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Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods

Structures en bambou — Détermination des propriétés physiques et mécaniques des tiges de bambou — Méthodes d'essais

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Foreword

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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 165, *Timber structures*.

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.

This first edition cancels and replaces ISO 22157-1:2004.

Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods

1 Scope

This document specifies test procedures for specimens obtained from round bamboo culms. The data obtained from the test methods can be used to establish characteristic physical or mechanical properties to be used in structural engineering design or for other scientific purposes. This document provides methods for evaluating the following physical and strength properties: moisture content, density, mass per unit length; strength properties parallel to the fibre direction, compression, tension and bending, and strength properties perpendicular to the fibre direction, tension and bending. It also provides methods to estimate moduli of elasticity in bending, compression and tension parallel to fibres, and bending perpendicular to fibres.

The test methods reported in this document are intended for commercial testing applications. The test methods reported in this document are intended for commercial testing applications and can also be adopted as benchmark methods for scientific research.

This document is organized to provide requirements for standard tests to be carried out to determine the material properties of full-culm bamboo as a structural material.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

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

3.1
bamboo culm
single shoot of bamboo comprised of the entire unaltered bamboo cross-section, which is usually a hollow cylinder except at *nodes* (3.11)

3.2
bamboo clump
clump
cluster of bamboo shoots emanating from two or more rhizomes at the same location

3.3
cross-sectional area
A
area of the net section perpendicular to the direction of the longitudinal axis of the culm

3.4
equilibrium moisture content
moisture content (3.10) at which bamboo is neither gaining moisture from, nor losing moisture to, the environment

3.5
fibre
set of cellulosic fibres in bundles aligned parallel primarily in the longitudinal direction of the culm in the internodes

Note 1 to entry: At nodes, the fibres radiate into the node plate, where they become entangled and their orientation varies greatly.

3.6
fibre saturation point
FSP
moisture level in the bamboo solid material whereby no free liquid water remains in the cell cavities but the cell wall structure is fully saturated by chemically bound water molecules

Note 1 to entry: The maximum content of bound water in bamboo tissue is approximately 30 % by weight of the fully dried tissue.

3.7
green
condition of recently harvested bamboo that has not been dried and has a *moisture content* (3.10) greater than the *fibre saturation point* (3.6)

3.8
internode
hollow region of bamboo culm between two *nodes* (3.11)

3.9
outer diameter
D
diameter of the cross-section of a piece of bamboo taken as the average of two perpendicular measurements made across opposite points on the outer surface

Note 1 to entry: Measurement is usually made at the centre of an internode region.

3.10
moisture content
w
portion of culm weight consisting of water expressed as percentage of oven-dry weight

3.11
node
intermittent transverse diaphragm region located along length of culm separating adjacent *internodes* (3.8), which, when alive, is a location of leaf growth

3.12
traveller specimen
specimen identical to, and stored and conditioned identically to specimens to be tested used to obtain properties whose testing method affects the specimen

Note 1 to entry: Traveller specimens are usually used for determination of moisture content and density.

3.13
wall thickness
δ
thickness of wall of bamboo culm taken as the average of four measurements taken around the circumference of the culm at angular spacings of 90°

Note 1 to entry: Measurement is usually made at the centre of an internode region.

4 Symbols

Symbol	Description	Unit
A	cross-sectional area of the culm defined in 3.3 calculated as: $(\pi / 4) \times [D^2 - (D - 2\delta)^2]$ where D is the outer diameter; δ is the wall thickness	mm^2
A_g	mean cross-sectional area of the gauge portion of the tension test parallel to the fibres specimen described in Clause 11	mm^2
a	shear span (distance from support to nearest application of load) in a four-point bending test described in Clause 12	mm
b	width of tension test specimen gauge region described in Clause 11	mm
D	outer diameter of the bamboo culm defined in 3.9	mm
d	diameter of transverse hole in the tension perpendicular to the fibres specimen described in Clause 14	mm
$E_{c,0}$	compressive modulus of elasticity parallel to direction of fibres	N/mm^2
$E_{t,0}$	tensile modulus of elasticity parallel to direction of fibres	N/mm^2
$E_{m,0}$	apparent flexural modulus of elasticity parallel to direction of fibres	N/mm^2
$E_{m,90}$	circumferential modulus of elasticity	N/mm^2
F	load applied in test	N
F_{ult}	maximum (ultimate) load applied in test	N
$f_{c,0}$	compressive strength parallel to direction of fibres	N/mm^2
$f_{m,0}$	flexural strength parallel to direction of fibres	N/mm^2
$f_{m,90}$	flexural strength perpendicular to direction of fibres	N/mm^2
$f_{t,0}$	tension strength parallel to direction of fibres	N/mm^2
$f_{t,90}$	tension strength perpendicular to direction of fibres	N/mm^2
f_v	shear strength	N/mm^2
h	estimate of neutral axis location for a curved rectangular beam	mm
I_B	second moment of area, or moment of inertia, of the culm section calculated as: $(\pi / 64) \times [D^4 - (D\ 2\delta)^4]$ where D is the outer diameter; δ is the wall thickness	mm^4
L	length of test piece or clear span in bending between centres of supports (Clause 12)	mm
M_{ult}	maximum moment	N·mm
m_e	mass of test specimen	g
m_i	initial mass of test specimen	G
m_0	oven-dry mass of test specimen	g
q	mass per unit length	g/mm kg/m
q_{12}	mass per unit length normalized for 12 % moisture content	g/mm kg/m
R	characteristic radius of the centreline of the culm wall, calculated as $0{,}5(D - \delta)$	mm

V	volume of test piece	mm^3
V_0	volume of green test piece	mm^3
w	ratio of mass of embodied water to mass of oven-dry specimen, equivalent to moisture content defined in 3.10.	—
Δ	deflection	mm
δ	culm wall thickness, defined in 3.13	mm
ε	strain	mm/mm
ρ	density, when converted as indicated in 8.4	g/mm^3 kg/m^3
ρ_{12}	density normalized for 12 % moisture content, when converted as indicated in 8.4	g/mm^3 kg/m^3
ρ_{test}	density under conditions of test, when converted as indicated in 8.4	g/mm^3 kg/m^3

5 General requirements

5.1 Temperature and humidity

Unless required by specific conditioning protocols, test specimens shall be stored, conditioned and tested in an environment having a temperature range of (23 ± 3) °C, and relative humidity range of (65 ± 5) %.

However, if tests results are to be used in the same environmental conditions in which testing took place, or if the laboratory is unable to follow the standard, storage, conditioning and testing under ambient temperature and relative humidity is permitted. The values of the temperature (±3 °C) and the relative humidity (±5 %) for the laboratory shall be recorded in the test report, alongside the moisture content determined for individual specimens.

5.2 Rate of load application

The rate of load application of the testing machine shall be selected such that failure is reached within (300 ± 120) s. Tests that fail in less than 30 s shall be removed from analysis. The load shall be applied continuously without interruption at the required rate throughout the test. For tests run in displacement control, the rate of traverse of the movable head of the testing machine shall be the free running or no-load speed of the head for mechanical drive type machines, and the loaded head speed for hydraulic or servo-hydraulic driven testing machines. The time to failure for each individual specimen shall be recorded in the test report.

5.3 Calibration

All apparatus and testing equipment used in obtaining data shall be calibrated at sufficiently frequent intervals to ensure accuracy. A record of errors observed before calibration, the date and time of calibration and observations following calibration shall be maintained.

5.4 Test report

The test report shall include the following information:

a) a reference to this document, i.e. ISO 22157;

b) the name of laboratory, authority or organization which performed the test;

c) the details of the test specimens, as noted in 6.3;

d) a description of the sampling including:

   1) the method of grading and grade, if applicable;

   2) the size of the sample; and

   3) the moisture content at the time of sampling.

e) variations from the reference test conditions specified in Clause 5;

f) the equipment used, and any other information which may influence the use of the test results;

g) raw test data, including:

   1) the dimensions of the specimen including measured values of at least D, δ and L;

   2) the location of specimen along culm (B, M or T);

   3) the measured values of moisture content from specimen or companion traveller specimens obtained at the time of testing;

   4) the measured values of density and density adjusted to 12 % moisture content from specimen or traveller specimens obtained at the time of testing;

   5) the load-displacement diagram up to failure for each specimen;

   6) the observed location and mode of failure for each specimen;

   7) the calculated moduli and/or strength values;

   8) the range of data used to calculate the modulus of elasticity;

   9) the time to failure for each specimen;

   10) any other information which may influence the use of the test results;

h) the mean and coefficients of variation (and/or standard deviation) of the obtained test data; and

i) any additional information deemed to be important to interpretation of test data.

6 Sampling and storage of specimens

6.1 Sampling

Sampling should be representative of the population which test results are intended to represent and be appropriate for the objective of the testing program. Sampling methodology shall be included in the test report.

Bamboo material for any particular species shall be taken:

— in the case of tests on properties for commercial purposes: from a number of different localities, representative of different growth conditions throughout the geographical range of the species;

— in the case of quality control as required in a strength grading protocol or standard: from a randomly selected sample from a batch as required by the protocol or standard.

From each locality, the selection, marking, etc., of the different consignments, as well as all the details of the various clumps and culms, shall be reported.

Culms are to be cut to length taking care to record the provenance of a specimen along the culm in accordance to 6.3. For specimens that are to be used to determine bending strength, refer to Clause 12 for minimum lengths.

6.2 Selection

The culms selected shall fairly represent the total population that is to be used for construction purposes, even if the entire population is characterized by poor quality stock. Broken, damaged and discoloured culms shall be discarded. If a grading standard or protocol is being implemented, culms selected for testing should be subjected to the grading process prior to testing.

The required number of culms shall be randomly selected from different clumps.

6.3 Felling, marking and sample preparation

Before felling, the following data shall be marked and recorded:

— the name of the species (botanical and local);

— the name of the locality;

— the number of clumps and culms selected;

— the age of the culm(s);

— details about the marks on the culms; and

— date(s) of felling and despatch.

Prior to cutting a felled culm into shorter lengths, it shall be marked "bottom", "middle" and "top" (B, M and T, respectively) in approximately equal thirds. For felled culms shorter than 5 m in length, the culm may be cut in half, marking the halves "bottom" and "top" (B and T, respectively). The heights of each third, or half, (in millimetres) shall be recorded from the level at which the culm was felled.

6.4 Despatch

Material should be despatched as early as possible, preferably within two weeks of felling. In case it is not possible to despatch the material immediately, the material shall be stored in a manner consistent with 6.5.

6.5 Receipt and storage of the bamboo culms

Bamboo culms shall be stored in such a way as to minimize possibility of deterioration. Proper storage practices include:

a) no direct exposure to sunlight or rain;

b) no direct contact with soil or standing water; and

c) adequate air circulation to permit the equilibrium moisture content to be achieved for all stored culms.

6.6 Marking and conversion into test specimens

Specimens shall be cut for the various tests, and suitable markings (project number, consignment number, culm number, etc.) shall be made for complete identification of each specimen.

The sequence of tests shall be such as to eliminate, to the extent possible, changes due to storage and environment conditions, which can affect comparison of results.

Specimens shall be tested in air dry condition (12 ± 3) % moisture content or the equilibrium moisture content at the locality where the bamboo is to be used and subjected to the same preservation treatment that would be considered standard.

The number of specimens prepared for each test shall be sufficient to establish the desired characteristic data with 75 % confidence interval or as indicated in the grading standard. No fewer than 30 specimens is recommended.

7 Moisture content

7.1 Moisture content by oven-dry method

7.1.1 Apparatus

7.1.1.1 **Balance**, suitable to weigh a specimen with a precision of at least 0,5 % of the specimen mass.

7.1.1.2 **Oven**, capable of drying bamboo to the absolute dry condition.

7.1.2 Preparation of test pieces

Specimens for determination of moisture content shall be prepared immediately after each mechanical test. They shall be taken near the place of failure, weighed and placed in the drying oven. The number of specimens shall be equal to the number of test pieces for the physical or mechanical test.

If traveller specimens are used, these shall be prepared immediately after each mechanical test, and placed in the drying oven.

7.1.3 Procedure

The test pieces shall be weighed with a precision of at least 0,5 % of the dry specimen mass prior to being placed in an oven at a temperature of (103 ± 2) °C. The initial mass is m_i.

After 24 hours, the mass shall be recorded at regular intervals of not less than 2 hours. The drying shall be considered to be complete when the difference between successive determinations of mass do not exceed 0,5 % of the measured mass. The final oven-dry mass is m_0.

7.1.4 Calculation and expression of results

The moisture content, w, of each test piece shall be calculated with Formula (1)as the loss in mass, expressed as a percentage of the oven-dry mass:

$$w = \left[\frac{m_i - m_0}{m_0}\right] \times 100 \quad (1)$$

where

m_i is the initial mass of the test piece before drying;

m_0 is the mass of the test piece after drying.

Both m_i and m_0 are measured with a precision of at least 0,5 % of the dry specimen mass.

The calculated value of w shall be taken as representative of the tested specimen as a whole.

7.2 Moisture content by electrical moisture meter method

7.2.1 General

Alternatively, it can be sufficiently accurate to measure moisture content by means of a moisture meter, provided that the meter is calibrated against moisture content measurements determined using the

oven-dry method described in 7.1. Commercial electrical conductivity moisture meters are generally only reliable for wood moisture content between about 5 % and 25 %.

7.2.2 Apparatus

7.2.2.1 Moisture meter, of any design, calibrated for the species of bamboo concerned (using comparison with oven-dry method described in 7.1), and capable of making an individual measurement with an error of not more than 2 % at moisture contents from 7 % to 28 %.

7.2.3 Procedure

Measure the moisture content of the test piece or traveller specimen at a location within the culm wall thickness. Measurements should not be made on the surface of the culm wall. Measurements should be taken either at freshly cut cross-sections, or by driving deep, sharp probes into the wall from the side.

The area at which measurements are made shall not contain any dirt or visible defects. Drive the electrodes into the culm wall cross-section so that the line between the tips of the needles intersects only bamboo material.

Make at least three measurements in each measuring area, 10 mm to 15 mm apart, to avoid any error due to the electrodes piercing an invisible defect.

7.2.4 Calculation and expression of results

Calculate the mean of the three individual measurements closest in their values, and express the average moisture content, w, as a percentage by mass, to the nearest 1 %.

7.2.5 Test report

The moisture content shall be reported in the test report according to 5.4.

8 Density

8.1 General

This clause specifies three methods for determining the density, as mass by volume, of bamboo. For most scientific and commercial applications, determining the density at the time of test, ρ_{test}, is adequate, and shall be calculated from the mass and volume at the time of the test. To enable comparison between reported values, the density at time of test should be adjusted to the density at 12 % moisture content, ρ_{12}.

For some scientific purposes and accurate comparison between reported values, basic density, ρ, is most appropriate. It is determined from the oven-dry mass and green volume, since these remain unchanged irrespective of environmental conditions.

8.2 Apparatus

8.2.1 Measuring instrument, capable of determining the dimensions of the test pieces with a precision of 0,1 mm.

8.2.2 Balance, suitable to weigh a specimen with a precision of at least 0,5 % of the specimen mass.

8.2.3 Equipment for the determination of the moisture content in accordance with 7.1.

8.3 Preparation of test pieces

The density of bamboo varies in the cross-section and along the culm length. Therefore, specimen sampling shall be carefully selected to reflect the density values desired. Full culm section specimens are preferred, in which an immersion test is used to obtain specimen volume, though estimation of volume from geometric measurements is acceptable, provided the shape of the specimens enables accurate measurements to be obtained. An immersion test (Archimedes' principle) is permitted to obtain specimen volume provided the specimen moisture content exceeds the fibre saturation point at the time of obtaining the volume or consideration is made for water absorbed during the immersion process (e.g. measuring the mass before and after immersion).

Specimens for determination of the density at the time of test, ρ_{test}, shall be prepared immediately after each mechanical test. They shall be taken near the place of failure. The number of specimens shall be equal to the number of test pieces for the physical or mechanical test. If traveller specimens are used, these shall be prepared immediately after each mechanical test.

8.4 Procedure

Measure the dimensions of the test pieces with a precision of at least 0,1 mm, and calculate the volume, or determine the volume by another suitable method (e.g. immersion) to a precision of at least 0,5 % of the specimen volume. Determine the basic density, ρ, in the green condition. To determine the density at the time of test, ρ_{test}, measure the volume immediately after the mechanical test. In the latter case, determine the moisture content, w, as described in Clause 7.

For the density at time of test, ρ_{test}, determine the mass of the test piece, m_e, to a precision of 0,5 % of the specimen mass.

For the basic density, ρ, dry the test pieces to constant oven-dry mass (see 7.1.3). Carry out the weighing operations immediately after drying. Determine the mass of the oven-dry test pieces, m_0, to a precision of 0,5 % of the specimen mass.

8.5 Calculations and expressions of results

The density at the time of test, ρ_{test}, shall be calculated from Formula (2):

$$\rho_{test} = m_e / V \tag{2}$$

where

m_e is the mass of the test piece in grams (g);

V is the volume of the test piece in cubic millimetres (mm^3).

The density at 12 % moisture content, ρ_{12}, shall be calculated from Formula (3):

$$\rho_{12} = \rho_{test}\left[\frac{1,12}{1+w}\right] \tag{3}$$

where w is the moisture content at the time of test as determined in Clause 7, expressed as a decimal.

The basic density, ρ, shall be calculated from Formula (4):

$$\rho = m_0 / V_0 \tag{4}$$

where

m_0 is the oven-dry mass of the test piece in grams (g);

V_0 is the volume of the green test piece in cubic millimetres (mm^3).

Results are expressed in grams per cubic millimetre (g/mm^3). This can be converted to kilograms per cubic metre (kg/m^3) by multiplying the calculated values by 10^6.

8.6 Test report

The test report shall be in accordance with 5.4.

9 Mass per unit length

9.1 General

This clause specifies two methods for determining mass per unit length of bamboo culms. This method is only appropriate for specimens comprised of full culm cross-sections. For most scientific and commercial applications, determination of the mass per unit length at the time of the test, or in the green condition, q, is adequate, and shall be calculated from the test culm mass and length. To enable comparison between reported values, mass per unit length at the time of the test should be adjusted to mass per unit length at 12 % moisture content, q_{12}.

9.2 Apparatus

9.2.1 Measuring instrument (tape measure), capable of determining the length of the culm with a precision of 0,5 %;

9.2.2 Balance, capable of weighing specimen with precision of 0,5 %;

9.2.3 Equipment for the determination of the moisture content in accordance with 7.1.

9.3 Preparation of test pieces

Full culm cross-section specimens shall be prepared having a length over which the average mass per unit length is desired. Culms should be cut square at their ends. Test culms shall be selected according to Clause 6.

9.4 Procedure

Measure the length of the specimen with a precision of at least 0,5 %. To determine the mass per unit length at time of test, measure the length immediately **before** the mechanical test and determine the moisture content, w, as in Clause 7.

Determine the mass of the test pieces to a precision of 0,5 % of the specimen mass.

9.5 Calculations and expressions of results

The mass per unit length at time of test or in the green condition, q, shall be calculated from Formula (5):

$$q = m_e / L \quad (5)$$

where

m_e is the mass of the test piece in grams (g);

L is the length of the test piece in millimetres (mm).

The mass per unit length at 12 % moisture content, q_{12}, shall be calculated from Formula (6):

$$q_{12} = q\left[\frac{1,12}{1+w}\right] \tag{6}$$

where w is the moisture content at the time of test as determined in Clause 7 expressed as a decimal.

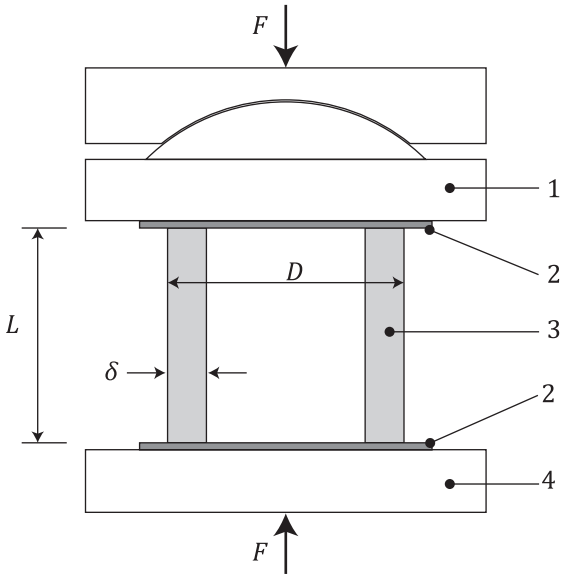
Results are expressed in grams per millimetre (g/mm). Alternatively, results may be expressed as kilograms per metre (kg/m).

10 Compression strength and stiffness parallel to the fibres

10.1 Apparatus

10.1.1 Test machine. Tests shall be carried out on a suitable testing machine capable of measuring compression load with a precision of at least 1 %. At least one platen of the testing machine shall be equipped with a spherical bearing surface to ensure that the load is concentrically applied, as in Figure 1.

10.1.2 Intermediate layer. In between both steel platens of the machine and both ends of the specimen, an intermediate layer shall be applied in order to minimize friction at, and radial restraint of, the specimen ends. Successfully used intermediate layer media include radially oriented steel shims, polytetrafluoroethylene (PTFE), sheets and sulphur "capping compound".



Key

D outer diameter
δ wall thickness
F load
L length of specimen (*L* is the lesser of *D* or 10*δ*. If *D* < 20 mm, *L* = 2*D*)
1 upper loading platen with spherical bearing
2 intermediate layer
3 bamboo specimen
4 intermediate layer
5 lower loading platen

Figure 1 — Compression test arrangement

10.2 Preparation of tests specimens

Test culms shall be selected according to Clause 6.

Compression tests parallel to the fibre shall be made on specimens, 50 %with a node and 50 %without. The length of the specimen shall be taken as the lesser of the outer diameter, *D*, or 10 times the wall thickness, 10*δ*. However, if *D* is 20 mm or less, the height may be taken as twice the outer diameter, 2*D*, irrespective of *δ*. Nodes, when present, shall be located approximately at mid-height.

The end planes of the specimen shall be parallel to each other and perpendicular to the length axis of the specimen; the end planes shall be flat, with a maximum deviation of 1 % of the diameter.

To determine the modulus of elasticity in compression parallel to the fibres, $E_{c,0}$, two or more electrical resistance strain gauges shall be fixed parallel to the loading axis, uniformly spaced around the circumference at the mid-height of the specimen. Alternatively, externally mounted mechanical gauges (e.g. clip or omega gauges) are permitted.

10.3 Procedure

Measure the specimen length, *L*, and wall thickness, *δ*, with a precision of 0,1 mm.

The specimen shall be placed such that its axis is aligned with the loading axis of the machine. A small load, not exceeding 1 % of the expected failure load, is initially applied to seat and hold the specimen in position.

The application of load shall comply with 5.2.

If applicable, the strain gauges shall be read a sufficient number of times during the test to be able to plot a sufficiently precise load-deformation diagram from which $E_{c,0}$ can be determined.

The maximum applied load, at which the specimen fails, F_{ult}, shall be recorded. If ductile behaviour is observed, the maximum load is considered to occur at a strain of 0,1.

Following each test, obtain specimens for the determination of moisture content in accordance with Clause 7.

10.4 Calculation and expression of results

The compression strength parallel to the fibres, $f_{c,0}$, shall be calculated from Formula (7):

$$f_{c,0} = F_{ult} / A \tag{7}$$

where

F_{ult} is the maximum load at which the specimen fails, in Newtons (N);

A is the cross-sectional area defined in Clause 4 in square millimetres (mm^2).

The modulus of elasticity in compression parallel to the fibres, $E_{c,0}$, shall be calculated as the secant between stress and strain pairs at 20 % and 60 % of F_{ult}. $E_{c,0}$ is calculated from Formula (8):

$$E_{c,0} = \frac{F_{60} - F_{20}}{A(\varepsilon_{60} - \varepsilon_{20})} \tag{8}$$

where

F_{20}, F_{60} are the applied load, in Newtons (N), at 20 % and 60 % of F_{ult}, respectively;

ε_{20}, ε_{60} are the mean of the strain gauge readings obtained at 20 % and 60 % of F_{ult}, respectively.

10.5 Test report

The test report shall be in accordance with 5.4. The observed failure mode for each test shall be reported. The nature of intermediate layer used shall be reported.

11 Tension strength and stiffness parallel to the fibres

11.1 Apparatus

11.1.1 Test machine. The tests shall be carried out on a suitable testing machine capable of measuring tension load with a precision of at least 1 %. The grips of the tension machine shall ensure that the load is applied concentrically along the longitudinal axis of the test piece, and shall prevent longitudinal twisting of the test piece. The grips shall compress the test piece perpendicular to the fibres. The grips should also be restrained from rotation about both principal axes of the specimen.

11.2 Preparation of test specimens

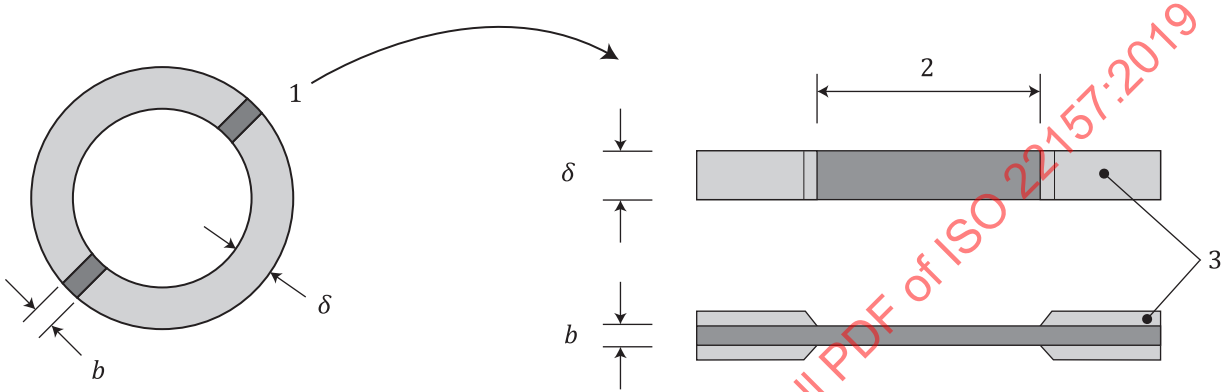
Test culms shall be selected according to Clause 6.

At least three specimens shall be extracted from each culm to account for variability within the culm.

Tension tests parallel to fibre shall be made on radially-oriented specimens having rectangular cross-section dimensions with breadth equal to the culm wall thickness, δ, and width, b, equal to one-half the culm wall thickness or less. Specimen width should not exceed 20 mm (see Figure 2). Specimens should include one node, which shall be in the gauge section.

The general orientation of the fibres shall be parallel to the longitudinal axis of the gauge portion of the test piece. The gauge length shall be between 50 mm and 100 mm.

The gripped ends of radially oriented test pieces shall have softwood (or similar material) "tabs" laminated to their breadth dimension, δ, to facilitate gripping by the test machine. The tabs shall be concentric and sufficient to ensure that the failure occurs within in the gauge portion of the specimen and to minimize stress concentration in the transition area.



Key

δ wall thickness

b width of specimen ($b < (\delta / 2) < 20$ mm)

1 culm section

2 gauge length = 50 mm to 100 mm

3 tabs

Figure 2 — Tension specimen orientation and tabbing

To determine the modulus of elasticity in tension parallel to the fibres, $E_{t,0}$, one electrical resistance strain gauge shall be fixed in the middle of the gage length parallel to the loading axis of the specimen. Alternatively, externally mounted mechanical gauges (e.g. clip or omega gauges) are permitted.

11.3 Procedure

Measure the cross-sectional dimensions, δ *and* b, (Figure 2) of the test piece with a precision of 0,1 mm, at three locations along the length of the gauge portion, and calculate the mean cross-sectional area with Formula (9):

$$A_g = \delta \times b \tag{9}$$

Clamp the ends of the test piece between the grips of the testing machine such that the clamping force is directed through the thinner dimension of the specimen (i.e. width dimension, b).

Application of load shall comply with 5.2.

If applicable, the strain gauge shall be read a sufficient number of times during the test to be able to plot a sufficiently precise load-deformation diagram from which $E_{t,0}$ can be determined.

Read the maximum load, F_{ult}, and record the failure mode. Test specimens that fail outside of the gauge portion shall be excluded from the strength analysis, but may be included in modulus of elasticity calculations.

Following each test, obtain specimens for the determination of moisture content in accordance with Clause 7 from the gauge region.

11.4 Calculation and expression of results

The tension strength parallel to the fibres, $f_{t,0}$, shall be calculated from Formula (10)

$$f_{t,0} = \frac{F_{ult}}{A_g} \tag{10}$$

where

F_{ult} is the maximum load at which the specimen fails, in Newtons (N);

A_g is the mean cross-sectional area of the gauge portion described in 11.3, in square millimetres (mm^2).

The modulus of elasticity in tension parallel to the fibres, $E_{t,0}$, shall be calculated as the secant between stress and strain pairs at 20 % and 60 % of F_{ult}. $E_{t,0}$ is calculated from Formula (11):

$$E_{t,0} = \frac{F_{60} - F_{20}}{A_g\left(\varepsilon_{60} - \varepsilon_{20}\right)} \tag{11}$$

where

F_{20}, F_{60} are the applied load, in Newtons (N), at 20 % and 60 % of F_{ult}, respectively;

ε_{20}, ε_{60} are the measured strain at 20 % and 60 % of F_{ult}, respectively.

11.5 Test report

For each culm tested, out of the three (or more) tested specimens, only the lowest tension strength parallel to the fibres, $f_{t,0}$, shall be reported. The test report shall be in accordance with 5.4. Method of tabbing, gripping and end restraint conditions provided by the tension grips shall also be reported.

12 Bending strength and stiffness parallel to the fibres

12.1 General

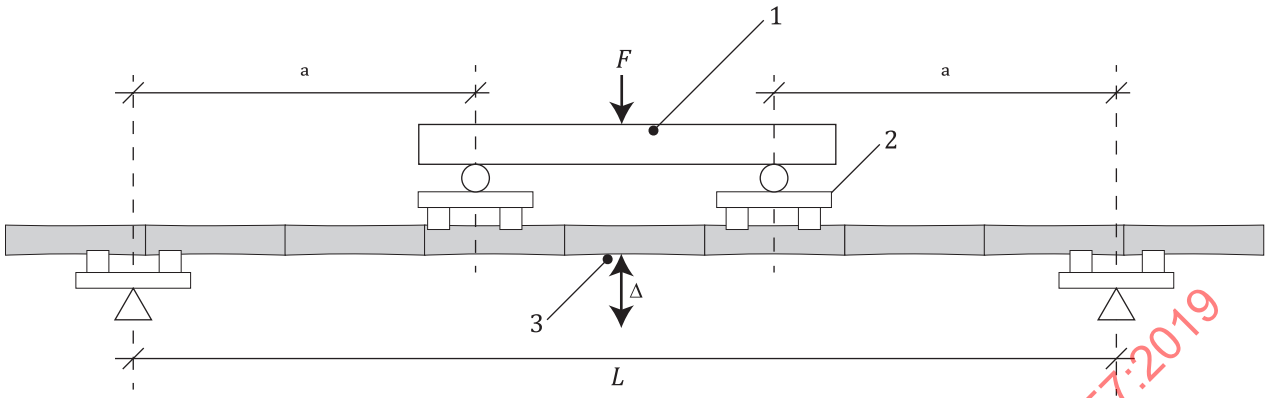
This clause specifies a method for determining the bending moment at failure, the bending strength parallel to fibres, the bending stiffness and the apparent modulus of elasticity in bending parallel to fibres for bamboo culms.

12.2 Apparatus

12.2.1 Test machine capable of measuring load with a precision of at least 1 % and deflection with a precision of 1 mm.

12.2.2 Flexure apparatus capable of applying two equal loads to a simply-supported specimen (i.e. four-point flexure) resulting in a region of constant moment between the load points. The applied loads and reaction forces at the supports shall be applied to the culms by means of four similar devices ("saddles") that spread the point loads as evenly as possible around one half of the culm circumference and along a sufficient longitudinal distance to avoid crushing or kinking of the culm wall. At the supports, the bamboo culm shall be allowed to rotate freely about its bending axis (i.e. no moment restraint). See Figure 3.

12.2.3 Mid-span displacement transducer capable of measuring the vertical displacement at mid-span (L / 2) with a precision of at least 1 mm.



Key

a	shear span
F	load
L	clear span
Δ	mid-span deflection
1	beam
2	saddle or strap
3	position of deformation measurement

Figure 3 — Schematic of bending test

12.3 Preparation of test culms.

Test culms shall be selected according to Clause 6.

In order to obtain a failure in bending, the distance between each support and the nearest point of load application (i.e. shear span a in Figure 3) shall be at least 10D, in which D is the outside diameter of the culm as defined in 3.9. Both shear spans shall be the same length. The minimum distance between loading points should be 10D, thus the minimum culm length is 30D.

12.4 Procedure

Place the culm in the flexure apparatus, resting on the saddles at the two supports, allowing the culm to "settle" into its own position. Bring the loading saddles into contact with the culm, and allow the culm to "settle" into position. Align the culm, the four saddles, the load beam and supports into one vertical plane.

The application of load shall comply with 5.2.

Observe cracks and their location. Describe the form and location of the failure. Failures that occur within the constant moment region shall be treated as failures in bending. Failures that occur in either shear span can be caused by shear, bending or a combination of these and should be excluded from bending moment and bending strength analyses, but may be included in stiffness and modulus of elasticity calculations.

Following each test, obtain specimens for the determination of moisture content in accordance with Clause 7 as close as possible to the point of failure.

12.5 Calculation and expression of results

For bending failures occurring within the constant moment region, the ultimate bending moment, M_{ult}, shall be calculated from Formula (12):

$$M_{ult} = \frac{F_{ult} \times a}{2} \tag{12}$$

where

F_{ult} is the maximum applied load (i.e. the total load applied to both load points), in Newtons (N);

a is the shear span (shown in Figure 3), expressed in millimetres (mm).

The bending strength parallel to the fibres, $f_{m,0}$, shall be calculated from Formula (13):

$$f_{m,0} = \frac{M_{ult} \times D}{2 \times I_B} \tag{13}$$

where

M_{ult} is the ultimate bending moment as per Formula (12), expressed in Newton millimetres (Nmm);

D is the outside diameter as described in Clause 4 obtained near the point of failure, in millimetres (mm);

I_B is the second moment of area (or moment of inertia) as described in Clause 4, calculated from the diameter and wall thickness obtained near the point of failure, in millimetres to the fourth power (mm^4).

The tangent bending stiffness of the culm, $E_{m,0} \cdot I_B$, is given by the slope of the linear portion of the load-deflection diagram defined between 20 % and 60 % of the ultimate capacity. $E_m \cdot I_B$ is calculated from Formula (14):

$$E_{m,0} \cdot I_B = \frac{(F_{60} - F_{20}) \cdot a\left(3L^2 - 4a^2\right)}{48\left(\Delta_{60} - \Delta_{20}\right)} \tag{14}$$

where

F_{20}, F_{60} are the applied loads, in Newtons (N) at 20 % and 60 % of F_{ult}, respectively;

Δ_{20}, Δ_{60} are the deflections at mid-span, in millimetres (mm), at 20 % and 60 % of F_{ult}, respectively;

L is the overall length (shown in Figure 3) in millimetres (mm);

a is the shear span length (shown in Figure 3) in millimetres (mm).

The apparent modulus of elasticity in bending parallel to the fibres, $E_{m,0}$, may be determined by dividing the tangent bending stiffness, $E_{m,0} \cdot I_B$, by I_B.

12.6 Test report

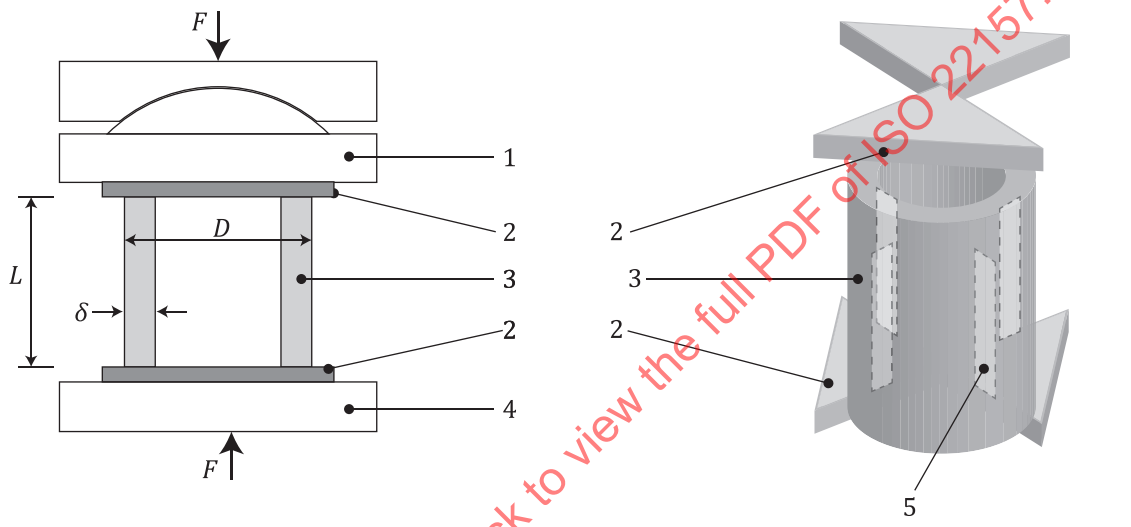
The test report shall be in accordance with 5.4. Observed failure mode and location shall be reported for each test.

13 Shear strength parallel to fibres

13.1 Apparatus

13.1.1 Test machine. Tests shall be carried out on a suitable testing machine capable of measuring compression load with a precision of at least 1 %. At least one platen of the testing machine shall be equipped with a spherical bearing surface to ensure that the load is concentrically applied, as in Figure 4.

13.1.2 Shear plates. The specimen shall be supported at its lower end over two opposing quadrants, and loaded at its upper end over the other two opposing quadrants. In this manner, loading the specimen results in four shear areas as shown in Figure 4. The centres of the upper and lower shear plates shall be aligned with the vertical axis of the test machine and fixed so that they may not move relative to each other (i.e. affixed to the platens).



Key

δ wall thickness
D outer diameter
F load
L length of specimen (L is the lesser of D or 10δ. If $D < 20$ mm, $L = 2D$)
1 upper loading platen with spherical bearing
2 shear plate
3 bamboo specimen
4 lower loading platen
5 shear area, normally calculated from $\delta \times L$

Figure 4 — Shear test

13.2 Preparation of test specimens

Test culms shall be selected according to Clause 6.

Shear tests parallel to fibre shall be made on specimens, 50 % with a node and 50 % without. The length of the specimen shall be taken as the lesser of the outer diameter, D, or 10 times the wall thickness 10δ. However, if D is 20 mm or less, the height may be taken as twice the outer diameter, $2D$, irrespective of δ.

The end planes of the specimen shall be parallel to each other and perpendicular to the length axis of the specimen. The end planes shall be flat, with a maximum deviation of 1 % of the outer diameter.

13.3 Procedure

Measure the specimen length, L, and wall thickness, δ, at each shear plane with a precision of 0,1 mm.

The specimen shall be placed such that its axis is aligned with the loading axis of the machine and the centre of the specimen coincides with the centre of shear plates. A small load of not more than 1 % of the expected failure load is initially applied to seat the specimen.

Application of load shall comply with 5.2.

The final reading of the maximum load, F_{ult}, at which the specimen fails, and the number of shear planes that fail, shall be recorded.

Following each test, obtain specimens for the determination of moisture content in accordance with Clause 7.

13.4 Calculation and expression of results

The shear strength, f_v, shall be calculated from Formula (15):

$$f_v = \frac{F_{ult}}{\Sigma(\delta \times L)} \tag{15}$$

where

F_{ult} is the maximum load at which the specimen fails in Newtons (N);

$\Sigma(\delta \times L)$ is the sum of the four measured areas at the shear planes in square millimetres (mm^2).

The failure is unlikely to occur at all four planes simultaneously. Therefore, f_v is interpreted to be a lower bound strength.

13.5 Test report

The test report shall be in accordance with 5.4. The number of observed failure planes shall be reported.

14 Tension strength perpendicular to the fibres

14.1 Apparatus

14.1.1 Test machine. Tests shall be carried out on a suitable testing machine capable of measuring tension load with a precision of at least 1 %.