or stainless steel) loading bars, adhesively bonded to the end of the specimen.

In compression, specimens are end-loaded between two hardened steel parallel platens. Failure of the specimens (type III only) occurs in local shear.

The procedures are performed using specimens, which can be either machined from flat areas of products, machined from semi-finished products such as mouldings, laminates and extruded or cast sheet, or made from test panels manufactured in accordance with ISO 1268.

The methods specify preferred dimensions for each type of specimen. Tests which are carried out on specimens of other dimensions or on specimens which are prepared under different conditions can produce results which are not comparable. Other factors, such as the speed of testing and the condition of the specimens can influence results. Consequently, when comparative data are required, these factors shall be carefully controlled and recorded.

5 Apparatus

5.1 Test machine

5.1.1 General

The test machine shall be in accordance with ISO 5893 as appropriate. The testing machine shall be capable of maintaining the required speed of testing (see 9.6).

5.1.2 Indicators for load and strain

The error for the indicated load shall not exceed ±1 % of applied full load, according to ISO 7500-1, and the error for the indicated strains shall not exceed ±2 %.

5.2 Strain gauges and strain acquisition

Strain shall only be determined by means of strain gauges. For maximum accuracy, the strain shall be measured on all four faces of the specimen (types I and III only). The active length of the strain gauge shall not be more than 2 mm. The gauges, surface preparation and bonding agents shall be chosen to give adequate performance on the subject materials, and suitable strain-recording equipment shall be employed. Strain-recording equipment should have 8 channels, of which 4 channels should be used to measure the axial strain on 4 surfaces and 4 channels should be used to measure the transverse strain on those surfaces.

5.3 Micrometer

Micrometer, or equivalent, reading to less than or equal to 0,01 mm, shall be used to determine the cross-sectional dimensions of the specimen at the specimen mid-length.

The shape of the anvils shall be suitable for the surface being measured (i.e. flat faces for flat, and hemispherical faces for irregular surfaces).

5.4 Loading fixtures

5.4.1 General

The loading arrangement shall load the specimen so that the requirement on allowable specimen bending in 9.10 is achieved. For tensile tests the use of hydraulic grips is recommended. The fixture in use shall be identified in accordance with Clause 12.

The main design points for all test methods and specimen types are alignment (initial and throughout the test) and the prevention of failure at the end of the specimen.

NOTE The use of hydraulic grips has been shown [1] to provide a means of achieving acceptable and repeatable alignment (see 9.10).

5.4.2 Method A - Tension loading

The tensile loading bars shall be in accordance with, or similar to, that shown in Figure 2. Load is applied direct to the end of the specimen via adhesively bonded loading bars. The loading bars shall be manufactured from either aluminium or stainless steel and the contact surfaces shall be flat and parallel to within ±0,01 mm.

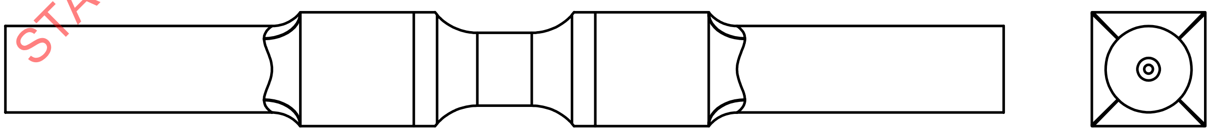
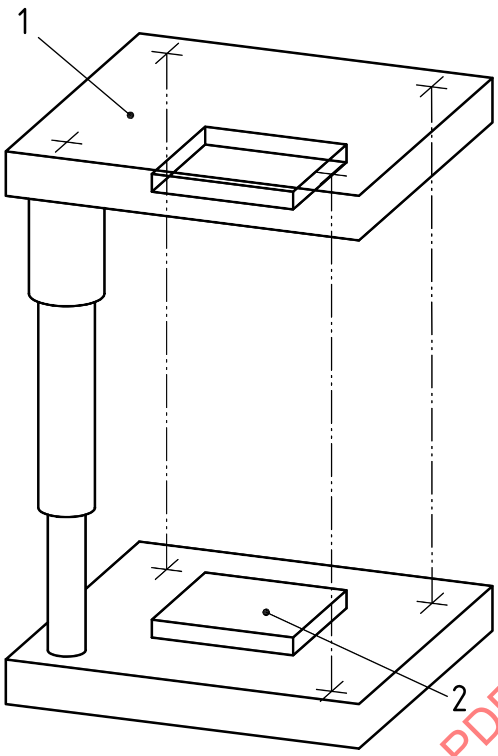


Figure 2 — Schematic of Method A — Tension loading arrangement

5.4.3 Method B - Compression loading

Compression loading shall be between hardened surfaces on the test machine platens, or a die set (see Figure 3). The contact surfaces shall be flat and parallel to within ±0,01 mm.



Key

1 die set

2 hardened and ground loading plate

Figure 3 — Schematic of Method B — Compression loading

6 Test specimens

6.1 Shape and dimensions

6.1.1 Type I specimens

The specimens shall be straight sided and of rectangular cross-section (see Figure 4) with the dimensions given in Table 1.

Dimensions in millimetres

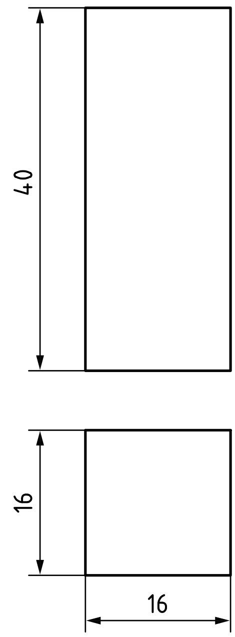


Figure 4 — Schematic of type I specimen

Table 1 — Dimensions for type I specimens

Dimensions in millimetres

Overall height, *h*	**Width**, *a*	**Depth**, *b*
40 ± 1	16 ± 0,1	16 ± 0,1

NOTE Requirements for specimen quality and parallelism of specimen are given in 6.2.2.

6.1.2 Type II specimens

The specimens shall have a circular profile extending along the entire gauge-length of the specimen (see Figure 5). The radius of curvature, *R*, of the gauge-length shall be 30 mm. The cross-section along the entire specimen length is square but varies in cross-sectional area. The dimensions are given in Table 2.

Dimensions in millimetres

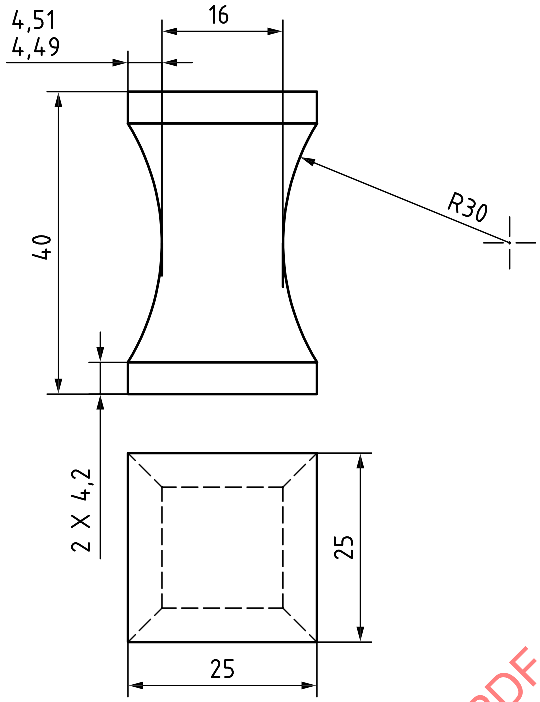


Figure 5 — Schematic of type II specimen

Table 2 — Dimensions for type II specimens

Dimensions in millimetres

Parameter	Dimensions
Overall height, *h*	40 ± 1
Gauge-length, *L*	32 ± 0,25
Mid-section width, *a*	16 ± 0,1
Mid-section depth, *b*	16 ± 0,1
Base-section width	25 ± 0,1
Base-section depth	25 ± 0,1

NOTE The reduction in cross-sectional area promotes failure at the specimen mid-thickness and away from the specimen ends.

6.1.3 Type III specimens

The specimens shall have a constant rectangular cross-section extending along the entire gauge-length of the specimen (see Figure 6). The dimensions are given in Table 3.

Dimensions in millimetres

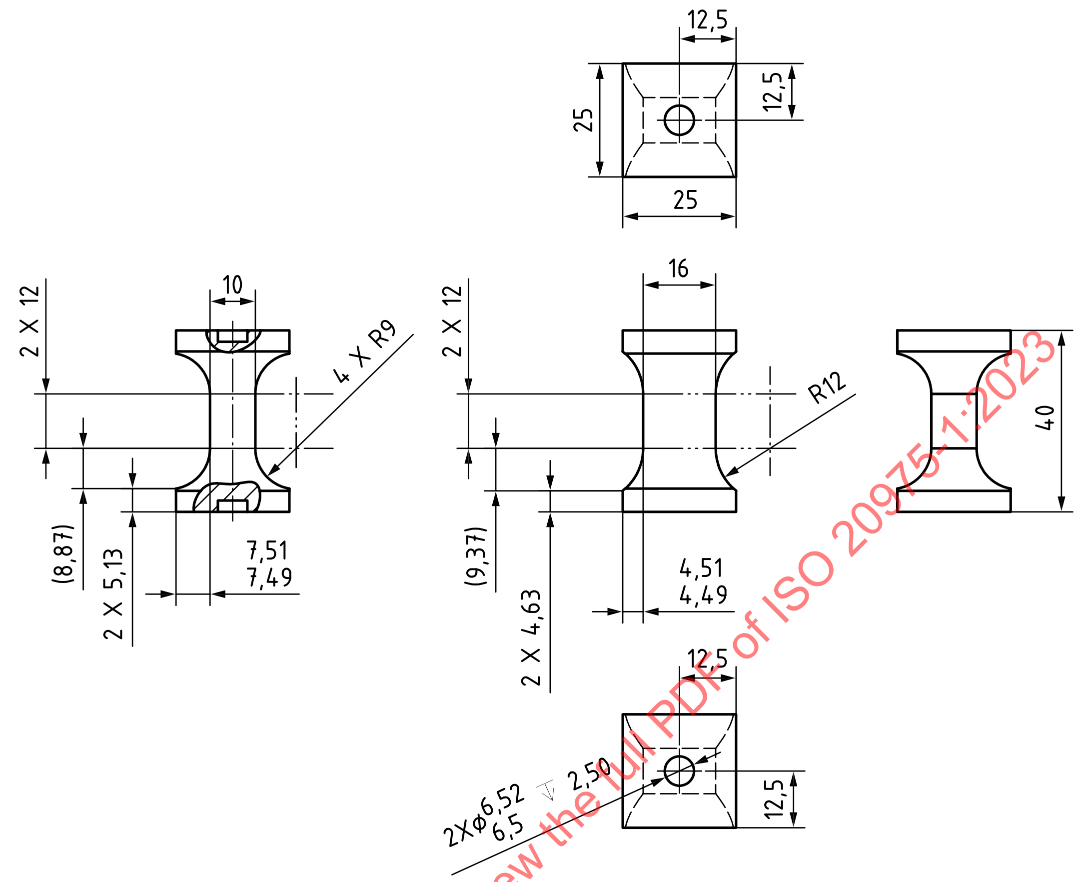


Figure 6 — Schematic of type III specimen

Table 3 — Dimensions for type III specimens

Dimensions in millimetres

Parameter	Dimensions
Overall height, *h*	40 ± 1
Gauge-length, *L*	12 ± 0,05
Mid-section width, *a*	16 ± 0,025
Mid-section depth, *b*	10 ± 0,025
Base-section width	25 +0, −0,015
Base-section depth	25 +0, −0,015

6.1.4 Non-standard test specimens

Specimens less than 40 mm thick may be used, provided that all the linear dimensions are scaled in accordance with *h*/40.

Specimens greater than 40 mm thickness may be used, provided that the specimen is not scaled by keeping to the gauge-section geometry of the 40 mm specimen and extending the length of the 16 mm or 25 mm square sections for type I, and type II and III specimens, respectively.

Due to difficulties in handling (machining and testing) a minimum thickness of 20 mm should be used.

6.2 Preparation of test specimens

6.2.1 General

A panel from which specimens are to be extracted shall be prepared in accordance with the relevant part of ISO 1268 or other specified/agreed procedure. Individual specimens or groups of specimens shall be machined to the required size. Some parameters for machining are specified in ISO 2818. For further guidance on cutting specimens, see ISO 527-4:2021, Annex A[2], ISO 2818[3] and Reference [4].

Pre-formed diamond grinding wheels or WA 60 grit wheels, formed using a wheel dressing attachment, are recommended for machining of the required specimen profiles. It is recommended that a suitable coolant be used during machining operations to minimize damage to the material.

6.2.2 Parallelism

Machine the loading ends of each specimen to be parallel to one another and perpendicular to the loading axis of the specimen. The allowed deviation in the parallelism of the loading areas is 0,1 % of the overall base width. The tolerance on the parallelism along the specimen length shall be a maximum of 1 % of the initial length. For laminated composites, the “apparent” plane of individual layers shall be parallel with the loading faces.

Avoid working under conditions that can create a large build-up of heat in the test specimen. It is recommended that a coolant is used, dry the test specimens immediately after machining.

NOTE Check that cut surfaces of the test specimen are free from machining defects.

6.2.3 Application of end-loading blocks for Method A — Tension only

The end-loading blocks shall be bonded to the specimen using a fixture that allows for good axial alignment of the end-tabs to the specimen. Adhesive manufacturer’s instructions (when available) must be followed for the surface preparation and bonding.

The use of metallic loading bars with spigots that align with circular recesses machined in the ends of all specimen types is permitted (see Figure 6). This provides a means by which alignment of bonded loading bars can be improved. However, the use of loading bars with spigots and hence specimens with corresponding recesses, is not mandated and should only be used for tensile measurements.

6.3 Checking

The specimens shall be free of twist and shall have mutually perpendicular pairs of parallel surfaces. The surfaces and edges shall be free from scratches, pits, sink marks and flashes. The specimens shall be checked for conformity with these requirements as a minimum by visual observation against straight-edges, squares and flat plates, and by measuring with micrometer callipers. Specimen showing measurable or observable departure from one or more requirements shall be rejected or machined to the proper size and shape before testing.

7 Test specimens

At least five test specimens, giving valid modulus of elasticity measurements and/or failures, shall be tested. The number of measurements may be more than five if greater precision of the mean value is required. It is possible to evaluate this by means of the confidence interval (95 % confidence interval, see ISO 2602).

The results of specimens that do not fail within the gauge-section in accordance with 9.10 shall be discarded and new specimens tested in their place.

8 Conditioning

The test specimens shall be conditioned as specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, e.g. for testing at elevated or low temperatures. The preferred set of conditions in ISO 291 is standard atmosphere 23/50.

9 Test procedure

9.1 Test atmosphere

Conduct the test in the atmosphere which is specified in the International Standard for the material tested. In the absence of this information, select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties, e.g. for testing at elevated or low temperatures. The preferred set of conditions in ISO 291 is standard atmosphere 23/50.

9.2 Specimen dimensions

Measure the width, a, and depth, b, of each test specimen to the nearest 0,01 mm at the mid-length of the specimen.

9.3 Specimen preparation Method A — Tension only

Bond the metallic loading bars to the specimen ensuring good axial alignment between specimen and the loading bars. Ensure there is no spew fillet at the bond-line between the specimen and the loading bars.

An alignment jig is recommended for bonding the loading bars to the specimen and for checking the axial alignment of the test equipment.

9.4 Strain recording

Attach strain gauges and employ the necessary strain-recording equipment. Four strain measurements (one on each face of the specimen) are required to ascertain that column bending is not occurring. The active length of the strain gauge, which shall be centrally bonded on the specimen, shall be 2 mm or less. Bending can be detected if the strain on one face reverses (decreases) when the strain on the opposite face increases rapidly.

Biaxial strain gauges are required for measurements of Poisson's ratio. Uniaxial strain gauges shall be used if only modulus and strain-to-failure are to be measured.

Cyanoacrylate adhesives are generally suitable for bonding of strain gauges in most test cases; however, other adhesives may be used if the test conditions demand it. Strain gauges should be bonded using the installation procedures provided by the strain gauge manufacturer (where available) for the gauge and bonding technique selected.

9.5 Specimen alignment

9.5.1 Method A – Tension

Mount the specimen with loading bars in the test machine to be used and check that the strain data in the elastic region indicate good alignment for the first test in each batch, using the calculations given in 9.10.

9.5.2 Method B – Compression

Mount the specimen in the compression fixture to be used and check that the strain data in the elastic region indicate good alignment for the first test in each batch, using the calculations given in 9.10.

9.6 Testing speed, *v*

Set the speed of testing by adjusting the crosshead displacement rate to 1 mm/min ± 0,2 mm/min.

9.7 Data collection

Record load and strain (or deformation) continuously, using, if practicable, an automatic recording system that yields a complete load/displacement curve for this operation.

9.8 Maximum load

Record the maximum load carried by the specimen during the test. For type I coupons only, the test should be stopped once a strain of 0,3 % has been reached.

9.9 Failure mode

Record the mode of failure.

9.10 Test acceptance

Check that the test was valid. The test is valid only if failure occurs within the gauge-section (not at the specimen ends). End and bond-line failures for Method A (Tension) are unacceptable.

Bending is acceptable if the difference between strains recorded on each face of the specimen for between 10 % and 90 % of the failure load is such that:

$$\left[\frac{\varepsilon_{33b}-\varepsilon_{33a}}{\varepsilon_{33b}+\varepsilon_{33a}}\right]\leq 0{,}10 \text{ and } \left[\frac{\varepsilon_{33d}-\varepsilon_{33c}}{\varepsilon_{33d}+\varepsilon_{33c}}\right]\leq 0{,}10$$

where

ε_{33a} and ε_{33b} are one set of axial strains on opposite faces of the specimen;

ε_{33c} and ε_{33d} are the other set of opposing axial strains.

10 Expression of results

10.1 Method A — Tension

10.1.1 Tensile strength

Calculate the tensile strength, σ_{33TM}, expressed in megapascals, using Formula (1):

$$\sigma_{33TM}=\frac{F_{max}}{a\times b} \tag{1}$$

where

F_{max} is the maximum load, in newtons;

a is the width, in millimetres, of the test specimen;

b is the depth, in millimetres, of the test specimen.

10.1.2 Modulus of elasticity (chord) in tension

Calculate the modulus of elasticity (chord) in tension, $E_{33\mathrm{T}}$, expressed in megapascals, using Formula (2) (see Figure 7):

$$E_{33\mathrm{T}} = \frac{\Delta F \times L}{a \times b \times \Delta L} = \frac{\sigma''_T - \sigma'_T}{\varepsilon''_T - \varepsilon'_T} \qquad (2)$$

where

L is the gauge-length, in millimetres;

ΔL is the increase in gauge-length, in millimetres, corresponding to the strain difference (ε''_T = 0,002 5 minus ε'_T = 0,000 5);

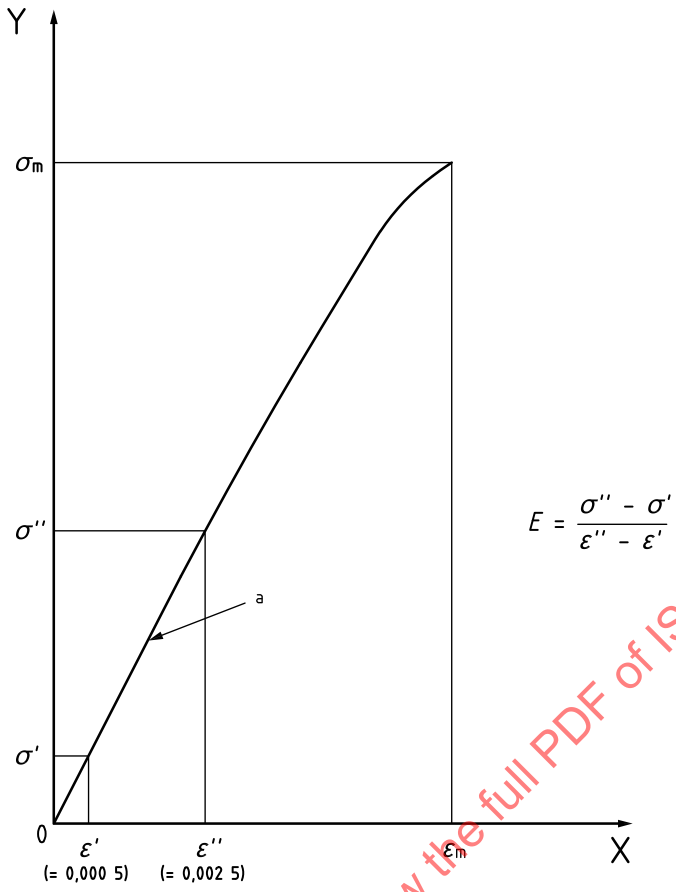
ΔF is the load increment, corresponding to the strain difference, in newtons;

a is the width, in millimetres, of the test specimen;

b is the depth, in millimetres, of the test specimen;

σ''_T is the tensile stress at ε''_T = 0,002 5, expressed in megapascals;

σ'_T is the tensile stress at ε'_T = 0,000 5, expressed in megapascals.



Key

X strain, ε

Y stress, σ

a Slope *E*.

Figure 7 — Generic tensile stress-strain diagram

10.1.3 Tensile failure strain

Calculate the tensile failure strain, ε_{33TM}, from the mean longitudinal strains at failure.

10.2 Method B — Compression

10.2.1 Compressive strength

Calculate the compressive strength, σ_{33CM}, expressed in megapascals, using Formula (3):

$$\sigma_{33CM} = \frac{F_{max}}{a \times b} \tag{3}$$

where

F_{max} is the maximum compressive load, in newtons;

a is the width, in millimetres, of the test specimen;

b is the depth, in millimetres, of the test specimen.