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**Bamboo structures — Engineered  
bamboo products — Test methods  
for determination of physical and  
mechanical properties**

*Structures en bambou — Produits en bambou reconstitués —  
Méthodes d'essai pour la détermination des propriétés physiques et  
mécaniques*

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Published in Switzerland

# Contents

|                                                                                                         | Page      |
|---------------------------------------------------------------------------------------------------------|-----------|
| Foreword.....                                                                                           | v         |
| <b>1 Scope.....</b>                                                                                     | <b>1</b>  |
| <b>2 Normative references.....</b>                                                                      | <b>1</b>  |
| <b>3 Terms and definitions.....</b>                                                                     | <b>1</b>  |
| <b>4 Symbols.....</b>                                                                                   | <b>3</b>  |
| 4.1 Symbols.....                                                                                        | 3         |
| <b>5 Determination of dimensions of test specimens.....</b>                                             | <b>5</b>  |
| <b>6 Determination of moisture content of test specimens.....</b>                                       | <b>5</b>  |
| 6.1 Moisture content by oven-dry method.....                                                            | 5         |
| 6.1.1 Apparatus.....                                                                                    | 5         |
| 6.1.2 Preparation of test pieces.....                                                                   | 5         |
| 6.1.3 Procedure.....                                                                                    | 5         |
| 6.1.4 Calculation and expression of results.....                                                        | 6         |
| 6.2 Moisture content by electrical moisture meter method.....                                           | 6         |
| 6.2.1 General.....                                                                                      | 6         |
| 6.2.2 Apparatus.....                                                                                    | 6         |
| 6.2.3 Procedure.....                                                                                    | 6         |
| 6.2.4 Calculation and expression of results.....                                                        | 6         |
| 6.3 Test report.....                                                                                    | 7         |
| <b>7 Determination of density of test specimens.....</b>                                                | <b>7</b>  |
| 7.1 General.....                                                                                        | 7         |
| 7.2 Apparatus.....                                                                                      | 7         |
| 7.3 Preparation of test pieces.....                                                                     | 7         |
| 7.4 Procedure.....                                                                                      | 7         |
| 7.5 Calculations and expression of results.....                                                         | 7         |
| 7.6 Test report.....                                                                                    | 8         |
| <b>8 Conditioning of test specimens.....</b>                                                            | <b>8</b>  |
| <b>9 Determination of local (shear-free) modulus of elasticity in bending.....</b>                      | <b>8</b>  |
| 9.1 Test specimen.....                                                                                  | 8         |
| 9.2 Procedure.....                                                                                      | 8         |
| 9.3 Expression of results.....                                                                          | 9         |
| <b>10 Determination of global modulus of elasticity in bending.....</b>                                 | <b>10</b> |
| 10.1 Test specimen.....                                                                                 | 10        |
| 10.2 Procedure.....                                                                                     | 10        |
| 10.3 Expression of results.....                                                                         | 11        |
| <b>11 Determination of shear modulus — Variable span method.....</b>                                    | <b>12</b> |
| 11.1 General.....                                                                                       | 12        |
| 11.2 Test piece.....                                                                                    | 12        |
| 11.3 Procedure.....                                                                                     | 12        |
| 11.4 Expression of results.....                                                                         | 13        |
| 11.4.1 Determination of $K_1$ .....                                                                     | 13        |
| 11.4.2 Shear modulus.....                                                                               | 13        |
| <b>12 Determination of bending strength.....</b>                                                        | <b>14</b> |
| 12.1 Test specimen.....                                                                                 | 14        |
| 12.2 Procedure.....                                                                                     | 14        |
| 12.3 Expression of results.....                                                                         | 15        |
| <b>13 Determination of the strength and modulus of elasticity in tension parallel to the fibre.....</b> | <b>15</b> |
| 13.1 General.....                                                                                       | 15        |

|           |                                                                                                                                                             |           |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 13.2      | Test specimen .....                                                                                                                                         | 15        |
| 13.3      | Procedure .....                                                                                                                                             | 16        |
| 13.4      | Expression of modulus results .....                                                                                                                         | 17        |
| 13.5      | Expression of strength results .....                                                                                                                        | 17        |
| <b>14</b> | <b>Determination of the strength and modulus of elasticity in compression parallel to the fibre of the engineered bamboo product .....</b>                  | <b>17</b> |
| 14.1      | General .....                                                                                                                                               | 17        |
| 14.2      | Test specimen .....                                                                                                                                         | 18        |
| 14.3      | Procedure .....                                                                                                                                             | 18        |
| 14.4      | Expression of modulus results .....                                                                                                                         | 18        |
| 14.5      | Expression of results .....                                                                                                                                 | 18        |
| <b>15</b> | <b>Determination of the strength and modulus of elasticity in compression and tension perpendicular to the fibre of the engineered bamboo product .....</b> | <b>19</b> |
| 15.1      | Requirements for test specimens .....                                                                                                                       | 19        |
| 15.2      | Procedure .....                                                                                                                                             | 19        |
| 15.3      | Expression of results .....                                                                                                                                 | 21        |
| 15.3.1    | Compression strength perpendicular to the fibre .....                                                                                                       | 21        |
| 15.3.2    | Compression modulus perpendicular to the fibre .....                                                                                                        | 22        |
| 15.3.3    | Tension strength perpendicular to the fibre .....                                                                                                           | 23        |
| 15.3.4    | Tension modulus perpendicular to the fibre .....                                                                                                            | 23        |
| <b>16</b> | <b>Determination of shear strength parallel to the fibre .....</b>                                                                                          | <b>24</b> |
| 16.1      | Requirements for test specimens .....                                                                                                                       | 24        |
| 16.1.1    | Fabrication .....                                                                                                                                           | 24        |
| 16.2      | Procedure .....                                                                                                                                             | 26        |
| 16.3      | Expression of results .....                                                                                                                                 | 26        |
| <b>17</b> | <b>Test report .....</b>                                                                                                                                    | <b>26</b> |
| 17.1      | General .....                                                                                                                                               | 26        |
| 17.2      | Test specimen .....                                                                                                                                         | 26        |
| 17.3      | Test method .....                                                                                                                                           | 27        |
| 17.4      | Test results .....                                                                                                                                          | 27        |
|           | <b>Bibliography .....</b>                                                                                                                                   | <b>28</b> |

## 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](http://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](http://www.iso.org/patents)).

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For an explanation on 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 the following URL: [www.iso.org/iso/foreword.html](http://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](http://www.iso.org/members.html).

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# Bamboo structures — Engineered bamboo products — Test methods for determination of physical and mechanical properties

## 1 Scope

This document specifies test methods suitable for determining the following mechanical properties of engineered bamboo products:

- a) modulus of elasticity in bending;
- b) shear modulus;
- c) bending strength;
- d) modulus of elasticity in tension parallel to the fibre;
- e) tension strength parallel to the fibre;
- f) modulus of elasticity in compression parallel to the fibre;
- g) compression strength parallel to the fibre;
- h) modulus of elasticity in tension perpendicular to the fibre;
- i) tension strength perpendicular to the fibre;
- j) modulus of elasticity in compression perpendicular to the fibre;
- k) compression strength perpendicular to the fibre and shear strength;
- l) shear strength parallel to the fibre.

In addition, the determination of dimensions, moisture content and density are specified.

This document is applicable to prismatic shapes of glued laminated bamboo and bamboo scrimber intended to resist flexure, shear, axial loads, or combinations thereof.

## 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 22157, *Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods*

ISO 21625, *Vocabulary related to bamboo and bamboo products*

## 3 Terms and definitions

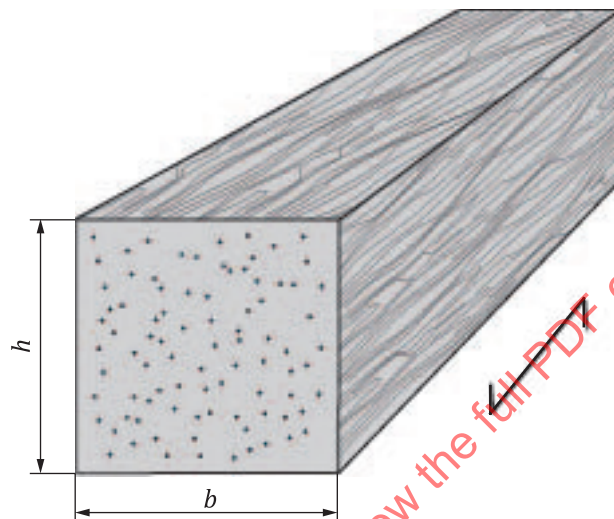
For the purposes of this document, the terms and definitions given in ISO 22157, ISO 21625 and the following apply.

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 <https://www.electropedia.org/>

**3.1**  
**bamboo scrimber**  
 panel or structural member made of compressed bamboo fibre bundle strips or compressed bamboo fibre bundle sheet

[SOURCE: ISO 21625:2020, 3.2.17]



**Key**

- 1 width,  $b$
- 2 depth,  $h$

↗ indicates parallel to fibre orientation

**Figure 1** — Example of bamboo scrimber

**3.2**  
**bamboo strip**  
 bamboo piece with outer and inner layers intact, made by cutting bamboo culm in longitudinal direction

**3.3**  
**bamboo lamina**  
 thin and flat bamboo piece with rectangular cross-section, processed from *bamboo strip* (3.2) by removing the outer and inner layers of the bamboo culm wall

**3.4**  
**engineered bamboo member**  
 assembly of individual elements made of bamboo

**3.5**  
**glued laminated bamboo**  
 structural member formed by bonding together *bamboo strips* (3.2) with their fibres running essentially parallel

[SOURCE: ISO 21625:2020, 3.3.1.14]

### 3.6

#### non-structural joint

non-structural connection (e.g. butt, hook joint) to support manufacturing process and is not designed to transfer stress across the connection

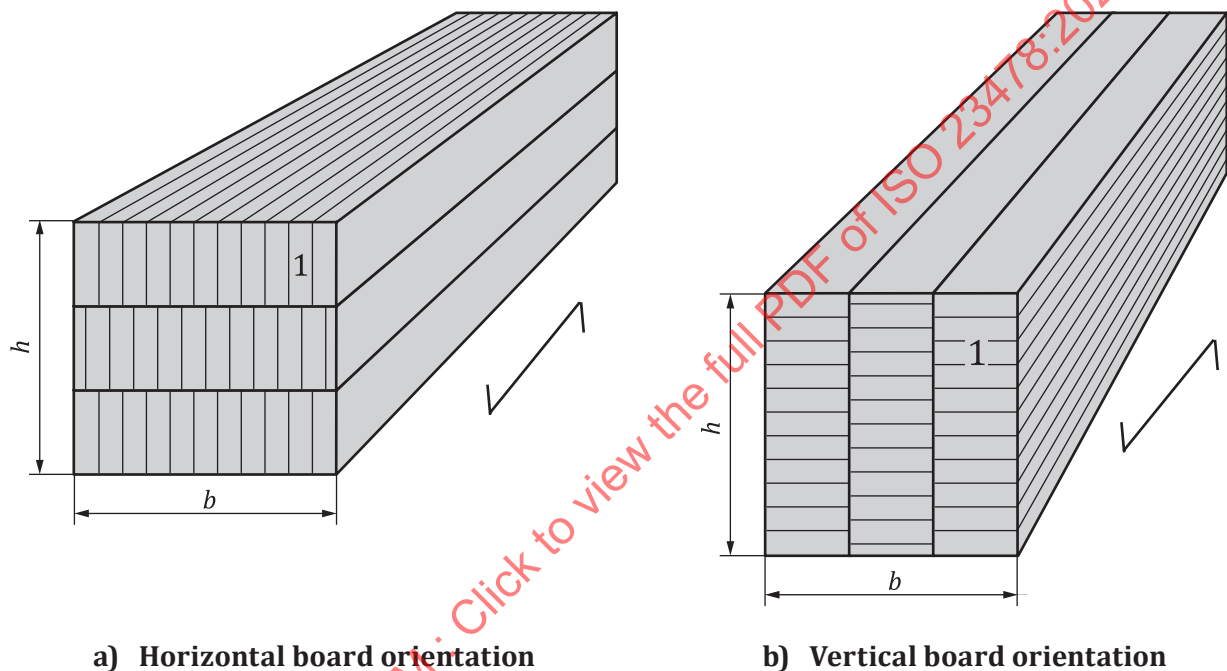
### 3.7

#### 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.

[SOURCE: ISO 22157:2019, 3.12]



#### Key

|     |                                         |
|-----|-----------------------------------------|
| $b$ | width, $b$                              |
| $h$ | depth, $h$                              |
| 1   | bamboo lamina                           |
| ↕   | indicates parallel to fibre orientation |

Figure 2 — Example of glued laminated bamboo

## 4 Symbols

### 4.1 Symbols

|     |                                                                                                          |
|-----|----------------------------------------------------------------------------------------------------------|
| $A$ | cross-sectional area, in square millimetres;                                                             |
| $a$ | distance between a loading position and the nearest support in a bending test, in millimetres;           |
| $b$ | width of cross-section in a bending test, or the smaller dimension of the cross-section, in millimetres; |

|                    |                                                                                                                           |
|--------------------|---------------------------------------------------------------------------------------------------------------------------|
| $E_{c,0}$          | modulus of elasticity in compression parallel to the fibre, in Newton per square millimetre;                              |
| $E_{c,90}$         | modulus of elasticity in compression perpendicular to the fibre, in Newton per square millimetre;                         |
| $E_{m,g}$          | global modulus of elasticity in bending, in Newton per square millimetre;                                                 |
| $E_{m,app}$        | apparent modulus of elasticity in bending, in Newton per square millimetre;                                               |
| $E_{t,0}$          | modulus of elasticity in tension parallel to the fibre, in Newton per square millimetre;                                  |
| $E_{t,90}$         | modulus of elasticity in tension perpendicular to the fibre, in Newton per square millimetre;                             |
| $F$                | load, in Newtons;                                                                                                         |
| $F_{c,90,max}$     | maximum compressive load perpendicular to the fibre, in Newtons;                                                          |
| $F_{c,90,max,est}$ | estimated maximum compressive load perpendicular to the fibre, in Newtons;                                                |
| $F_{max}$          | maximum load, in Newtons;                                                                                                 |
| $F_{max,est}$      | estimated maximum load, in Newtons;                                                                                       |
| $F_{t,90,max}$     | maximum tensile load perpendicular to the fibre, in Newtons;                                                              |
| $F_y$              | yield load, in Newtons;                                                                                                   |
| $F_{ult}$          | maximum (ultimate) load applied in test, in Newtons;                                                                      |
| $f_{c,0}$          | compressive strength parallel to the fibre, in Newton per square millimetre;                                              |
| $f_{c,90}$         | compressive strength perpendicular to the fibre, in Newton per square millimetre;                                         |
| $f_m$              | bending strength, in Newton per square millimetre;                                                                        |
| $f_{t,0}$          | tensile strength parallel to the fibre, in Newton per square millimetre;                                                  |
| $f_{t,90}$         | tensile strength perpendicular to the fibre, in Newton per square millimetre;                                             |
| $G$                | shear modulus, in Newton per square millimetre;                                                                           |
| $h$                | depth of cross-section in a bending test, or the larger dimension of the cross-section, in millimetres;                   |
| $h_0$              | gauge length, in millimetres;                                                                                             |
| $h_t$              | test specimen height in perpendicular to fibre tests, in millimetres;                                                     |
| $I$                | second moment of area, in millimetres to the fourth power;                                                                |
| $l$                | span in bending, or length of test specimen between the testing machine grips in compression and tension, in millimetres; |
| $l_1$              | gauge length for the determination of modulus of elasticity or shear modulus, in millimetres;                             |
| $m_e$              | mass of the test piece before drying, in grams;                                                                           |
| $m_i$              | initial mass before drying, in grams;                                                                                     |
| $m_0$              | final oven-dry mass, in grams;                                                                                            |

|                      |                                                                                              |
|----------------------|----------------------------------------------------------------------------------------------|
| $S$                  | section modulus, in millimetres to the third power;                                          |
| $V$                  | volume of the test piece, in millimetres to the third power;                                 |
| $V_0$                | volume of the test piece in the absolutely dry condition, in millimetres to the third power; |
| $w$                  | moisture content;                                                                            |
| $\Delta$             | displacement, in millimetres;                                                                |
| $\delta$             | change in slope;                                                                             |
| $\rho_{\text{test}}$ | density under conditions of test, in grams per millimetre to the third power;                |
| $\rho_0$             | dry density, in grams per millimetre to the third power.                                     |

## 5 Determination of dimensions of test specimens

The dimensions of the test specimen shall be measured to a precision of 1 % of the least cross-sectional dimensions of the member. All measurements shall be made when the test specimens are conditioned as specified in [Clause 8](#). If the width or thickness varies within a test specimen, these dimensions should be recorded as the average of three separate measurements taken at different positions on the length of each specimen.

## 6 Determination of moisture content of test specimens

### 6.1 Moisture content by oven-dry method

#### 6.1.1 Apparatus

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

**6.1.1.2 Oven**, capable of drying specimen to the absolute dry condition.

#### 6.1.2 Preparation of test pieces

Specimens for determination of moisture content shall be prepared immediately after each mechanical test. 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.

The moisture content of the test specimen shall be determined on a section taken from the test specimen. For engineered bamboo products the section shall be of full cross-section. For perpendicular to fibre test specimens the moisture content shall be determined from the whole specimen.

In strength tests for bending, shear, tension parallel and perpendicular to fibre and compression parallel and perpendicular to fibre, the moisture content of the test specimen shall be determined near the place of failure.

#### 6.1.3 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  $(103 \pm 2) ^\circ\text{C}$ . The initial mass is  $m_i$ .

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

The following modifications for bamboo scrimber shall be made. After 48 h, the mass shall be recorded at regular intervals of not less than 6 h. The drying shall be considered to be complete when the difference between successive determinations of mass do not exceed 0,1 % of the measured mass. The final oven-dry mass is  $m_0$ .

#### 6.1.4 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 oven-mass of the test piece.

Both  $m_i$  and  $m_0$  are measured with a precision of at least 0,5 % of the dry specimen mass for laminated bamboo and of at least 0,1 % of the dry specimen mass for bamboo scrimber.

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

### 6.2 Moisture content by electrical moisture meter method

#### 6.2.1 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 using the oven-dry method described in [6.1](#). Commercial conductivity moisture meters are generally only reliable for wood moisture content between about 5 % and 30 %.

#### 6.2.2 Apparatus

**6.2.2.1 Moisture meter**, of any design calibrated for laminated bamboo and bamboo scrimber (using the oven-dry method described in [6.1](#)), and capable of making an individual measurement with an error of not more than 2 % at moisture contents from 7 % to 30 %.

#### 6.2.3 Procedure

Measure the moisture content of the test piece or traveller specimen at a location within the specimen. Measurements should be taken either at freshly cut cross-sections, or by driving deep, sharp probes into the specimen.

The area at which measurements are made shall not contain any contaminants or visible defects. Drive the electrodes into the cross-section so that the line between the tips of the needles intersects the specimen.

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.

#### 6.2.4 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 %.

### 6.3 Test report

The moisture content shall be reported in the test report in accordance with [17.4](#).

## 7 Determination of density of test specimens

### 7.1 General

This clause specifies the method for determining the density, as mass by volume.

### 7.2 Apparatus

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

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

**7.2.3 Equipment**, for the determination of the moisture content in accordance with [6.1](#).

### 7.3 Preparation of test pieces

For perpendicular to fibre test specimens, the density of the test specimens shall be determined prior to testing based on the whole test specimen.

For parallel to fibre and bending test specimens, the density shall be determined immediately after each mechanical test. The density shall be determined on a portion of the cross-section or the entire cross-section taken from the test specimen near the place of failure. The section shall be measured based on a minimum sample volume with at least three laminae in section and 50 mm in length.

For perpendicular to fibre test specimens, the density of the test specimens shall be determined prior to test from the measurements of mass and volume of the whole test specimen.

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.

### 7.4 Procedure

Measure the dimensions of the test pieces with a precision of at least 0,1 mm and calculate the volume,  $b \times h \times l$ .

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

For the dry density,  $\rho_0$ , dry the test pieces to a constant oven-dry mass (see [6.1.3](#)). 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.

### 7.5 Calculations and expression of results

The density at the time of test,  $\rho_{\text{test}}$ , shall be calculated from [Formula \(2\)](#):

$$\rho_{\text{test}} = \frac{m_e}{V} \quad (2)$$

where

$m_e$  is the mass of the test piece before drying;

$V$  is the volume of the test piece.

The dry density,  $\rho_0$ , of each test piece in the absolutely dry condition shall be calculated from [Formula \(3\)](#):

$$\rho_0 = \frac{m_0}{V_0} \quad (3)$$

where

$m_0$  is the oven-dry mass of the test piece;

$V_0$  is the volume of the test piece in the absolutely dry condition.

## 7.6 Test report

The density shall be reported in the test report in accordance with [17.4](#).

## 8 Conditioning of test specimens

All tests shall be carried out on pieces, which are conditioned at the standard environment of  $23 \pm 3$  °C and  $65 \pm 5$  % relative humidity.

A test piece is conditioned when it attains constant mass. Constant mass is considered to be attained when the results of two successive weight measurements, carried out at an interval of 6 h, do not differ by more than 0,1 % of the mass of the test piece.

Where the test piece to be tested is not readily conditioned to the above standard environment that fact shall be reported.

For small specimens, unless otherwise protected, test pieces shall not be removed from the conditioning environment more than 1 h before testing.

NOTE 1 Test pieces can be stored in the test area for up to 24 h provided they are close piled and wrapped in vapour tight sheeting.

## 9 Determination of local (shear-free) modulus of elasticity in bending

### 9.1 Test specimen

The test piece shall have a minimum length of 19 times the depth of the section. Where this is not possible, the span of the beam shall be reported.

### 9.2 Procedure

The test specimen shall be a simply supported span of  $18 \pm 3$  times the specimen depth as shown in [Figure 3](#). Load shall be applied at two points spaced 6 times the specimen depth apart arranged symmetrically about the centre line of the specimen span.

NOTE 1 Small steel plates having a width equal to the beam width and a length not greater than one-half of the depth of the test specimen can be inserted between the specimen and the loading heads or supports to minimize local indentation.

Lateral restraint shall be provided at the supports and points of load application. This restraint shall permit the specimen to deflect without frictional resistance.

Load shall be applied at a constant rate and the test should be completed within approximately 300 s but not less than 180 s.

Ideally, the load application rate is determined from the results of preliminary tests. The estimated maximum load,  $F_{\max, \text{est}}$  of the material under test shall be obtained either from tests on at least ten pieces of the appropriate material and size or from appropriate existing test data. The objective is that the average time to reach  $F_{\max}$  is 300 s.

For the purpose of calculations, the value of  $F_{\max}$  shall be determined as the proportional limit observed in the test.

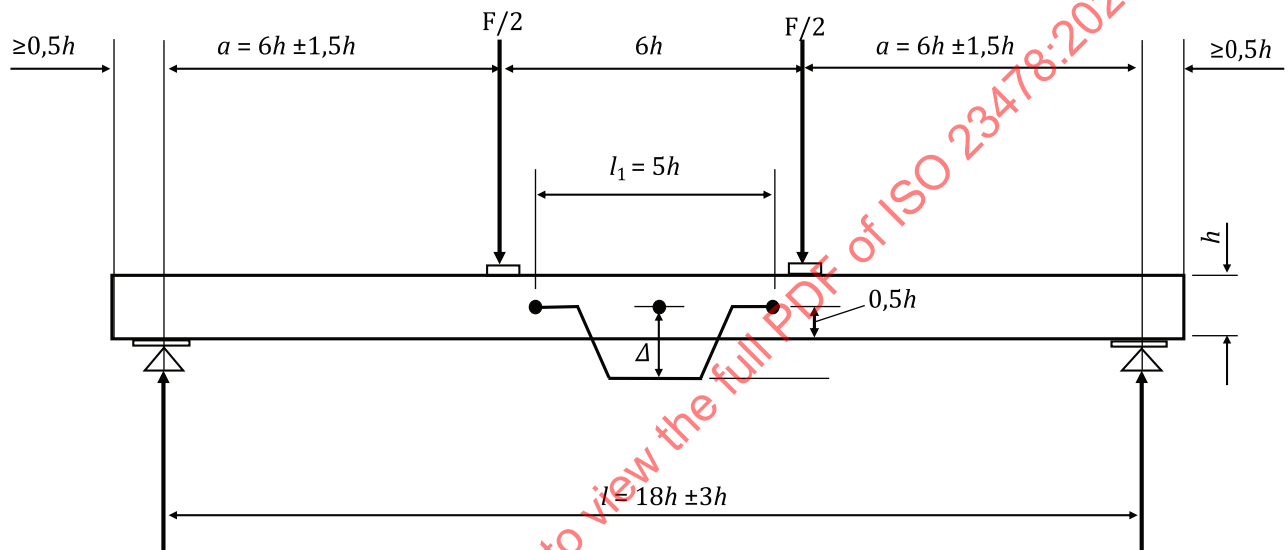


Figure 3 — Test arrangement for measuring local modulus of elasticity in bending

The loading equipment used shall be capable of measuring the applied load with a precision of 1 %.

The displacement,  $\Delta$ , shall be taken as the average of measurements on both side faces at the neutral axis, and shall be measured at the centre of a central gauge length of five times the depth of the section (see Figure 3).

The measuring equipment used shall be capable of measuring deformation with a precision of 1 %.

NOTE 2 ASTM D198 provides a description of an acceptable deflection measuring device and the yoke.

### 9.3 Expression of results

For glued laminated bamboo, specify the orientation of the strips along the specimen length e.g. horizontal or vertical relative to the direction of load application. See Figure 2.

For a rectangular section, the local modulus of elasticity in bending,  $E_{m,l}$ , is given by Formula (4):

$$E_{m,l} = \frac{3al_1^2}{4bh^3} \left( \frac{F_{40} - F_{10}}{\Delta_{40} - \Delta_{10}} \right) \quad (4)$$

where

$a$  distance between a loading position and the nearest support, as shown in Figure 3;

|                             |                                                                                                                             |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| $b$                         | width of cross-section;                                                                                                     |
| $h$                         | depth of cross-section;                                                                                                     |
| $l_1$                       | gauge length, as shown in <a href="#">Figure 3</a> ;                                                                        |
| $F_{40} - F_{10}$           | $F_{40}, F_{10}$ are applied loads at 40 % and 10 % of $F_{\max}$ , respectively (for $F_{\max}$ see <a href="#">9.2</a> ); |
| $\Delta_{40} - \Delta_{10}$ | displacement corresponding to $F_{40}$ and $F_{10}$ , respectively.                                                         |

The local modulus of elasticity,  $E_{m,l}$  shall be calculated to a precision of 1 %.

## 10 Determination of global modulus of elasticity in bending

### 10.1 Test specimen

The test piece shall have a minimum length of 19 times the depth of the section. Where this is not possible, the span of the beam shall be reported.

### 10.2 Procedure

The test specimen shall be a simply supported span of  $(18 \pm 3)$  times the specimen depth as shown in [Figure 4](#). Load shall be applied at two points spaced 6 times the specimen depth apart arranged symmetrically about the centre line of the specimen span.

**NOTE** Small steel plates having a width equal to the beam width and a length not greater than one-half of the depth of the test specimen can be inserted between the specimen and the loading heads or supports to minimize local indentation.

Lateral restraint shall be provided at the supports and points of load application. This restraint shall permit the specimen to deflect without frictional resistance.

Load shall be applied at a constant rate and the test should be completed within approximately 300 s but not less than 180 s.

Ideally, the load application rate is determined from the results of preliminary tests. The estimated maximum load,  $F_{\max,est}$  of the material under test shall be obtained either from tests on at least ten pieces of the appropriate material and size or from appropriate existing test data. The objective is that the average time to reach  $F_{\max}$  is 300 s.

For the purpose of calculations, the value of  $F_{\max}$  shall be determined as the proportional limit observed in the test.

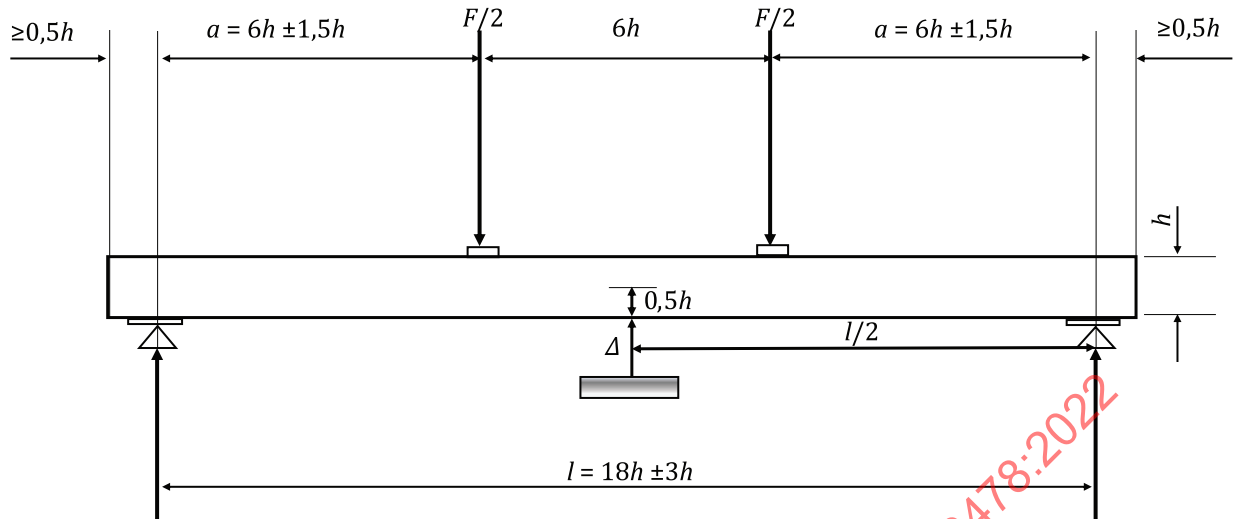


**Figure 4 — Test arrangement for measuring global modulus of elasticity in bending**

The loading equipment used shall be capable of measuring the load to a precision of 1 % of the load applied to the test piece or, for loads less than 10 % of the applied maximum load, with a precision of 0,1 % of the maximum applied load.

The displacement,  $\Delta$ , shall be measured at the neutral axis and it shall be the mean of measurements made on both sides of the test piece.

Displacement shall be determined with a precision of 1 %, or for displacement less than 2 mm, with a precision of 0,02 mm.

### 10.3 Expression of results

For glued laminated bamboo, specify the orientation of the strips along the specimen length, e.g. horizontal, or vertical, relative to the direction of load application. See [Figure 2](#).

Based on requirement that beams remain below their limit of proportionality, elastic analysis may be used.

For a rectangular section, the global modulus of elasticity in bending,  $E_{m,g}$ , is given by [Formula \(5\)](#):

$$E_{m,g} = \frac{a}{4bh^3} (3l^2 - 4a^2) \left( \frac{F_{40} - F_{10}}{\Delta_{40} - \Delta_{10}} \right) \quad (5)$$

where

- $a$  distance between a loading position and the nearest support, as shown in [Figure 4](#);
- $b$  width of cross-section;
- $h$  depth of cross-section;
- $l$  span in bending, as shown in [Figure 4](#);
- $F_{40} - F_{10}$   $F_{40}$ ,  $F_{10}$  are applied loads at 40 % and 10 % of  $F_{max}$ , respectively (for  $F_{max}$  see [10.2](#));
- $\Delta_{40} - \Delta_{10}$  displacement corresponding to  $F_{40}$  and  $F_{10}$ , respectively.

The local modulus of elasticity,  $E_{m,g}$ , shall be calculated to a precision of 1 %.

## 11 Determination of shear modulus — Variable span method

### 11.1 General

This method involves the determination of the apparent modulus of elasticity,  $E_{m,app}$ , for each test specimen over a number of spans with the same cross-section at the centre.

### 11.2 Test piece

The test specimen shall have a minimum length of 19 times the depth of the section as shown in [Figure 5](#), with a maximum simply supported test span of  $(18 \pm 3)$  times the depth of the section.

### 11.3 Procedure

The test specimen shall be a simple supported span loaded in centre point bending over at least four different spans with the same cross-section at the centre of each, as shown in [Figure 5](#). The spans shall be chosen so as to have approximately equal increments of  $\left(\frac{h}{l}\right)$  between them, within the range 0,05 to 0,20. The test spans shall be reported.

**NOTE** Small steel plates having a width equal to the beam width and a length not greater than one-half of the depth of the test specimen can be inserted between the specimen and the loading heads or supports to minimize local indentation.

Lateral restraint shall be provided at the supports and points of load application. This restraint shall permit the specimen to deflect without frictional resistance.

Load shall be applied at a constant rate and the test should be completed within approximately 300 s but not less than 180 s.

Ideally, the load application rate is determined from the results of preliminary tests. The estimated maximum load,  $F_{max,est}$  of the material under test shall be obtained either from tests on at least ten pieces of the appropriate material and size or from appropriate existing test data. The objective is that the average time to reach  $F_{max}$  is 300 s.

For the purpose of calculations, the value of  $F_{max}$  shall be determined as the proportional limit observed in the test.

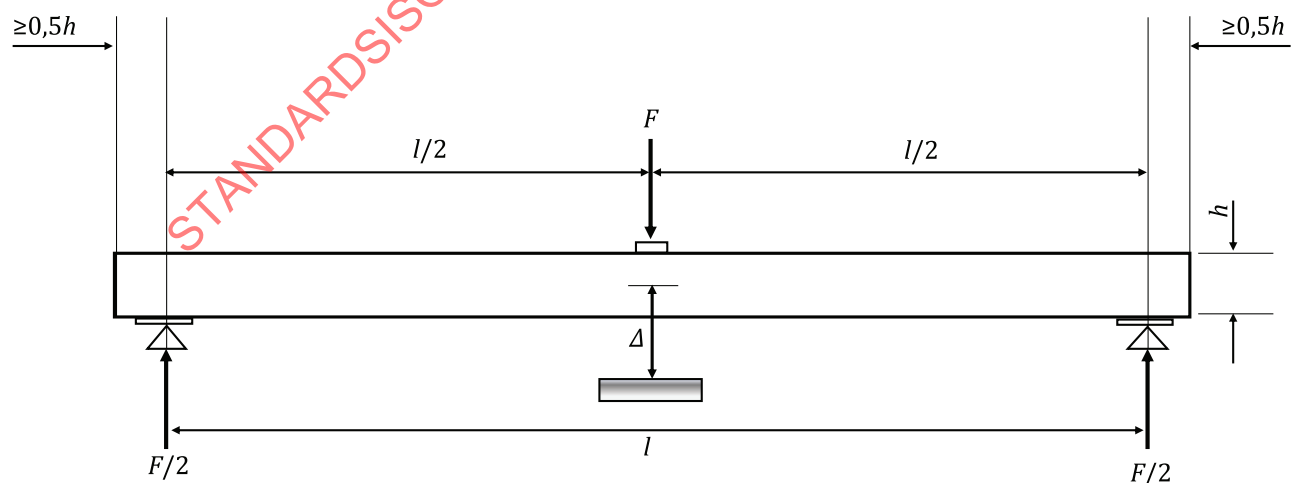


Figure 5 — Test arrangement for measuring shear modulus

The loading equipment used shall be capable of measuring the load with a precision of 1 % of the load applied to the test specimen.

Displacement shall be measured at the centre of the span.

The displacement measuring devices and recording system shall be such as to permit measuring deflections with 1 % precision.

## 11.4 Expression of results

For glued laminated bamboo, specify the orientation of the strips along the specimen length e.g., horizontal, or vertical relative to the direction of load application. See [Figure 2](#).

### 11.4.1 Determination of $K_1$

The apparent modulus of elasticity,  $E_{m,app}$ , for each test specimen is given by [Formula \(6\)](#):

$$E_{m,app} = \frac{l^3 (F_{40} - F_{10})}{4bh^3 (\Delta_{40} - \Delta_{10})} \quad (6)$$

where

$b$  width of cross-section;

$h$  depth of cross-section;

$l$  span in bending, as shown in [Figure 5](#);

$F_{40} - F_{10}$   $F_{40}, F_{10}$  are applied loads at 40 % and 10 % of  $F_{max}$ , respectively (for  $F_{max}$  see [11.3](#));

$\Delta_{40} - \Delta_{10}$  displacement corresponding to  $F_{40}$  and  $F_{10}$ , respectively.

The local modulus of elasticity,  $E_{m,app}$ , shall be calculated to a precision of 1 %.

For each specimen, the values of  $1/E_{m,app}$  shall be plotted against  $\left(\frac{h}{l}\right)^2$  as shown in [Figure 6](#) and the slope  $K_1$  of the best straight line through the points shall be determined.

### 11.4.2 Shear modulus

For a rectangular or square section, the shear modulus  $G$  is given by [Formula \(7\)](#):

$$G = \frac{1,2}{K_1} \quad (7)$$

where  $K_1$  is the slope of the straight line (see [Figure 6](#)).

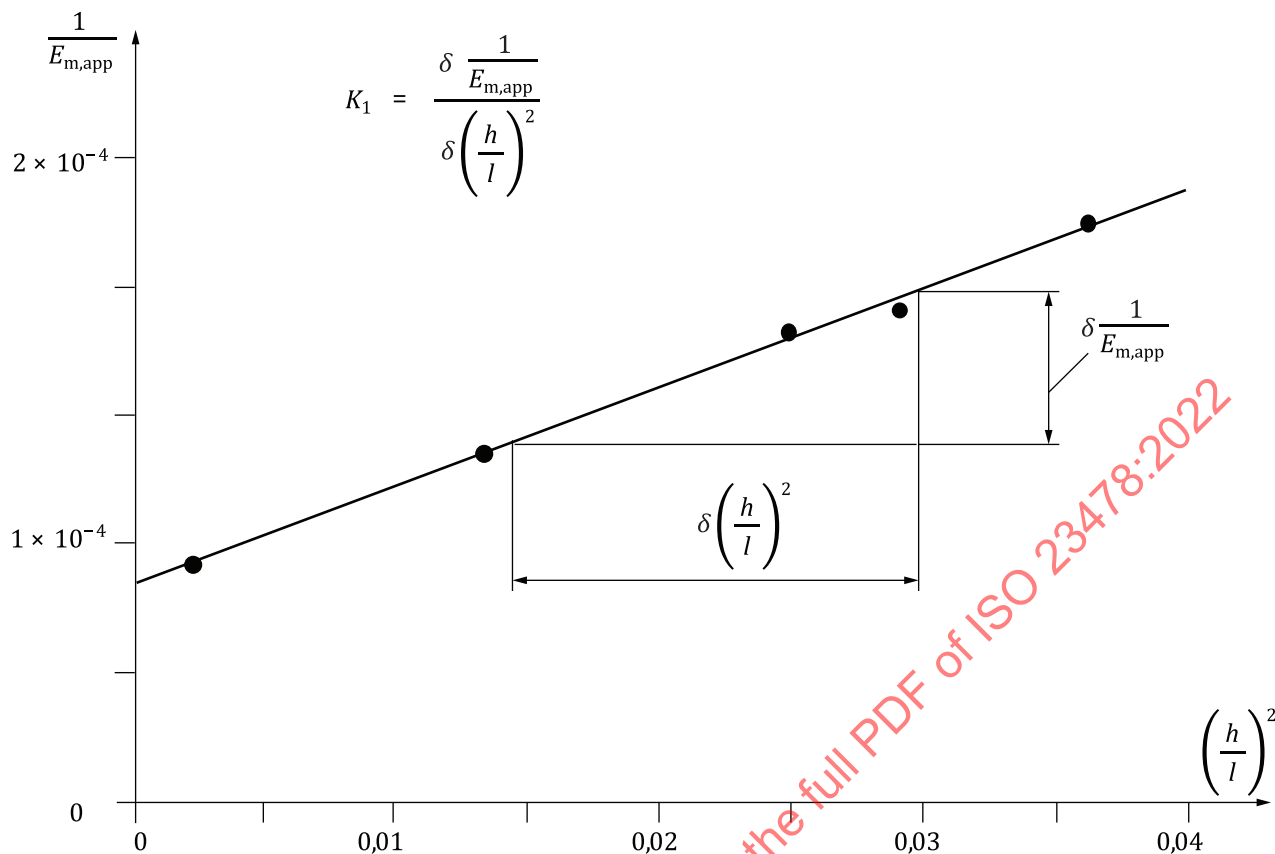


Figure 6 — Determination of shear modulus — Variable span method

## 12 Determination of bending strength

### 12.1 Test specimen

The test specimen shall have a minimum length to permit testing with a span of approximately 19 times the depth of the section as shown in Figure 4, with a minimum test span of 18 times the depth of the section. Where this is not possible, the test span shall be reported.

### 12.2 Procedure

The test specimen shall be a simply supported span of  $(18 \pm 3)$  times the specimen depth as shown in Figure 4. Load shall be applied at two points spaced 6 times the specimen depth apart arranged symmetrically about the centre line of the specimen span.

**NOTE** Small steel plates having a width equal to the beam width and a length not greater than one-half of the depth of the test specimen can be inserted between the specimen and the loading heads or supports to minimize local indentation.

Lateral restraint shall be provided at the supports and points of load application. This restraint shall permit the specimen to deflect without frictional resistance.

Load shall be applied at a constant rate and the test should be completed within approximately 300 s but not less than 180 s.

Ideally, the load application rate is determined from the results of preliminary tests. The estimated maximum load,  $F_{\max, \text{est}}$ , of the material under test shall be obtained either from tests on at least ten pieces of the appropriate material and size or from appropriate existing test data. The objective is that the average time to reach  $F_{\max}$  is 300 s.

For the purpose of calculations, the value of  $F_{\max}$  shall be determined as the proportional limit observed in the test.

The loading equipment used shall be capable of measuring the load with a precision of 1 % of the load applied to the test specimen.

### 12.3 Expression of results

For glued laminated bamboo, specify the orientation of the strips along the specimen length, e.g. horizontal, or vertical, relative to the direction of load application. See [Figure 2](#).

The bending strength,  $f_m$ , is given by [Formula \(8\)](#):

$$f_m = \frac{3aF}{bh^2} \quad (8)$$

where

- $a$  distance between a loading position and the nearest support, as shown in [Figure 4](#);
- $b$  width of cross-section;
- $h$  depth of cross-section;
- $F$  load, which can be  $F_y$ ,  $F_{\max}$ , or  $F_{\text{ult}}$ , as required.

The mode of fracture and the growth characteristics at the fracture section of each test piece shall be reported.

NOTE 1 ISO/TR 21141 provides definitions of  $F_y$  and  $F_{\text{ult}}$ .

## 13 Determination of the strength and modulus of elasticity in tension parallel to the fibre

### 13.1 General

The measurement of strength and modulus of elasticity in tension parallel to fibre of an engineered bamboo member presents considerable difficulty but values suitable for use in design can be obtained using the method of this section. The axial strength modulus of elasticity may also be estimated as the volume-weighted average of the modulus of elasticity of the individual laminations for glued laminated bamboo.

### 13.2 Test specimen

The test piece shall have a rectangular section of  $b \times h$  and be of sufficient length to provide a test length clear of the testing machine grips of at least nine times the greater dimension of  $b$  or  $h$  as shown in [Figure 7](#).

For laminated bamboo, the test specimen shall be a single ply board having at least one bamboo strip through the dimension  $h$ . For bamboo scrimber, the test specimen shall be at least 12 mm wide through the dimension  $h$ .

The length of the specimen between the testing machine grips shall be at least 900 mm or at least 8 times the larger cross-sectional dimension and the minimum size of the specimen shall not be less than the minimum structural size manufactured.

If the length of the specimen between the testing machine grips is different than the reference length of 900 mm, the test results may need to be adjusted to a common size or value based on national codes. A failure in the grips of the test machine invalidates the results and a new test shall be required.

NOTE 1 The provisions of ASTM D5456 provide an example of a methodology that can be used to adjust for length effects.

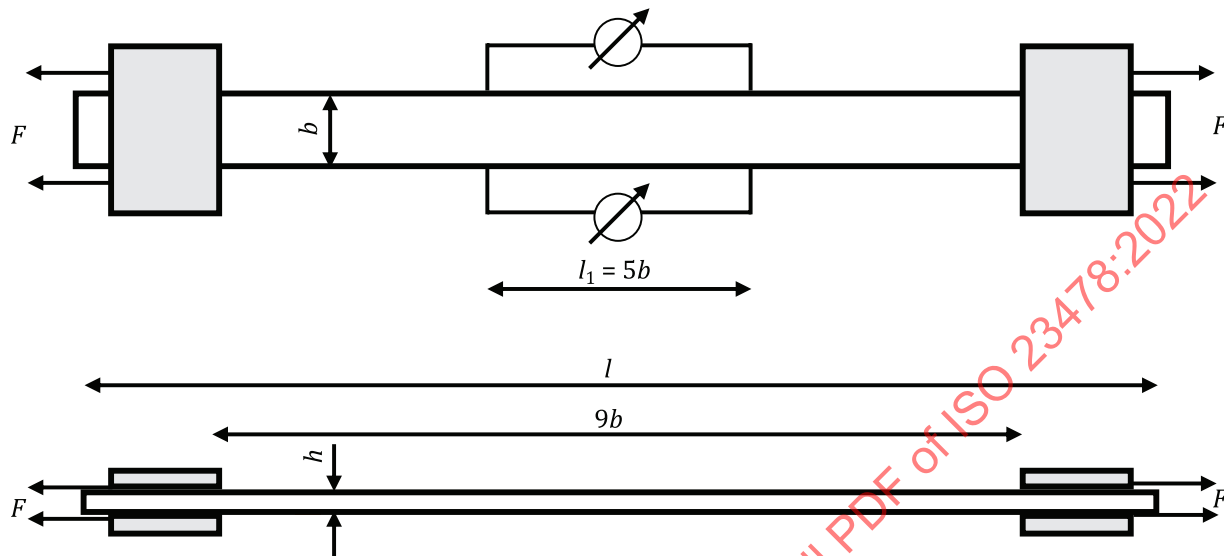


Figure 7 — Test setup tensile strength parallel to fibre

### 13.3 Procedure

The tension strength tests parallel to the fibre shall be carried out using gripping devices which permit as far as possible the application of a tensile load without inducing bending. The gripping devices and loading conditions used shall be reported.

Tension specimens should be gripped across their greater dimensions (through the smaller).

NOTE 1 When necessary, aluminium or steel tabs can be used to avoid crushing in the grip area.

The loading equipment used shall be capable of measuring the load to a precision of 1 % of the load applied to the test piece or, for loads less than 10 % of the applied maximum load, with a precision of 0,1 % of the maximum applied load.

Load shall be applied at a constant rate. The rate of strain in the piece shall be not greater than 0,00 005/s.

Displacement shall be measured over a length of five times the width ( $5b$ ) of the piece, located not closer to the ends of the grips than twice this width.

Two extensometers shall be used on opposite sides of the specimens and shall be positioned to minimize the effects of distortion. Displacement shall be determined with a precision of 1 % or for deformations less than 2 mm, with a precision of 0,02 mm.

Ideally, the load application rate is determined from the results of preliminary tests. The estimated maximum load,  $F_{\max, \text{est}}$ , of the material under test shall be obtained either from tests on at least ten pieces of the appropriate material and size or from appropriate existing test data. The objective is that the average time to reach  $F_{\max}$  is 300 s.

### 13.4 Expression of modulus results

For glued laminated bamboo, specify the orientation of the strips along the specimen length, e.g. horizontal, or vertical, relative to the direction of load application. See [Figure 2](#).

The modulus of elasticity in tension,  $E_{t,0}$ , is given by [Formula \(9\)](#):

$$E_{t,0} = \frac{l_1 (F_{40} - F_{10})}{bh(\Delta_{40} - \Delta_{10})} \quad (9)$$

where

$b$  width of cross-section;

$h$  depth of cross-section;

$l_1$  gauge length, as shown in [Figure 7](#);

$F_{40} - F_{10}$   $F_{40}$ ,  $F_{10}$  are applied loads at 40 % and 10 % of  $F_{\max}$ , respectively (for  $F_{\max}$  see [13.3](#));

$\Delta_{40} - \Delta_{10}$  displacement corresponding to  $F_{40}$  and  $F_{10}$ , respectively.

The modulus of elasticity,  $E_{t,0}$ , shall be calculated to a precision of 1 %.

### 13.5 Expression of strength results

For glued laminated bamboo, specify the orientation of the strips along the specimen length, e.g. horizontal, or vertical, relative to the direction of load application. See [Figure 2](#).

The tensile strength  $f_{t,0}$  is given by [Formula \(10\)](#):

$$f_{t,0} = \frac{F_{\max}}{bh} \quad (10)$$

where

$b$  width of cross-section;

$h$  depth of cross-section;

$F_{\max}$  maximum load.

The mode of fracture and growth characteristics at the fracture section of each test specimen shall be recorded. Failure associated with the presence of a node shall be reported. If failure is associated with the presence of a non-structural joint, this shall be reported.

When failure is associated with the grips, that result shall be reported and excluded from the evaluation of the results.

## 14 Determination of the strength and modulus of elasticity in compression parallel to the fibre of the engineered bamboo product

### 14.1 General

The measurement of strength and modulus of elasticity in compression parallel to fibre of engineered bamboo products presents considerable difficulty but values suitable for use in design can be obtained using the method of this section. The axial strength modulus of elasticity may also be estimated as the average weighted average of the modulus of elasticity of the individual laminations for glued laminated bamboo.

## 14.2 Test specimen

The test specimen shall have a length of six times the smaller cross-sectional dimension. The end surfaces shall be accurately prepared to ensure that they are plane and parallel to one another and perpendicular to the axis of the piece.

## 14.3 Procedure

The test specimen shall be loaded concentrically using spherically seated loading-heads or other devices that permit the application of a compressive load without inducing bending. The loading conditions used shall be reported.

Load shall be applied at a constant rate and the test should be completed within approximately 300 s but not less than 180 s.

Ideally, the load application rate is determined from the results of preliminary tests. The estimated maximum load,  $F_{\max, \text{est}}$ , of the material under test shall be obtained either from tests on at least ten pieces of the appropriate material and size or from appropriate existing test data. The objective is that the average time to reach  $F_{\max}$  is 300 s.

The loading equipment used shall be capable of measuring the load with a precision of 1 %.

Displacement shall be measured over a central gauge length of four times the smaller cross-sectional dimension of the piece. Two extensometers shall be used on opposite sides of the specimen and shall be positioned to minimize the effects of distortion.

## 14.4 Expression of modulus results

For glued laminated bamboo, specify the orientation of the strips along the specimen length, e.g. horizontal, or vertical, relative to the direction of load application. See [Figure 2](#).

The modulus of elasticity in compression,  $E_{c,0}$ , is given by [Formula \(11\)](#):

$$E_{c,0} = \frac{l_1 (F_{40} - F_{10})}{bh(\Delta_{40} - \Delta_{10})} \quad (11)$$

where

$b$  width of cross-section;

$h$  depth of cross-section;

$l_1$  gauge length, equal to four times the smaller cross-sectional dimension;

$F_{40} - F_{10}$   $F_{40}$ ,  $F_{10}$  are applied loads at 40 % and 10 % of  $F_{\max}$ , respectively (for  $F_{\max}$  see [14.3](#));

$\Delta_{40} - \Delta_{10}$  displacement corresponding to  $F_{40}$  and  $F_{10}$ , respectively.

The local modulus of elasticity,  $E_{c,0}$ , shall be calculated to a precision of 1 %.

## 14.5 Expression of results

For glued laminated bamboo, specify the orientation of the strips along the specimen length, e.g. horizontal, or vertical, relative to the direction of load application. See [Figure 2](#).

The compressive strength,  $f_{c,0}$  is given by [Formula \(12\)](#):

$$f_{c,0} = \frac{F_{\max}}{bh} \quad (12)$$

where

$b$  width of cross-section;

$h$  depth of cross-section;

$F_{\max}$  maximum load.

The mode of fracture and growth characteristics at the fracture section of each test piece shall be reported.

## 15 Determination of the strength and modulus of elasticity in compression and tension perpendicular to the fibre of the engineered bamboo product

### 15.1 Requirements for test specimens

The test specimens (see [Figure 8](#)) shall have a cross-sectional area of 25,000 mm<sup>2</sup> with the minimum dimension,  $b$ , or  $l$ , not less than 100 mm. The height,  $h_t$ , of the test specimen for tension perpendicular to fibre tests shall be 400 mm. The height,  $h_c$ , of the test specimen for compression perpendicular to fibre tests shall be 200 mm. Specimens shall have their ends planed smooth and parallel to allow for uniform application of the load to the test pieces.

For the compression perpendicular to fibre tests, the test specimen shall be loaded uniformly across  $bl$ .

For tension perpendicular to fibre tests, the test specimen shall be glued to end blocks suitable to transmit tension to the full cross-section of the specimen uniformly. The gluing process shall be capable of ensuring the specified position of the test specimen during testing.

NOTE A suitable adhesive for fixing the steel plates to the engineered bamboo test specimen is a two-part epoxy. Immediately prior to gluing, the surfaces to be joined is prepared by planing the bamboo test specimen surfaces and cleaning the steel plates.

The loaded surfaces shall be accurately prepared to ensure that they are parallel to each other and perpendicular to the test specimen axis. This preparation shall be carried out after conditioning.

### 15.2 Procedure

The test specimen shall be mounted vertically between the test machine plates and the appropriate compression or tension loads applied. The test specimen shall be loaded concentrically such as by applying the load through a pin located at the geometric centre of the specimen cross-section.

NOTE This can also be achieved using spherically seated loading-heads.

In the case of either a tension or a compression perpendicular to fibre test the longitudinal axis of the test piece shall be aligned with the axis of the machine and fixed in such a way that no initial stresses in the test piece are introduced, except those due to the weight of the test piece and the equipment.

For the compression perpendicular tests, the gauge length,  $h_0$ , is the distance between the test machine plates,  $h_t$ .

In the case of tension perpendicular to fibre tests, the test piece shall have pinned ends, with the axis of the pin parallel to the fibre direction of the test piece.

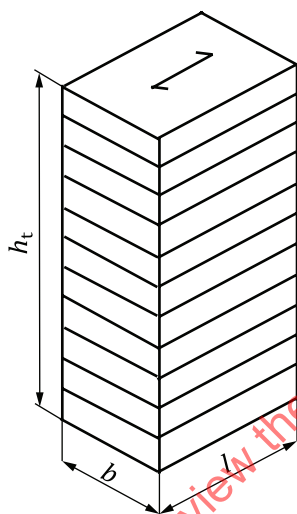
For the tension perpendicular to fibre tests, the test piece shall be mounted vertically between the test machine plates and the appropriate compression or tension loads applied. The gauge length,  $h_0$  (approximately 0,6  $h$ ), shall be located centrally in the test piece height and not closer than one-third of the length ( $l/3$ ) and one-third of the width ( $b/3$ ) to the loaded ends of the test piece (see [Figure 9](#)).

The load  $F$  shall be applied at a constant rate of cross head movement throughout the test so adjusted that the maximum load  $F_{c,90,max}$  or  $F_{t,90,max}$  is reached within approximately 300 s but not less than 180 s.

Ideally, the load application rate is determined from the results of preliminary tests. The estimated maximum load,  $F_{max,est}$ , of the material under test shall be obtained either from tests on a least ten pieces of the appropriate material and size or from appropriate existing test data. The objective is that the average time to reach  $F_{max}$  is 300 s.

NOTE 2 The relationship between  $F_{c,90,max,est}$  and  $F_{c,90,max}$  is discussed in [15.3.1](#).

The loading equipment used shall be capable of measuring the load with a precision of 1 % of the load applied to the test specimen.



**Key**  
 indicates parallel to fibre orientation

**Figure 8 — Engineered bamboo test specimen for perpendicular to fibre tests**

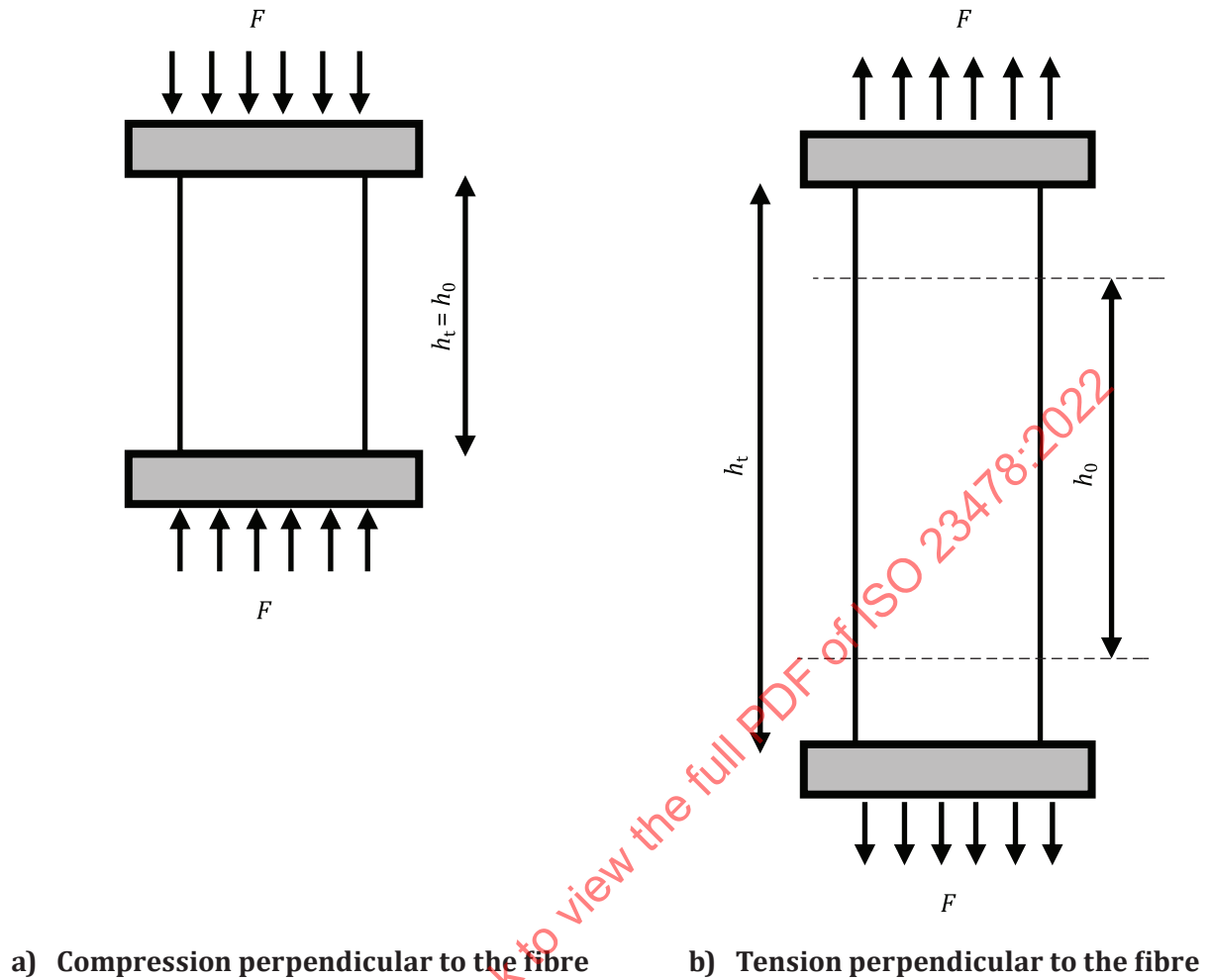


Figure 9 — Test principle

Two extensometers shall be used and shall be positioned to minimize the effects of distortion. The extensometers shall permit the measurement of the displacement with a precision of 0,1 %. The displacement in the load direction refers to the centre of the loaded section and is calculated on the basis of measurements on opposite sides of the test piece.

The data from each extensometer shall be recorded separately.

### 15.3 Expression of results

For glued laminated bamboo, specify the orientation of the strips along the specimen length e.g. horizontal, or vertical relative to the direction of load application. See [Figure 2](#).

#### 15.3.1 Compression strength perpendicular to the fibre

The compressive strength,  $f_{c,90}$ , shall be determined from [Formula \(13\)](#):

$$f_{c,90} = \frac{F_{c,90,max}}{bl} \quad (13)$$

where

$b$  smaller dimension of the cross-section;

$l$  larger dimension of the cross-section;

$F_{c,90,max}$  maximum compressive load perpendicular to the fibre.

The determination of  $F_{c,90,max}$  shall be carried out as follows:

- Using the test results, plot the load-displacement curve in the form shown in [Figure 10](#).
- calculate the slope of the initial linear portion of the curve (line 1).
- draw a parallel line (line 2) having the same slope at an offset of  $\Delta = 0,01h_0$ .
- the intersection of line 2 and the load-deflection curve defines  $F_{c,90,max}$

It is acceptable to carry out this process graphically.

NOTE 1 ISO 12122-3 provides more information, concerning the compressive strength perpendicular to fibre,  $f_{c,90}$ , for glued laminated timber.

### 15.3.2 Compression modulus perpendicular to the fibre

The modulus of elasticity,  $E_{c,90}$ , shall be calculated from [Formula \(14\)](#):

$$E_{c,90} = \frac{(F_{40} - F_{10})h_0}{(\Delta_{40} - \Delta_{10})bl} \quad (14)$$

where

$b$  smaller dimension of the cross-section, as shown in [Figure 8](#);

$h_0$  gauge length, as shown in [Figure 9](#);

$l$  larger dimension of the cross-section, as shown in [Figure 8](#);

$F_{40} - F_{10}$   $F_{40}$ ,  $F_{10}$  are applied loads at 40 % and 10 % of  $F_{c,90,max}$ , respectively (for  $F_{c,90,max}$  see [15.3.1](#));

$\Delta_{40} - \Delta_{10}$  displacement corresponding to  $F_{40}$  and  $F_{10}$ , respectively.

The local modulus of elasticity,  $E_{c,90}$  shall be calculated to a precision of 1 %.